Eugene L. Chiappetta | Thomas R. Koballa, Jr.

SCIENCE INSTRUCTION IN THE MIDDLE AND SECONDARY SCHOOLS

Developing Fundamental Knowledge and Skills

EIGHTH EDITION

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About the Authors

Eugene L. Chiappetta is a professor emeritus at the University of Houston in the Department of Curriculum and Instruction who is still active in advising students, teaching science education courses, and engaging in scholarly work. Dr. Chiappetta holds a bachelor's degree in biology from Allegheny College, a master's degree in general science, and a Ph.D. in science education from Syracuse University. He developed and taught many science education methods courses, coordinated teacher certification programs, and held summer programs for science teachers for over three decades at the University. Professor Chiappetta has been a coauthor of this science methods textbook for many years and has written numerous modules on teaching science. He has pursued several lines of research, such as determining competencies for secondary school science teachers and analyzing the content of science textbooks for their presentation of the nature of science.

Thomas R. Koballa, Jr., is Dean of the College of Education at Georgia Southern University. Dr. Koballa holds a bachelor's degree in biology and a master's degree in science education from East Carolina University, as well as a Ph.D. in curriculum and instruction from the Pennsylvania State University. He is past president of the National Association for Research in Science Teaching and the recipient of the Association of Science Teacher Education's Outstanding Mentoring Award. He has authored or coauthored more than 80 journal articles and chapters and continues to work with science education students and teachers. His research interests include science teacher learning and mentoring.

Brief Contents

Contents

Preface

In an age when scientific and engineering advancements occur daily, how does science education develop a scientifically literate society that can appreciate, understand, participate in, and contribute to science and engineering? The answer to this question resides within the individuals who are now entering the science teaching profession. These men and women want to know how to use their understandings of science and engineering to prepare the next generation of Americans for life in the 21st century. In readying themselves for this responsibility, they need to develop understandings about how to help students see science and engineering as ways of thinking about and investigating the world around them, as well as viewing it as an accessible body of knowledge. Furthermore, these men and women need to understand how to help students see the wonderment of science and engineering, and recognize the relationship between science and engineering, on the one hand, and their daily lives, a healthy environment, and a productive society, on the other. This eighth edition of *Science Instruction in the Middle and Secondary Schools* is designed to provide individuals with the guidance for addressing both the excitement and challenges associated with entering the science teaching profession.

New to This Edition

This eighth edition is designed to support science teaching and learning as reflected in the Next Generation Science Standards (NGSS). The book's chapters include explicit references to the NGSS, and discussion provides guidance for teachers about how to engage students in learning experiences that bring together the practices of science and engineering, crosscutting concepts, and core science ideas. Equally important, the chapters of this edition are organized to enable users to systematically develop a solid grounding in the fundamentals of science teaching, including professional attributes, instructional practices, and major themes of science education. It is the view of the authors that fundamental understandings about science teaching are critical to a teacher's early and sustained success. A solid understanding of the fundamentals will serve as the bedrock for instructional refinements and enhancements throughout a science teacher's career.

The development of a fundamental understanding of science teaching is facilitated through the organization of the book into three independent, yet mutually supportive, sections. The first, "Getting Into Science Teaching," comprises Chapters 1–6. The chapters of this section address the informational and personal concerns of beginning teachers by attending to the essential knowledge needed to initiate informed and purposeful teaching. The second section, "Foundations for Science Teaching," encompasses Chapters 7–10 and addresses basic understandings critical to planning for instruction and guiding the science learning experiences of adolescents. These chapters encourage the reader to consider both teaching that supports diverse learners and teaching in light of what is known about human learning. The final section, "Strategies for Science Teaching," comprehends Chapters 11–15 and extends the reader's exploration of science teaching and learning. The chapters of this section challenge the reader to refocus on learners and their welfare and safety, and look for ways to improve and refine the science learning experience.

Along with the NGSS, the applicable National Science Teachers Association (NSTA) Standards for Science Teacher Preparation are highlighted where relevant in each chapter of this edition. Another refinement is the alignment of chapter objectives with questions and tasks described in the "Assessing and Reviewing" section of each chapter. An assessment is now presented for each chapter objective. More specific improvements found in this edition include the following:

- Each of the first six chapters opens with a new and engaging vignette. The vignettes are written to draw the reader into the chapters, to highlight professional challenges and dilemmas, and to serve as referents for many points of discussion throughout the chapters.
- A new conceptual framework to orient readers to the multiple dimensions of science teaching is introduced in Chapter 1, "Thoughts and Actions of Beginning Science Teachers." The framework is presented as a tool, helping the reader to develop a big-picture view of science teaching and to bring attention to the personal

attributes, as well as teaching skills and strategies, that are linked to effective instruction and student learning. Comparisons between effective and ineffective teaching practices also are provided, to aid in orienting the reader to the teaching profession.

- Chapter 2, "Purpose of Science Teaching," has been rewritten on the basis of both the NGSS and current directions in science education, in order to provide context for science teaching. The history of science teaching in the United States is outlined, with attention paid to the current reform driven by both international comparisons and the desire for education that prepares students for college and careers. The NGSS, the Common Core State Standards in English language arts and in mathematics, and associated assessment initiatives are discussed in this chapter, as are the NSTA Standards for Science Teacher Preparation.
- Chapter 4, "Assessing Science Learning," now includes sections on interpreting assessment data. Stressed here is the important process of making sense of assessment data and using data purposefully to guide instructional interventions. These sections both complement revisions that emphasize the centrality of continuous assessment and present the science learning assessment system as a means of aligning learning goals with diagnostic, formative, and summative assessments.
- Chapter 7 has been expanded to better address the new vision for science education reflected in the NGSS. The new title for Chapter 7 is "The Nature of Science and of Engineering and Technology." Sections have been added that discuss the relationship of science to engineering and technology and to the practices of engineering.
- Chapter 8, "Inquiry and Teaching Science," has been modified to describe the concept of inquiry in light of the presentation of practices of science and engineering in the National Research Council's *A Framework of K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. In this chapter, the practices of science and engineering are discussed as complementary elements of inquiry and important considerations of inquiry-based instruction. In addition, to guide readers to a better understanding of teaching science as inquiry, the chapter calls attention to three fundamental elements of scientific inquiry: the phenomena under investigation, the practices applied to study the phenomena, and the outcomes of investigations.
- Chapter 9, "Diverse Adolescent Learners and Differentiated Instruction," places greater emphasis than the same chapter in the seventh edition did on the American cultural mosaic and what teachers need to know and do to ensure that all students have opportunities to learn science. This chapter also sports new sections that present understandings about equitable science learning that serve as drivers for the NGSS.
- Chapter 10, "Learning in the Middle Grades and Secondary Schools," addresses new understandings about science learning. Discussions about learning progressions and the significance of motivation to the learning process are additions to this chapter. The information-processing model of learning is presented as a major conceptual scheme for understanding learning.
- Consistent with the NGSS, the themes of argumentation, modeling, and investigation bring coherence to the chapters of Section Three: "Strategies for Science Teaching." For example, in Chapter 11, the instructional strategies of lecture, discussion, and demonstration are presented as tools for promoting scientific discourse and the analysis of scientific argumentation. Similarly, the discussion of socioscientific issues in Chapter 12 highlights opportunities for the reader to envisage scientific argumentation as a vehicle both for understanding the activities of scientific communities and for developing science understandings. Further, Chapter 12 has been modified to stress the interdependence of science and engineering and the utility of the engineering design process.
- Changes also have been made to Chapters 13, 14, and 15. Chapter 13, "Laboratory Work and Fieldwork," now includes new examples of teaching practices for encouraging meaningful learning when students are engaged in laboratory work and fieldwork. Chapter 14, "Safety in the Laboratory and Classroom," has been modified to reflect new understandings about safe uses and maintenance of chemicals and other substances in science classrooms and to address especially the 2012 NSTA Safety Standard. Finally, Chapter 15, "Computers and Educational Technologies," includes a new section about teaching science courses online and gives greater emphasis to the process by which teachers select technologies to support students' science learning. This process is aided by the presentation of a new framework that stresses the effective use of educational technologies as cognitive tools to enable students to achieve the performance expectations set forth in the NGSS.

Alignment with the NSTA Standards for Science Teacher Preparation

This edition of *Science Instruction in the Middle and Secondary Schools* is strategically designed to aid science teacher education programs in preparing teacher candidates to demonstrate the knowledge, skills, and dispositions called for in the 2012 NSTA Standards for Science Teacher Preparation. As the foundation for a performance assessment system, those standards describe expectations for teacher performance in science content, science pedagogy, and their students' learning. A program's success in meeting the standards is documented through a minimum of six assessments that serve as the basis for recommending the program for accreditation to the Council for the Accreditation of Educator Preparation. The standards and how the chapters of this edition support a program meeting them are described next.

NSTA Standard 1: Content Knowledge. This standard targets students' science content knowledge. Evidence of meeting the standard includes teacher candidates' performance on state content licensure tests (e.g., PRAXIS II or other state content tests) and grades in science content courses, disaggregated by licensure levels and area (e.g., secondary school biology). It is assumed that teacher candidates will have achieved some measure of competence in the content areas in which they will seek licensure before enrolling in the course or courses in which *Science Instruction in the Middle and Secondary Schools* is used.

NSTA Standard 2: Content Pedagogy. This standard focuses on the teacher candidate's ability to plan and assess student learning effectively on the basis of understandings of how students learn and how to engage all students in the construction of scientific knowledge. Evidence of meeting this standard is most often demonstrated through the instructional units developed by teacher candidates. Chapter 3, "Planning for Science Teaching," of this text is designed especially to guide candidates through the process of unit planning, and Chapter 4, "Assessing Science Learning," is organized to help candidates understand the assessment process as well as to build and use appropriate assessments of student learning. In addition, Chapter 7, "The Nature of Science and of Engineering and Technology"; Chapter 8, "Inquiry and Teaching Science"; Chapter 12, "Science, Engineering, and Societal Issues"; and other chapters in Part Three of this text provide important information to support the unit development process.

NSTA Standard 3: Learning Environments. This standard addresses the teacher candidate's ability to prepare an inviting and safe learning environment that involves students in active learning experiences. As with Standard 2, evidence of meeting this standard is most often demonstrated through the instructional units developed by teacher candidates, but observations of candidates teaching in middle and high schools also may provide evidence of meeting Standard 3. Chapter 5, "Teaching Science," and Chapter 6, "The Science Learning Environment," are organized to support teacher candidates in building instructional lessons and units that engage students actively in the learning process and address considerations of student safety. Moreover, Chapter 9, "Diverse Adolescent Learners and Differentiated Instruction"; Chapter 11, "Lecture, Discussion, and Demonstration"; Chapter 13, "Laboratory Work and Fieldwork"; and Chapter 15, Computers and Educational Technologies," can aid teacher candidates in building understandings that enhance their planning and practice in support of this standard.

NSTA Standard 4: Safety. Attending to the use and maintenance of chemicals and the ethical treatment of live organisms, this standard highlights the ability of the teacher candidate to engage in teaching practices that consider the health and welfare of students. As with Standard 3, evidence of meeting Standard 4 may be demonstrated through instructional units developed by candidates and through classroom observations. Chapter 14, "Safety in the Laboratory and Classroom," is developed especially to guide candidates to plan with safety in mind and to engage in safe and ethical classroom practices. Other chapters of the text augment the understanding presented in Chapter 14 with regard to laboratory work and fieldwork; issues involving science, engineering, and technology; and matters pertaining to inquiry teaching.

NSTA Standard 5: Impact on Student Learning. The focus of this standard is the impact of the teacher candidate's practice on the students he or she teaches. Evidence of meeting Standard 5 typically involves the use of assessments administered before and after instruction that show the abilities of candidates to affect learning. Chapter 4, "Assessing Science Learning," is purposely designed to help candidates plan assessments aligned to learning outcomes as well as analyze and interpret assessment results. Other chapters address engaging students in classroom, laboratory, and field experiences that help them build understandings about the nature of science and engineering, about the processes of scientific inquiry and engineering design, and about the uses of electronic technologies to support learning.

NSTA Standard 6: Professional Knowledge and Skills. This final standard focuses on the continuing professional education of the teacher candidate. Documentation of candidates' learning about and participating in professional education opportunities provides evidence of meeting Standard 6. The sections titled "Resources to Consider," presented at the end of each chapter, provide recommendations to candidates for enhancing their knowledge and understandings about a host of topics specifically related to science teaching and learning.

Acknowledgments

This textbook continues the tradition of informing beginning as well as experienced science teachers about the craft of middle and high school science teaching. Since its first publication in 1959, the content of the book has evolved, but the objective of using teaching skills and instructional strategies in an effective manner to support the major themes of science education has remained constant. To this end, we thank Alfred Collette and Walter Thurber, the authors of the first edition, *Teaching Science in Today's Secondary Schools*. We also acknowledge our science education

colleagues who have contributed their excellent work to the literature on teaching and learning science. In addition, there are many individuals to whom we are indebted for their important contributions to the current and previous editions of the book and for assisting us in our professional work.

Coauthor Eugene Chiappetta gives special thanks to the following individuals:

Jill Bailer, a middle school science teacher who taught for many years in the Houston Independent School District, assisted me for many years with the secondary science methods course at the University of Houston, in which hundreds of pre- and in-service teachers enrolled. Along with her physical presence during certain classes, Jill provided many insights into teaching science at the middle school level. Robert Dennison, a distinguished high school biology teacher and biology teacher educator, has kept me informed about the evolution-versus-creationism controversy and the personal life and professional work of Charles Darwin. In addition, Robert assisted with the biology teaching methods course that was offered for many years by the Department of Curriculum and Instruction.

David Fillman, a former high school biology teacher and Director of Science for the Galena Park Independent School District, assisted with the content analysis of many middle and high school science textbooks, which used a comprehensive list of dimensions and descriptors of the nature of science. An understanding of the nature of science has been a central theme of science education for many decades. David also supported numerous funded programs coordinated at the University of Houston that affected many science teachers in the Houston area. Steve Fleming of the Pasadena Independent School District helped to validate what is and is not possible with regard to effective teaching practices in public school settings. Many of his ideas were implemented in the physical science and chemistry methods courses that were offered by the Department of Curriculum and Instruction.

Patricia Harrison, a former chemistry teacher and erstwhile Director of Secondary Science for the Alief Independent School District, was instrumental in providing many ideas about effective science instruction. She stressed the importance of using multi-instructional approaches and brain-based research that support good teaching practices. Matthew Wells is an outstanding environmental and biology teacher in the Cypress Fairbanks Independent School District. He put forth and modeled ideas on how he helps *all* students to learn and appreciate science.

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Science teachers must learn well the contents of the chapter on safety in the laboratory and classroom. Kenneth Roy, a public school science educator and writer of many NSTA books and journals on science safety, provided ideas to update Chapter 14, "Safety in the Laboratory and Classroom." James Kaufman, the CEO of the Laboratory Safety Institute, was extremely helpful in examining information about safety and the use and storage of chemicals in school science. I am most grateful to him for sharing his vast knowledge of science safety.

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Chuck Hodges, Associate Professor of Instructional Technology at Georgia Southern University, was always willing to talk about educational technologies and their power for enhancing student learning. Conversations with Dr. Hodges informed my thinking about frameworks that are useful for describing how to integrate educational technologies into science learning experiences.

Also, I wish to thanks the pre- and in-service teachers who populated my science education courses for 20 years at the University of Georgia. My thoughts were often about their triumphs and challenges as middle and high school science teachers. I would ask myself as I wrote, "How would Steve, Bob, Libby, Hope, Donna, and others respond to this information? Would it help them become stronger teachers?" My perceptions about their responses to these questions guided what I chose to include in chapters and how I chose to present it.

Special thanks go to my family. Balancing the demands of serving as dean of a college of education and working on this edition left little time for family life. My plan is to spend more evenings and weekends enjoying the company of my family in the coming year.

Finally, we would like to thank the reviewers of the eighth edition for providing valuable guidance on ways to improve the book: April Dean Adams, Northeastern State University; Julie Andrew, University of Colorado, Boulder; Scott M. Graves, Southern Connecticut State University; John Pecore, University of West Florida; and Thomas E. Ricks, Louisiana State University.

Chapter 1

Thoughts and Actions of Beginning Science Teachers

Personal attributes and instructional skills and strategies are important characteristics of beginning teachers.

The setting of the introductory vignette for this chapter is the classroom of a beginning science teacher, Virginia Locke, who is teaching eighth-grade physical science in an urban middle school. When Mrs. Locke graduated from college with a major in chemistry and a minor in mathematics, she went to work for a chemical company. After 3 years in industry, she married and decided to go into teaching. She has just completed an online certification program that included one general secondary school methods course but did not include a science methods course.

Let's listen in on Mrs. Locke's interactions with her class of middle school students. Later we'll have the opportunity to hear Mrs. Locke discuss her class with her mentor teacher.

Mrs. Locke: Good morning class. Today we are going to talk about magnetism and some of the individuals throughout history who studied this concept. Can anyone tell me what is magnetism? Jolene, can you tell us about magnetism?

Jolene: Well, metals are magnets.

Mrs. Locke: Are all metals magnets?

Jolene: Um, I'm not sure.

Mrs. Locke: Reginald, you have your hand up.

Reginald: You cannot pick up pennies with a magnet. I know. I've tried.

Mrs. Locke: That is correct. Not all metals are magnets, nor are all metals magnetic—that is, attracted by magnets. Before we continue and learn more about magnetism, I would like to give you some history about the concept, beginning with the Greeks, then William Gilbert, Hans Christian Oersted, Michael Faraday, and James Clerk Maxwell.

At this point in the lesson, Mrs. Locke spent about 15 minutes discussing the contributions of the Greeks and other individuals who contributed to our understanding of magnetism. Unfortunately, the students did not seem very attentive during the discussion about the historical development of our scientific knowledge of magnets and magnetism. The teacher followed the historical review with a short lecture on magnetic forces surrounding a magnet, beginning with a diagram on the board showing lines of force emanating from a bar magnet.

Mrs. Locke: Class, please observe how I draw the lines going from the north to the south pole of this bar magnet. These lines represent the magnetic field that surrounds a magnet. I will label the magnetic field and the north and south poles. Observe the direction of the arrows on lines going from the magnet's north pole to its south pole. Does everyone have this?

Class response: Yes, Mrs. Locke.

Mrs. Locke: Now I would like to show you a YouTube video of the earth's magnetic field. I think that you will enjoy it.

At first the students were attentive, but after 10 minutes of watching the video, many students began to squirm in their seats and some began to talk to others sitting around them. When the 15-minute video ended, Mrs. Locke held up a bar magnet in front of the class.

Mrs. Locke: Who can tell us about the magnetic lines of force that run around the bar magnet? Denise, can you answer this question?

Denise: They go like this. (Student demonstrates with her hands the lines of force between the north and south poles of the magnet.)

Mrs. Locke: Denise, please go to the board and draw the bar magnet and the magnetic lines of force emanating from it.

As Denise completes the diagram of the bar magnet with lines going from the north to the south pole, Mrs. Locke congratulates the student on her effort, emphasizing Denise's knowledge of the polarity and lines of force associated with magnetism. Then the teacher goes to the diagram drawn by the student and adds arrows showing the direction of the magnetic forces, which emanate from the north to the south pole. Now Mrs. Locke places a second magnet on the stage of the overhead projector, at a distance of 1 inch between the south pole of one magnet and the north pole of the other. Mrs. Locke holds onto the magnets so that they do not smack together, as one would expect from the attraction represented by the lines of force between the north and south poles of magnets.

Mrs. Locke: What will happen if I let go of the bar magnet in my right hand? Who can tell us? Tomás, can you tell us what will happen?

Tomás: The magnets will come together like this. (He demonstrates with his hands.)

Mrs. Locke: Very good.

Then Mrs. Locke introduces a concept from chemistry with a brief discussion about polar molecules and how they have slightly negative and slightly positive charged regions on opposite ends; she thinks that this concept will reinforce the idea of polarity and magnetic fields. She points out to the students that these types of molecules are referred to as dipolar molecules. Mrs. Locke illustrates with a diagram of hydrogen chloride, accompanying the illustration with stories about her work as a chemist and the importance of molecular structure in chemical reactions. Mrs. Locke feels that conveying her experiences in the chemical industry will enhance student learning.

Toward the end of the class period, Mrs. Locke gives students some information about the next class period and how it will build on what they have learned today. She points out that the students may perform a lab on magnets tomorrow if time permits. At this point, the bell sounds for class to end and Mrs. Locke calls out to the students, who are now moving from their seats, to read over the chapter on magnetism in the textbook. As the students clear out of the classroom, the beginning teacher has an empty feeling of dissatisfaction that the lesson was subpar, lacking excitement and coherence.

Stop and Reflect!

Obviously, there are aspects of Mrs. Locke's science lesson that were effective and aspects that could be improved. Examine how the beginning teacher addressed the five basic teaching functions, and write statements concerning how they were implemented or not implemented in the lesson. The five teaching functions are (a) planning, (b) purpose, (c) assessment, (d) teaching, and (e) management. For each of these functions, state the effective actions demonstrated by the teacher, followed by suggestions for improvement. After you have completed this task, read further along in the chapter to learn more about Mrs. Locke's assessment of her teaching. You can do so through the vignettes and conversations presented between Mrs. Locke and her mentor teacher, Mr. Carlson. Their conversations will help guide your thinking about effective teaching practices.

CHAPTER OBJECTIVES

Use the following learning outcomes to guide your thinking about how to strengthen the relationship between science teaching and student learning:

1. Discuss the *thoughts and actions* of *beginning* science teachers, which often lead to ineffective instruction with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
2. Discuss the *thoughts and actions* of many *experienced* science teachers, which usually lead to effective instruction with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
3. Analyze and evaluate a teacher's instructional effectiveness as observed in a video recording or written vignette with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
4. Demonstrate, in both instructional plans and a brief teaching episode, effective instructional practices with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
5. Describe how you could go about establishing a mentoring relationship with an experienced teacher. What challenging aspects of teaching science might a mentor help you develop into successful practices?

The purpose of this chapter is to provide a vision of effective science education and to place you on the road to success as a science teacher. You need to have both a big picture of the profession and a focus on the professional attributes, skills, and strategies that will lead to effective instruction and efficient student learning. Figure 1.1 shows a framework for conceptualizing science teaching. The lower section of the framework presents a number of science education themes, important areas that should inform your thinking and actions related to science education. The upper section shows fundamental attributes and abilities that support the major themes. Without an understanding of the professional attributes of successful teachers and the abilities necessary to implement effective science instruction, little can be accomplished in classrooms with large numbers of active adolescents, many of whom have a high interest in matters other than science.

FIGURE 1.1 Professional teacher attributes, instructional practices, and major themes that support science education goals and learning outcomes.

Professional Teacher Attributes,Instructional Practices, and Major Science Education Themes

Professional Attributes
- Exhibits knowledge of science
- Shows interest in making science relevant
- Displays enthusiasmabout teaching science
- Demonstrates "with-it-ness" in the classroom
- Desires to help students learn science

Teaching Skills
- Introducing lessons
- Giving directions
- Asking questions during instruction
- Using a variety of teaching aids
- Managing the learning environment
- Reviewing to assess and reinforce learning

Instructional Strategies
- Lectures
- Demonstrations
- Discussions
- Laboratory and fieldwork
- Reading in the content area
- Group work and projects
- Modeling to learn
- Simulations and games
- Electronic instruction and the Internet

Learning and Reinforcement Techniques
- Taking notes
- Keeping a journal
- Writing summaries and short papers
- Identifying similarities and differences
- Making concept maps and visual maps

Major Science Education Goals and Themes

Science Literacy
- Nature of science
- Nature of engineering
- Nature of technology
- Nature of mathematics

Practices of Science and Engineering
- Asking researchable questions
- Gathering data
- Constructing evidence
- Presenting results
- Using mathematics
- Making arguments
- Concluding investigations
- Communicating results
- Designing devices and systems

Student Diversitiy
- Demographics
- Socioeconomic status
- Gender difference
- Cultural background

Human Learning
- Constructivism
- Information processing
- Motivation to learn
- Reasoning
- Visualization

Accountability and Testing
- Teacher accountability
- High-stakes testing
- Student achievement
- Comparisons of U.S.and foreign students
- College and career readiness

EXAMINING THE THOUGHTS AND ACTIONS OF BEGINNING SCIENCE TEACHERS GUIDED BY BASIC TEACHING FUNCTIONS

The challenges facing beginning science teachers are many, but not insurmountable. The remaining sections of this chapter will highlight critical features of science teaching that beginning teachers should consider. These features are *planning*, *purpose*, *assessment, instruction*, and *management*. In order to develop a mind-set for effective teaching, the discussions that follow will contrast the thoughts and actions of many preservice teachers, as well as some who are in the classroom as a beginning teacher, with teachers who are more informed and experienced. Toward this end, you should reacquaint yourself with the vignette at the beginning of the chapter to prepare for discussions of how the beginning science teacher, Mrs. Locke, engages students in her science class and how she might instruct them differently in order to be more effective in supporting their learning.

The Planning of the Lesson

Planning is one of the most important teaching functions (see Table 1.1). A teaching plan is a blueprint for accomplishing a set of learning outcomes, offering a vision of the intended teaching and learning that are to take place, achievable only through careful thinking and organization before any instruction occurs. Planning requires considerable background knowledge of the subject and of pedagogy, plus creativity. It is obvious when a teacher has not planned well, because the instruction results in a lack of student engagement and little learning.

Science teachers must plan frequently and thoroughly to be successful. Further, their goal must be twofold: (1) to engage students in activities that are instructive and meaningful—activities that help students to construct important concepts—and (2) to develop lifelong understandings, dispositions, and skills. In addition, with very abstract subject matter, one goal might be to focus on a limited number of key concepts, rather than on an overview of many. Lesson plans are the most basic elements of a curriculum that is designed for one period of instruction.

Let's listen in on a conversation between Mrs. Locke and her mentor as they discuss Mrs. Locke's planning for the lesson on magnetism.

Mr. Carlson: Tell me Virginia, when did you begin planning for the first lesson that you taught on magnetism?

Mrs. Locke: I began the night before, because they keep you busy in this school. There sure are a lot of paperwork and after-school duties, which leave very little time to sit and plan for the next day.

Mr. Carlson: I can appreciate what you are saying about all of the paperwork and duties. They seem to get worse each year. Nevertheless, we have course materials and resources that can help you with your planning. Be sure to frequently examine the notebook that we prepared for the integrated physics and chemistry course. Other teachers and I spent a great deal of time and effort assembling it. Although it may not be perfect, the notebook is organized into units, and it provides national, state, and district standards for each unit. In addition, you will find goals, instructional objectives, suggested activities, assessments, and a ton of supporting materials in it.

Mrs. Locke: I did briefly look over the information in the notebook about magnetism, but I tried to make the lesson different.

Mr. Carlson: That's fine, and I encourage you to be creative in designing your own lesson. Nevertheless, reflect carefully on what is in the course notebook, some of which is on the district's intranet. Then modify what the district has to accommodate your teaching style and students' abilities. Please study the purpose, assessment, instruction, and management suggestions that the district has set down; they could be a big help in your thinking about each lesson. And perhaps most important, study the instructional objectives; I can tell you more about learning outcomes when we talk later about planning and assessment.

Mrs. Locke: Perhaps I have not put in enough time in my planning. In the future, can I show you some of my plans before I teach?

Mr. Carlson: I look forward to that.

Through district-wide or small-group efforts, most teachers have access to an assemblage of resources that are useful for planning instruction for particular courses. The discussion between Mrs. Locke and her experienced mentor indicates that Mrs. Locke could benefit from reviewing the district's notebook, which contains lesson plans for the entire course. As the discussion suggests, this assemblage of information can provide a great deal of direction for those teaching science for the first time.

Nevertheless, we feel strongly that beginning teachers should not rely solely on resources assembled by others. Each teacher should modify lesson plans and other materials to best accommodate his or her teaching style and the needs of students. Further, each teacher should modify and expand the instructional objectives presented, because doing so will provide personal ownership of the learning outcomes considered most appropriate for students.

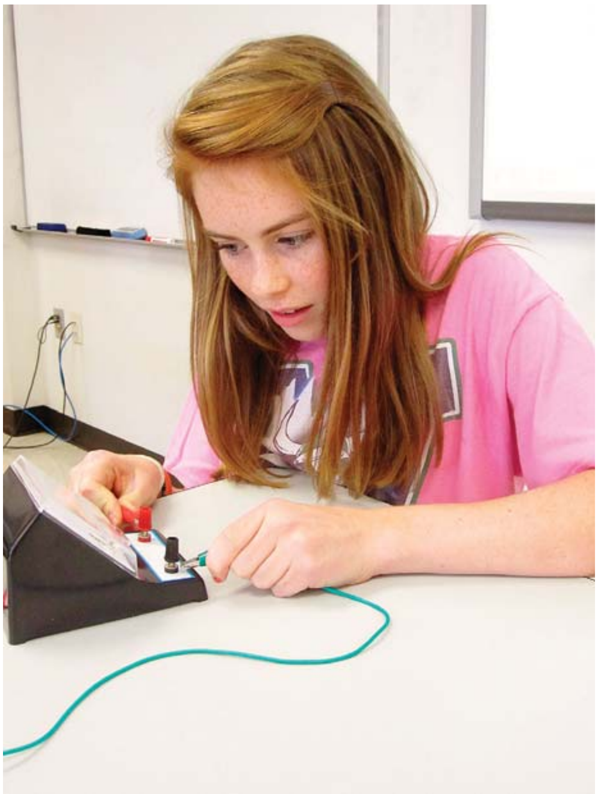
Some educators are adamant in their belief that you cannot teach someone else's lesson plan. Although there is certainly some truth to this statement, we believe that beginning teachers can benefit tremendously from using lesson plans and other available resources as the foundation for their teaching. These materials can then be modified to personalize instruction in ways that are most suitable for teachers and students alike.

The Purpose of the Lesson

Teachers must have a clear set of ideas regarding what they want to accomplish in a lesson (see Table 1.1). They should be focused on student learning and success, as well as on the core ideas of the discipline they are teaching. Students should leave the class period with new information and experiences that will stick in their long-term memory.

The lesson should spark interest in science, expanding the students' understanding of the concepts and practices of science rather than the feeling that science class is one big vocabulary lesson.

Before reading further, write down several sentences that capture your thoughts about the purpose that Mrs. Locke envisioned for the magnetism lesson described in the chapter's opening vignette. Then, listen in on a conversation between Mrs. Locke and her mentor, Mr. Carlson, to learn about her thoughts concerning the lesson's purpose.



A teacher's ultimate concern should be with students and their success.

Mr. Carlson: I had an opportunity to examine your lesson plan on magnetism and to think about your dissatisfaction with the first lesson in the unit. Tell me Virginia, what was your overall purpose for the lesson?

Mrs. Locke: Well, I wanted to teach the students about the lines of force associated with magnets—just some basics about magnetism. I thought that getting into the details of the subject and using a variety of different instructional activities would have garnered more interest from the students. I tried to make the learning concrete and engaging, but the lesson did not come up to my expectation.

Mr. Carlson: I applaud your effort and I think your purpose is admirable. I certainly like the focus on content and the variety of instructional strategies that you implemented. This is an important way to plan and teach science lessons, because it generates interest. The attention span of many eighth-grade students is short, and variety is important. Although I did not observe the lesson, you do seem to be enthusiastic about teaching science. Enthusiasm is an important attribute for all teachers to possess (see Figure 1.1). I would like to stress the importance of building relationships with the students. Your positive relationships with students will likely enhance the success of most lessons that you teach. Try to expand the interaction and engagement that takes place. You want students to view you as being supportive of their learning and success.

Mrs. Locke: I generally focus on the content of the lesson as the main factor, but I agree that I should consider other aspects as well. I have had so much chemistry in my education and training that I automatically focus on what I'm teaching and not so much on how I'm teaching.

Mr. Carlson: In no way do I want to minimize the importance of science content. A science teacher must know a great deal about the subject matter he or she teaches in order to plan creative instruction and ask meaningful questions. Nevertheless, there are other aspects of teaching that are just as important in promoting student learning—personal attributes, such as enthusiasm, "with-it-ness," and the ability to build a rapport with students (see Figure 1.1). Further, you should introduce the expectation that the lesson will also prepare students to investigate some questions about magnetism that arise later on in the unit. That's enough for now, however; we can talk more about teaching science as inquiry and the practices of scientists and engineers at a later time.

In the brief conversation between the beginning science teacher and her mentor, it is evident that Mrs. Locke is moving toward becoming an effective teacher but needs to broaden her perspective of the purpose of teaching science. In subsequent conversations between Mrs. Locke and her mentor, you will learn about Mr. Carlson's suggestions for how to infuse learning experiences into lessons to enhance students' language development and to incorporate "minds-on" activities that support major science education themes such as scientific literacy and inquiry, and how to accommodate the needs of diverse student learning and address motivation (see Figure 1.1).

The Assessment of the Lesson

Assessment, which involves the process of gathering information about the overall effectiveness of a particular instance of teaching and learning, serves at least two purposes: to determine how well students are achieving the intended learning outcomes and to ascertain the effectiveness of the instruction. At the level of teaching lessons, assessment is best done if it takes place before, during, and at the end of the instructional period. Comparisons are then readily made.

With regard to using assessment for generating grades, information can be gathered from students' work, their behaviors and oral responses, and test results, as well as other outcomes (see Table 1.1). With regard to all teaching plans and instruction, the assessment must be tied directly to instructional objectives, often referred to as learning outcomes or behavior objectives. Instructional objectives state exactly what the learner should *know* or be able to *do* by the end of the lesson. These objectives should be measurable and must be an integral part of the written plan, the instruction, and the assessment. Too often, teaching plans have vague statements of the intended learning outcomes, leading to less effective teaching and learning.

Let's listen in on a conversation between Mrs. Locke and Mr. Carlson regarding the assessment associated with the magnetism lesson.

Mr. Carlson: As I think about your lesson, I would like to zero in on the assessment that you used to determine student learning. Tell me about your instructional objectives.

Mrs. Locke: The instructional objectives that I included in my plan were for the students to

1. Define magnetism.
2. Understand about the lines of force associated with magnets.

Mr. Carlson: Virginia, I am pleased that you have set down at least two instructional objectives for the lesson. You begin with a definition, which is fine. I do have a problem with the second objective. Can you think of a reason for my reservation about number two?

Mrs. Locke: Not really. Here I am looking for student understanding. In my certification program, I was taught that understanding is important.

Mr. Carlson: Certainly! We want to teach for understanding. But if we are serious about achieving this outcome, we must state the outcome it in a manner in which the learning can be observed and measured. From an instructional design point of view, understanding must be stated in such a way that you can observe it happening during and after the instruction. Would you like to try to state objective number two in a more observable manner?

Mrs. Locke: Sure. How about like this:

2. Describe the lines of force around a magnet.

Mr. Carlson: You are on the right path. Let's give the learning outcomes a bit more specificity. What do you think about this?

2. Draw and describe the lines of force around a bar magnet, including the direction of the forces from the north to the south pole or from the south to the north pole.

Do you think my modification of the original objective is more to the point of what you want the students to be able to know as the result of this lesson and at the completion of the magnetism unit?

Mrs. Locke: Definitely.

Mr. Carlson: I would add a third instructional objective to your lesson, because you addressed another learning outcome during your instruction:

3. Given a diagram of bar magnets, or given real bar magnets placed near each other, with their poles labeled, predict whether the magnets will attract or repel.

You also may wish to ask students to explain their predictions.

Mrs. Locke: I think that is what I want students to be able to do on the test.

Mr. Carlson: Great! Let's touch on another aspect of assessment: assessing students' knowledge at the beginning of the lesson. You did begin the lesson by asking students what they know about magnetism. That was a good start, but I recommend spending more time on ascertaining this knowledge from all of the students. You called on just two students to tell you what they know about magnetism. I recommend that you call on many more students. Can you think of how to determine what students know about magnetism at the beginning of the lesson?

Mrs. Locke: I can ask students to write a short paragraph explaining magnetism and then go around the room asking for certain students to read their paragraphs.

Mr. Carlson: Exactly! That is a good approach to determining what students know about a concept at the beginning or, indeed, at any point during instruction.

Mr. Carlson continues to talk with Mrs. Locke about assessment. In addition to discussing assessment during the lesson and at its end, they talk about assessing students' learning during the lesson. This focus leads Mrs. Locke to realizes that *during the lesson* she should have asked more questions and called on many more students to answer questions, about magnetism—questions that are tied directly to the desired learning outcomes for the lesson and are described explicitly in the instructional objectives. Further discussion about assessment also led Mrs. Locke to realize that a review of students' knowledge of the learning outcomes should have been conducted *at the end of the lesson*. Such a review would provide feedback on where to begin the instruction in the next period and how much review and reteaching is needed.

The Teaching of the Lesson

Teaching or instruction is what people usually think of when they visualize a classroom: a teacher guiding student learning. Instruction can take many forms, such as asking questions, reviewing material presented earlier, lecturing, discussing, engaging students in simulations, performing laboratory work, solving problems, reading, taking notes, or guiding students' learning with the use of the Internet or an interactive whiteboard. As seen in Figure 1.1, instruction can be thought of in terms of the use of teaching skills, instructional strategies, and learning techniques. Some forms of instruction are more teacher centered, while others are more student centered.

Teacher education has a long history of observing and giving feedback to preservice teachers, student teachers, and individuals who are participating as interns in teacher induction programs. This process of giving evidence-based guidance to newcomers to the teaching profession is an effective way to improve teaching and student learning. Much of this science methods textbook focuses on the act of teaching and its many facets—all geared toward enhancing student learning and success.

Let's again listen in on a conversation between Mrs. Locke and her mentor, Mr. Carlson, regarding her teaching of the magnetism lesson.

Mr. Carlson: I was delighted to see that you used a variety of teaching skills and instructional strategies. This is a good way to think about and carry out your teaching. From your lesson plan, I see that you used at least five different modes of teaching:

- an introduction to the lesson, with questions for students to answer
- a lecture that included contributors to our knowledge of magnetism
- a 15-minute YouTube presentation illustrating the earth's magnetic lines of force
- a short question-and-answer session on the mechanism of magnetism, using the overhead projector
- a closing of the lesson at the end

How do you feel about the manner in which you carried out your teaching with respect to these five aspects of instruction?

Mrs. Locke: At first, I thought that I was doing well with the lesson. Then, about midway into the period, I felt that I wasn't getting enough from students, and I noticed that they were losing interest in my teaching.

Mr. Carlson: Can I give you some suggestions concerning the instruction that might help you in the future?

Mrs. Locke: Sure, I'm here to learn how to be a better teacher.

Mr. Carlson offers feedback on the way Mrs. Locke opened and closed the lesson and on the instructional strategies she employed:

Opening. You started off the first part of the lesson on the right foot by asking questions about magnets. This approach caused students to think. However, you called on only a few students. I recommend that you engage all students at the beginning of the lesson by asking them to express their knowledge of magnets in their notebooks. Place the questions on the board or project them with a SMART Board. Then, continue by asking students to answer specific questions regarding magnetism.

After the students complete their writing with you, walk among them, examining some of the written responses, and call on many students to answer each question. Also, ask students to verify the correctness of the other students' responses. Encourage students to express themselves orally. Toward the end of the opening of the lesson, you can list the important concepts the students studied and the instructional objectives of the lesson.

Short Lecture. I like to bring in historical figures—men and women who have contributed to science, engineering, and technology. Their stories enrich learning. For these sessions, you should get into the habit of planning short lectures with PowerPoint slides or other teaching aids that grab students' attention. There are some excellent PowerPoint presentations in the course notebook assembled by other teachers from across the district teaching this same course. Think about how you might modify one of the PowerPoint presentations from the notebook to meet your needs. Remember to always plan a set of questions to accompany a PowerPoint presentation in order to focus and maintain students' attention.

I can show you a PowerPoint presentation that I developed for the notebook about the contributions of William Gilbert and Michael Faraday to our understanding of magnetism. I think the presentation will pique students' interest and will give you an idea of what I am talking about.

YouTube Presentation. You are on the right path for using the multitude of resources available from the Internet. The YouTube video that you used had instructional value for the lesson. It extended students' learning about magnetic fields. I would place some questions on the whiteboard or SMART Board, however, before showing the video, to again focus students' attention and guide their learning. Also, you might show only a portion of a 15-minute video if that is all that is needed to reinforce your desired learning outcomes.

Question-and-Answer Session. You asked some questions during the lesson. Nevertheless, you must ask far more questions to engage student thinking, assess their learning, and expand their understanding. I notice that you tend to call on two students per question. I recommend that you call on many more in order to get a better sense of what the entire class knows. When you ask a question, encourage students to elaborate on their responses. Probe for understanding. Along with lower order questions that assess knowledge and recall, ask higher order questions that assess students' comprehension and that enable them to demonstrate their abilities to both analyze and synthesize information. Also, provide a wait time between the end of your stating your question and when you call on individuals to respond. Students need time to think in order to provide thoughtful answers. We will discuss your stand-up and teaching performance more at a later date.

Closing the Lesson. You closed the lesson very briefly. The ending of a lesson is just as important as the lesson opening. Planned closures not only ascertain what has and has not been learned, but they can expand and reinforce the content of the lesson. Remember that this segment of the instruction must focus on the instructional objectives of the lesson; they are the desired learning outcomes. In addition, provide time to ease students into homework for the next day and for what they will be studying during the next class period. You must use every method you know to help students become successful.

Management of the Learning Environment

You seem to have a good rapport with students, learning their names and showing enthusiasm for their success. You haven't mentioned any concerns about student behavior problems with your classes. Happily, I have not heard of any classroom management issues in your teaching. As you plan other lessons in the magnetism unit, I encourage you to organize some instruction for small-group learning. In such situations, students will be active, moving around and talking. You must devise a way to give students some freedom while providing sufficient structure to ensure that learning occurs. It takes some doing to teach students to monitor their behavior so that the learning environment is orderly and productive. Your fifth-period class is a challenge with a wide range of student abilities and a few repeaters, students who failed last year. Let's discuss things further as you plan to include more student-centered instruction into your teaching. It is important that you master both teacher-centered and student-centered instruction.

Stop and Reflect!

Let's stop and reflect once again on the beginning teacher's instruction and the feedback that was provided by the mentor teacher. How would you evaluate the teacher's thoughts and actions, compared with those of a more experienced teacher with regard to the major teaching functions that are presented in Table 1.1, which gives comparisons between the thoughts and actions of beginning versus experienced science teachers.

TABLE 1.1 Comparison Between the Thoughts and Actions of Beginning and Experienced Science Teachers With Regard to the Five Basic Teaching Functions

Thoughts and Actions of Beginning Science Teachers	Thoughts and Actions of Experienced Science Teachers
Planning	
Focus on covering textbook chapter material. Organize lecture notes by content. Assume that students understand what should be learned. Plan for students who will most likely learn what will be taught during the lesson.	Identify what students may find meaningful about the core concepts or principles. Plan for several instructional activities. Construct specific learning outcomes for each lesson. Anticipate students who will have difficulty achieving the objectives.
Purpose	
Focus on teaching subject matter content. Convey large chunks of subject matter from the textbook. Get right into the details of the subject. Touch on many ideas.	Focus on teaching students as well as content. Teach a few concepts or principles from the course syllabus. Provide meaningful overviews of course content to be studied. Help students grasp a few concepts well. Provide a relevant context for learning.
Assessment	
Rarely check for student learning during instruction. Use mostly paper-and-pencil tests to determine what students know and can do. Fail to use test results and grades to evaluate teaching effectiveness.	Review frequently to check for student learning. Use multiple methods to determine grades. Consider student performance to gauge teaching effectiveness and improve instruction.
Teaching	
Attempt to transfer information to students. Ask students to take notes and to remember what they hear and what they see written. Use few teaching skills and strategies.	Engage students in thinking and finding out with questions and other means. Ask students to explain their understandings. Use many teaching skills and strategies.
Management	
Attempt to keep students in their seats. Make students listen and follow instruction. Discipline students who misbehave.	Provide opportunities for active student learning. Give students opportunities to express their ideas. Encourage students to monitor their own behavior.

INDUCTION PROGRAMS AND MENTORING BEGINNING TEACHERS

Induction programs are designed to assist teachers in dealing with the complexities of schooling and instruction in their early years of teaching. These programs must include many elements necessary for success in educating large numbers of students from many different backgrounds. The tasks novice teachers face can be overwhelming; therefore, new teachers require an extended period of enculturation (Moir, Barlin, Gless, & Miles, 2009). In addition to planning lessons and teaching, the novice teacher must take attendance, test and grade students, report progress, pursue professional development, and learn and follow numerous district and school policies. Unfortunately, most induction programs are too short—1 or 2 years in duration—and too general. These programs should last at least 3 years, and preferably longer, and have a science content focus (Luft et al., 2011). When interviewing for a science teaching position in a certain school district, ask many questions about the induction experiences provided for beginning teachers. The answers to your questions may determine whether you choose to accept a job in that school district.

A critical piece of an induction program is the mentoring that takes place between the beginning teacher and a more experienced educator. In order to guide professional growth, mentors need to be trained not only in the skills of mentoring, but preferably in the same content area as the novice teacher. Some mentoring programs, however, are too general and do not provide content-specific assistance. Also, it is common for districts to hire teachers to teach one subject for which they are well prepared—say, biology—and then ask them to teach other subjects in which they have little background, such as chemistry or physics. In the middle school, science teachers often teach multidisciplinary courses that require a good background in multiple science areas. In such cases, seeking advice from more than one content mentor is recommended (Koballa & Bradbury, 2009). Mentoring in the content area is just as important as mentoring regarding administrative duties, instruction, assessment, and so forth.

We advise beginning teachers to identify more than one mentor to help them during their early years of teaching. Because expertise in mentoring varies considerably and your needs as a beginning teacher will range from content specific to general, we recommend that you develop relationships with a number of individuals from whom you can seek advice. Consider developing relationships with several teachers to support your professional growth in the following areas: administrative duties, planning instruction, methods of teaching, and management of the learning environment. Induction and mentoring can support your developing mastery of the basic teaching functions and long-term success in the science classroom. Be aware, however, that some mentoring ends up in a buddy–buddy relationship with little expert guidance; thus, seek as many mentors as you can.

FINAL THOUGHTS ON PLANNING FOR SUCCESS

In closing this chapter, we must emphasize the enormous challenges that face beginning as well as experienced science teachers in a rapidly changing electronic communication age and a competitive global economy. All educators face tremendous pressures from inside and outside the profession to perform at high levels. Schools and school districts impose many administrative duties on teachers, such as keeping careful attendance records, assessing and grading students frequently, reporting progress, communicating with parents, attending district workshops, and more. In addition, society has high expectations for science teachers. Society expects science teachers to prepare a scientific and technologically literate citizenry for the 21st century, individuals who are prepared to make important decisions and take their places in a high-skilled workforce. You need to be acutely aware of the internal and external expectations that are placed on them. It is such expectations that make science teaching challenging, but also professionally rewarding.

Besides meeting the high expectations placed on you as a beginning science teacher, understanding and reconciling your personal beliefs about teaching has a role in your ultimate success. Beliefs play a critical role in how beginning teachers view science, plan lessons, approach instruction, conduct assessment, and set expectations for student learning (Jones & Carter, 2007). Beliefs about planning, assessing, teaching, and managing the learning environment, as well as beliefs about other aspects of schooling, can be viewed as an individual's school-related belief system. Therefore, it is prudent to be aware of your own beliefs, and the beliefs of others, regarding many aspects of the educational process. As you learn about new ways of teaching and their impact on student learning, you may experience dissonance between what you believe about teaching, and about schooling in general, and what others believe. This dissonance is a natural aspect of professional growth and calls for sensitivity in dealing with other education professionals and with the public.

Not all of what you learn through participating in a science teacher preparation program will fit well in all school settings. The sociocultural context of public and private schools may be different from that which you experience in your teacher preparation program. For example, teachers in the school where you are employed or do your student teaching may view assessment differently from what you will learn about in this textbook and in your science teacher preparation program. Further, your experiences in schools will shape your thinking about teaching and learning as much, if not more than, your teacher preparation program will. Nevertheless, the understandings, skills, and dispositions that you construct by reading this textbook and participating in a teacher preparation program can serve you well as a middle or high school science teacher. We strongly recommend beginning your preparation for a career in science teaching with mastery of the basic teaching functions, and we encourage you to select several mentors who can assist you in extending your understanding of science teaching and learning. These actions will put you on the road to becoming successful in your teaching.

As you conclude this chapter on the thoughts and actions of beginning science teachers, this may be a good place for you to examine your ideas with regard to teaching and learning science. Accordingly, respond to the science teacher inventory shown in Figure 1.2, and check your responses in Appendix A.

FIGURE 1.2 Science Teacher Inventory.

Science Teacher Inventory

This inventory was developed for individuals interested in a career in science teaching to assess their beliefs about science teaching and learning. The inventory assumes that beginning science teachers believe and act on the basis of recollections of their own science learning experiences and their knowledge of today's adolescent learners, schools, and contemporary thinking about science teaching and learning. The inventory is intended to be self-administered and self-scored. Find the scoring key in Appendix A.

Directions: Choose either A or B for each item. Even though you may not completely agree with either choice, select the one that mostly closely matches your thinking.

1. A. The purpose of science teaching is to transmit subject matter knowledge to students.
   B. The purpose of science teaching is to help students develop science understandings.

2. A. Science lessons should be content focused and sequential.
   B. Science lessons should be flexible and inquiry centered.

3. A. The teacher is solely responsible for planning science lessons and units.
   B. The teacher should solicit input from students when planning science lessons and units.

4. A. The focus of science instruction should be the big ideas of science.
   B. The focus of science instruction should be students learning chunks of content.

5. A. The starting point for instruction should be students' misconceptions about science.
   B. When starting a lesson, a teacher should assume that students have no understanding of the content to be taught.

6. A. The outcome of science teaching is students knowing more science content.
   B. The outcome of science teaching is students understanding science content in depth.

7. A. The subject matter students learn in science class is applied in the class context, including tests and projects.
   B. The subject matter students learn in science class is used to make sense of the world.

8. A. In science class, assessment is distinct from learning.
   B. In science class, assessment is integrated with learning.

9. A. The purpose of assessment is to understand students' constructions of knowledge.
   B. The purpose of assessment is to measure science learning and grade students.

10. A. The function of laboratory work and fieldwork is to verify concepts taught in class.
    B. Through laboratory work and fieldwork, students can explore concepts they will encounter in life.

11. A. Student obedience is the centerpiece of science classroom management.
    B. Science classroom management emphasizes student responsibility.

12. A. Sound instructional planning will lessen classroom management problems.
    B. Student discipline problems can be curtailed by establishing strict classroom and laboratory rules.

Assessing and Reviewing

1. Write a few paragraphs describing the *thoughts and actions* of *beginning* science teachers, which tend to result in ineffective instruction with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
2. Write a few paragraphs describing the *thoughts and actions* of many *experienced* science teachers, which usually lead to effective instruction with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment.
3. Identify a teaching session taking place during class, as observed in a video recording or written vignette. Then analyze and evaluate the teacher's instructional effectiveness with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment. Share your analysis with other members who are participating in the science teacher preparation program.
4. After studying the contents of this chapter, demonstrate, in both instructional plans and a brief teaching episode, effective teaching practices with regard to (a) the purpose of science teaching, (b) planning to teach science, (c) assessing student progress, (d) teaching science, and (e) managing the learning environment. Develop a lesson plan that includes these teaching practices, and share the plan with others who are participating in the science teacher preparation program.
5. Identify three or more aspects of teaching science in schools that you should be prepared to develop in mentoring relationships with individuals to assist with your success as a beginning teacher.

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Chapter

2

Purpose of Science Teaching

The purpose of science teaching in America has changed over time to accommodate the needs of all learners.

Jeff Short worked as an electrical engineer for a successful and lucrative computer software company. When offered the opportunity of early retirement after 20 years of hard work, Jeff jumped at the chance. But after just a couple of years, he began to find retirement boring, and he started to think about reentering the workforce. Given his engineering background, financial security, and enthusiasm for education, family and friends suggested that he consider science teaching. Jeff moved quickly on this suggestion and was hired to teach sixth-grade science on the basis of his having earned a provisional teaching certificate. Within weeks of starting, Jeff recognized that his image of teaching did not match the reality of his experiences with classes of rambunctious 12- and 13-year-old boys and girls. On his way out of the building one afternoon, he decides to seek the advice of Verna Robertson, a veteran teacher who also teaches sixth-grade science. Let's listen in on their conversation as Ms. Robertson and Mr. Short consider the purpose of science teaching in today's public schools.

Mr. Short: Ms. Robertson, may I talk to you for a few minutes?

Ms. Robertson: Sure, Mr. Short. What's on your mind?

Mr. Short: Well, things aren't going as I expected. The students don't seem to want to do what I ask of them. You know, for the past 20 years, I supervised many engineering projects. These projects were challenging, and I worked with many different people to complete them. I had to select the best engineers and technicians for each project. When people performed poorly, I replaced them. It all seemed to work so well. However, with these students, I'm stumped. They seem resistant to my teaching. I'm not sure where to go from here.

Ms. Robertson: OK. Before talking about your planning, instructional methods, and classroom management, however, let me ask a question: What is our job with these students?

Mr. Short: It is to provide these kids with the knowledge they need to be successful in high school science and math courses and beyond. I want them to be able to get into college and study to become chemists, engineers, and computer scientists. That is what my teachers wanted for me, and that's what I want for these kids. I don't want them working for minimal wages or being unemployed.

Ms. Robertson: What you said fits well with the purpose of science education in the 1950s and 1960s, but not very well today. You may recall stories about the "Space Race" and the Cold War, when the United States and the Soviet Union were in direct competition. Our country's leaders at that time felt that producing more scientists was the answer to our problems. Or take the period of our Industrial Revolution. The primary purpose of science education during this time was considered to be preparing students for the workforce needed to support the country's growing industrial base. What I'm saying is that the purpose of teaching science and the purpose of schooling have changed over time and continue to evolve, often in response to societal changes and needs.

Mr. Short: But, I'm here to help the kids learn science, and learn it well, not to deal with changes in society. Shouldn't that be the focus of parents and Sunday school teachers?

Ms. Robertson: Perhaps, but much has always been expected of public schools. You mentioned during your interview that you attended school in this district. I'm not sure what it was like then, but I've seen many changes during the 25 years that I've taught here. Our students are different than they were when I started. As you know from your classes, many ethnic backgrounds and socioeconomic levels are represented, and a large percentage of our students are eligible for free and reduced-price lunches. Also, we have students whose families move in and out of the district during the school year. We worry about these kids staying in school and graduating, let alone going to college.

Mr. Short: I'm beginning to understand. So, the purpose of my teaching should not be solely to prepare students for taking advanced science and math courses in high school and to go on to college to major in science. So, then, what is the purpose of teaching science in public schools today?

Ms. Robertson: Mr. Short, you are now asking the right question! Your answer will serve to guide what you teach and how you teach for years to come. Rather than me tell you my answer to this question, let me provide you with a few readings to examine over the weekend, and we can discuss them on Monday. I know that this won't help you prepare for next week's lessons, but I think your reading and our discussion will likely help you along the path to becoming the teacher you want to be. What do you say?

Mr. Short: Sure, it can't hurt me to read a few articles. I look forward to our discussion.

As the conversation between Mr. Short and Ms. Robertson suggests, the purpose of public education in the United States has evolved over time, and with it, the purpose of science teaching in public schools. An understanding of the expectations placed on the public schools in the past and, particularly, in the present will enable a science teacher to engage preadolescents and adolescents in learning experiences that are deemed relevant and effective for today's student population. The content of this chapter will answer Mr. Short's question and hopefully help you to determine what purpose or purposes will be served by the science education that you provide for students.

CHAPTER OBJECTIVES

Use the following learning outcomes to guide your thinking and learning about the purposes of science teaching:

1. Describe how the expectations for public schooling in the United States have changed over time.
2. Construct a table that highlights (a) challenges associated with recent science education reform and (b) indicators of the need for further reform that precipitated the development of the Next Generation Science Standards.

3. Identify three dimensions of science education presented in the new Next Generation Science Standards, and describe how these dimensions compare with areas of emphasis in past standards documents.
4. Predict how expectations associated with the Next Generation Science Standards, the Common Core State Standards, assessment systems, and the National Science Teachers Association (NSTA) Standards for Science Teacher Preparation will affect the success of beginning science teachers.
5. Explain how you would organize a science course, unit, or lesson for today's students based on your understanding of the changing purposes of science teaching.

PUBLIC EDUCATION IN THE UNITED STATES

Before addressing the purpose of science teaching, let's consider the purpose of public education in the United States. The main reason for beginning here is because about 90% of all K–12 students in our country attend public schools and because the purpose of science teaching and that of public education are closely aligned.

A recent report by Wolpert-Gawron (2010) on the results of a survey of 300 people, both educators and non-educators, revealed a vast array of responses to the question "What is the purpose of public education?" The responses varied, but clustered around such purposes as teaching problem solving, analytical thinking, personal responsibility, and civility, as well as preparing students to be lifelong learners, investigators, questioners, and citizens of a democracy. Interestingly, only one person who responded to the survey, according the study's author, indicated that the purpose of public schools today is to teach students reading, writing, and mathematics. These survey results serve to amplify the words of Peter Hlebowitsh, "The American Public School has always carried a heavy burden of responsibility (2001, p. 4).

Indeed, public schools in the United States constitute a comprehensive yet largely community-based system of education. Elementary, middle, and high school teachers are expected to do a great deal for all students. They must increase students' understanding of fundamental knowledge and skills in the areas of language arts, mathematics, science, and social studies. They must guide the learning of immigrant children and adolescents, many of whom are learning to speak English, as well as help students develop the basic skills required to enter the job market. Further, teachers are expected to ensure that all students demonstrate mastery of core content on standardized tests, and in more and more states across the country, teachers are being held accountable for the successes and failures of their students.

The expectations placed on public schools and teachers today reflect our times and clearly are affected by societal and economic stressors. Just as in the past, these expectations are reflected in the purposes of public schooling and the education provided students. Presented in Figure 2.1 are the purposes served by public education in different periods of American history. Evident across the periods are two prominent functions of public education described by Tuomi and Miller (2011). First, public schooling has an integrating and socializing function. Public schooling teaches rules, routines, beliefs, and a common language, thus transferring a shared culture. Second, public schooling serves to foster social change and innovation. Schooling provides openings for diverse thinking, questioning, and the construction of new understandings. It is the tension between these seemingly opposing functions that has led, and continues to lead, to the emergence of different purposes for public schools in American history.

As we look more closely at science education in recent times, we see that these functions of public schooling are clearly operating to shape the purpose of science teaching. Since the early 1950s, a significant purpose of science teaching in the United States has been the development of a scientifically literate citizenry. However, what is meant by scientific literacy has been interpreted differently. George DeBoer (2000, pp. 591–593) summarized the meanings associated with scientific literacy over the years in nine statements:

1. Teaching and Learning About Science as a Cultural Force in the Modern World;
2. Preparation for the World of Work;
3. Teaching and Learning About Science That Has Direct Application for Everyday Living;
4. Teaching Students to Be Informed Citizens;
5. Learning About Science as a Particular Way of Examining the Natural World;
6. Understanding Reports and Discussions of Science That Appear in the Popular Media;
7. Learning About Science for its Aesthetic Appeal;
8. Preparing Citizens Who are Sympathetic to Science; and
9. Understanding the Nature and Importance of Technology and the Relationship Between Technology and Science.

FIGURE 2.1 Purposes served by public education in America from pre-Revolutionary times to the 1960s.

Purpose	Context	Schooling Characteristics
To inculcate religious and moral ideals in boys in preparation for civic leadership and the ministry	Pre-Revolutionary America, Latin Grammar schools opened by Puritans in Boston and other New England cities	Curriculum focused on the classics, including Latin and Greek language and literature, in addition to reading, writing, and mathematics, all blended with religion. All learning was in preparation for college entrance examination.
To foster shared values of freedom, patriotism, and liberty and prepare people to engage in the new democracy	Revolutionary America, period of nation building	No standardized curriculum, but some textbooks were used to teach spelling and grammar and to instill patriotic and moral values.
To train obedient and productive individuals for the industrial workforce and to serve as a vehicle for upward social and economic mobility	American Industrial Revolution and the growing belief in America as a meritocracy	Schooling emphasized reading, writing, and arithmetic, with students expected to demonstrate learning by reciting lessons to perfection. Science learning involved observing and discussing objects or pictures of objects.
To produce scientists and engineers in high numbers, specifically to provide the country with defense-oriented workers, as well as to produce other college-educated professionals	Cold War and Space Race, responses to threats from the Soviet Union, and the growing belief that financial security could be achieved through a college education	Greater emphasis was placed on basic and advanced science and mathematics, with new content-oriented curricula and instructional tools (e.g., language learning labs and educational films).

Based on information presented in I. Tuomi & R. Miller. [2011, January]. *Learning and Education After the Industrial Age. A Discussion Paper for the Confederation of Finnish Industries EK Project: Oivallus*. Retrieved from http://ek.multiedition.fi/oivallus/fi/liitetiedostot/arkisto/Keskustelupaperi_Tuomi_Learning-and-Education-After-the-Industrial-Age--final.pdf

Conspicuously absent from this list are "preparing the student for specific careers in science and engineering" and "teaching detailed information about science concepts and principles." Although knowledge of science and its processes, along with knowledge of the work of scientists, is deemed essential for advancing scientific literacy, just teaching science content for its own sake and increasing the number of scientists and engineers will not result in a scientifically literate citizenry. It is the interplay between the functions of public education described by Tuomi and Miller (2011)—maintaining stability and promoting change—that, in large measure, shapes the meaning of scientific literacy over time and, in so doing, determines what is emphasized in standards documents, high-stakes tests, and, ultimately, classroom instruction.

It's Monday afternoon, and Mr. Short has read several of the articles given to him by Ms. Robertson. Let's listen in on their continuing conversation about the purpose of teaching science in public schools.

Mr. Short: Thanks again for the articles. From my reading, I understand that the purpose of public schooling in America has changed over the years, from nation building in colonial times to preparing a workforce for our Industrial Revolution, and so on. And that public schooling can function as the vehicle for innovation and social change. I even talked to friends at a barbecue over the weekend about the role of public education in balancing stability and change even today.

Ms. Robertson: I'm impressed! You really dug into the articles.

Mr. Short: But the article about developing a scientifically literate citizenry really got me thinking. The list of meanings of scientific literacy helped me see the possible purposes for science teaching, and I feel more comfortable with some than with others. For example, I really resonate with helping students become informed citizens and with teaching science that has direct application to everyday life as purposes for science teaching. But thinking about all the possible meanings that could be attached to scientific literacy makes my head swim. Do I pick one and make it my purpose for teaching science or what? And what if I pick wrong and my purpose leads me to teach in ways that aren't aligned with our district's standards and the tests that the students have to take?

Ms. Robertson: I'm beginning to learn what led you to be a successful engineer. Your questions are ones that I didn't even think about asking until I had taught for 5 or 6 years. I recognized, as you have, that scientific literacy is a general concept that has many meanings. But through graduate coursework, I came to understand that scientific literacy implies a general K–12 education in science that will enable students to learn enough science in school to function effectively as adults. For me, that means I teach for students' general understanding and to promote interest, not necessarily to create scientists.

Mr. Short: Your statement makes me think about a book that I recently read, *Physics for Future Presidents,* by Richard Muller. The ideas about energy, global warming, and nuclear arms presented in this book are important for people in this country to understand. So, a general education in science that teaches the basics needed to be an informed, critical-thinking citizen will help our students become scientifically literate. Am I on the right track?

Ms. Robertson: You are on the right track, Mr. Short. To further your understanding of the purpose of science teaching, I'd like to recommend that you read excerpts from a few other works over the next couple of weeks: *A Nation at Risk, Science for All Americans,* and the *National Science Education Standards*. We can discuss them later. The latter two documents will provide you with insight about the meaning given to scientific literacy by science education leaders since about 1990, while *A Nation at Risk* will shed light on what precipitated the most recent science education reform movement.

Mr. Short: Why do you want me to read these documents that are more than 20 years old? I think I know enough about the purpose of public schooling and what science I should teach.

Ms. Robertson: I believe you'll find it interesting that the people who drafted these works also struggled with the meaning of *scientific literacy.* How they chose to operationalize it is revealed in the *National Standards* and the *Benchmarks for Science Literacy,* a document produced by the same group that authored *Science for All Americans*. As the philosopher George Santayana said, "Those who cannot remember the past are condemned to repeat it."

Mr. Short: I understand your point. Knowledge of the past will help me in my teaching today.

GOALS AND CHALLENGES OF SCIENCE EDUCATION FROM THE RECENT PAST

A review of the recent history of science education will prepare you for thinking about the goal of developing a scientifically literate citizenry as couched in today's Next Generation Science Standards (NGSS) and Common Core State Standards (CCSS).

The Call to Action in the 1980s

Much criticism and controversy surrounded education in the United States in the 1980s. As captured in the National Commission on Excellence in Education's report, *A Nation at Risk* (1983), "Our Nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovations is being overtaken by competitors throughout the world" (p. 5). This report and others released in the 1980s and early 1990s pointed to a need for a school curriculum that differed from that which existed at the time.

In science education, it was Project Synthesis, led by Norris Harms and Robert Yager, that provided guidance for curricular reform. The new curricular focus was balanced across four goals: the personal and societal needs of students, as well as their academic preparation and potential careers (Yager, 1982). Out of Project Synthesis and other studies came a movement that directed science education beyond its core discipline. This movement led to science education reform aimed at strengthening the economic viability of the nation. This focus, in turn, gave meaning to *scientific literacy* that carries on to today.

Our current Information Age society requires that citizens live with and develop technology. Science teachers must educate America's youths to participate in a technology-based world economy in which they must gather and use information accessible through computers and other electronic devices. However, in order to effectively utilize and profit from this information, citizens must possess sufficient knowledge in their long-term memory that will permit them to assimilate information from a host of sources, make sense of that information, and then use it. As in the 1980s, today there is a body of fundamental science knowledge that students should master.

Ambitious Standards of the 1990s

By the 1990s, the educational reform initiated in the 1980s was gaining momentum. In science education, a bold initiative was announced when national guidelines were published that were meant to not only set the philosophical tone for learning science in grades K–12, but also identify the content and skills to be learned. The time had arrived when policy makers believed that a country with 50 states, each containing many school systems, could benefit from the thinking of national committees of educators and scientists.

Given the large number of school systems across the United States, as well as their heterogeneity, science teachers needed standards for subject matter content for students to learn a similar body of knowledge by the time they completed high school. Adopting commercially produced textbook-based curricula or innovative instructional materials did not offer that direction. This failure was evident during the science education reform movement of the Cold War and Sputnik era that relied heavily on instructional materials, funded by the government, to initiate changes in school science programs. Three prominent organizations produced sets of standards to guide science education reform: the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), and the aforementioned NSTA. All shared the purpose of producing a scientifically literate society, but with slightly different goals. The work of each of the three organizations is summarized in Figure 2.2.

After almost two decades of reform, how are the science educational experiences of students and teachers different today as a result of the reform documents and intended changes than before the 1990s? The guidance documents clearly set a new tenor for science education in the United States. The documents de-emphasized the learning of science facts and information, covering many science topics, verifying science content through laboratory and field investigations, separating science knowledge from the processes of science, and implementing scientific inquiry as a set of sequenced steps and processes. They led to science learning experiences for students that tended to stress understanding science as inquiries about the natural and physical world and in the context of social and personal perspectives.

In these 1990s standards, students were challenged to understand the nature of science in the context of scientific explanation and argumentation, to elicit understandings from data, to use technology in investigations and understand the interplay between science and technology in the world, and to explore meaningful science questions rather than learning answers to questions considered irrelevant to students. Greater emphasis was also given to addressing few fundamental science concepts each school year and integrating science content across multiple courses and grade levels.

Unfortunately, standardized tests dominated by questions that require mastery of a great deal of detailed information and a high level of reading comprehension caused a narrowing of curricula that worked against a rich science learning experience. The drive to ensure student success on the standardized tests saw the manipulative, procedural, and cognitive processes of science de-emphasized in science classes. Tension between what teachers understood to be desirable science learning experiences for students and the pressure to ensure student success on standardized tests stymied the reform and lessened the impact of the guidance documents of this era (Reeves, 2011).

INDICATORS OF THE NEED FOR FURTHER REFORM IN SCIENCE EDUCATION: RESULTS FOR THE FIRST DECADE OF THE 21ST CENTURY

A country's economic competitiveness has long been viewed as a leading indicator of the quality of its educational system. Reports of America's slipping global competitiveness and leadership in science and technology released during the first decade of the 21st century pointed to a system of K–12 education failing to prepare students to address the nation's competitiveness challenges. *Rising Above the Gathering Storm: Energizing and Employing America for a Bright Economic Future* (National Academies, 2005) and *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5* (National Academies, 2010) presented sobering statistics on such indicators as U.S. patents awarded to non-U.S. companies, China's growing prominence in biomedical research, and the significant drop in the number

FIGURE 2.2 Science teaching and learning guidance provided by three prominent professional organizations.

American Association for the Advancement of Science: Project 2061
Prominent Publications: *Science for All Americans* (AAAS, 1990), *Benchmarks for Scientific Literacy* (AAAS, 1993)

The central theme of this project is to produce a scientifically literate society by the year 2061, when Halley's Comet will again be visible from Earth. *Science for All Americans* identifies serious shortcomings in the U.S. educational system of the day, including the idea that science courses cover too much material and that science instruction too often centers on learning answers rather than exploring questions. The publication also offered recommendations for improving science education. The recommendations are grounded in the understanding that scientific literacy can be achieved through a comprehensive and interdisciplinary education. The education proposed involves students becoming versed in the physical, life, and social sciences and coming to an understanding of the nature of science, mathematics, and technology, as well as of the integrated functioning of these disciplines. It also placed importance on providing students with a historical perspective on how fundamental science ideas have evolved over time and having students develop habits of mind associated with becoming versed in science, mathematics, and technology. *Benchmarks for Scientific Literacy* specifies a common core of learning for students and lists learning outcomes in science, mathematics, and technology for all students by the end of grades, 2, 5, 8, and 12.

National Research Council: National Science Education Standards
Prominent Publications: *National Science Education Standards* (NRC, 1996), *Inquiry and the National Science Education Standards*: *A Guide for Teaching and Learning* (NRC, 2000)

The *National Science Education Standards* make it clear that scientific literacy is at the core of the reform movement and that the knowledge and understanding of science is an important guideline for the realization of a scientifically literate citizenry. In addition to learning fundamental scientific facts, concepts, theories, and laws, students must be able to apply them in their decision-making and to distinguish between information that is based on good science and that which is not. Inquiry is a theme that runs though the *Standards* and is defined relative to scientific inquiry, which centers on humankind's probing of the natural world in search of explanations based on evidence and leading to an understanding of reality. The *Standards* stress that there are many ways to inquire, from conducting firsthand investigations to reading about what others have done. Science and technology are seen as compatible and necessary to the development of scientific literacy, yet they are different enterprises. The major aim of science is to understand nature, whereas the major aim of technology is to create devices and systems to assist society. Documents provide guidance for planning, organizing, developing, implementing, and evaluating science programs, all features deemed critical to science education reform.

National Science Teachers Association: Scope, Sequence, and Coordination
Prominent Publications: *Scope, Sequence, and Coordination of Secondary School Science, Volume 1: The Content Core* (NSTA, 1992); *Scope, Sequence, and Coordination: A Framework for High School Science Education* (NSTA, 1996).

The aim of the Scope, Sequence, and Coordination project is to change the content structure of middle and high school science curricula. The rationale for altering the structure that exists in most schools is the belief that teaching science in a "layered cake" fashion—biology, chemistry, earth/space science, and physics as separate 1-year courses—both is inefficient and does not integrate the sciences so that they make sense to students. It is recommended that all four of the major science disciplines be taught each year in grades 6 through 12 and that the curriculum adhere to a less-is-more design, enabling students to develop deeper understandings of a specified set of important ideas. In the context of this reform effort, the two *Scope, Sequence, and Coordination* publications refer to a coherent 6th–12th-grade science curriculum that is developmentally appropriate and spaced over time and that reflects the continuity of studying the four basic science disciplines.

of new drugs approved in the United States in recent years. These reports and others forecast a bleak future for the nation without vast improvements to K–12 science and mathematics education.

Readiness for College and Careers

Other indicators pointing to needed reform are reports of insufficient numbers of qualified candidates to fill the job vacancies for scientists and engineers as well as claims from business leaders that high school graduates are ill prepared for entering the workforce, possessing weak reading and writing skills and being unable to reason mathematically, think critically, and solve problems. Moreover, colleges were finding it necessary to provide remediation for students they admit as freshmen and to reteach basic skills and understandings that students should have learned in high school. According to a U.S. Department of Education report, about one out of three students enrolling in 4-year colleges during the 2007–2008 school year required remediation in reading, English, or mathematics, with the rate exceeding 40% for students at public 2-year colleges (Aud et al., 2011).

International Science Test Performance

International comparisons of students' performance on high-profile tests provide additional evidence of possible shortcomings in science education in U.S. public schools. The Trends in International Mathematics and Science Study (TIMSS) results over four administrations since 1997 placed the science performance of eighth-grade U.S. students in the middle of the pack, compared with students in the same grade in more than 40 other participating countries, but with some improvement shown in the 2007 results (Gonzales et al., 2008). Historically, the science test performance of U.S. students toward the end of high school is more toward the bottom quartile than in the middle with respect to students of other countries.

The Program for International Student Assessment (PISA) is a series of worldwide surveys of school learning in mathematics, reading, and science sponsored by the Organisation for Economic Co-Operation and Development and administered every third year since 2000. The 2009 PISA report for science showed findings similar to those of the TIMSS reports. The science performance of 15-year-old U.S. students, while above the international average, was significantly below that of top-performing countries, as shown in Figure 2.3. Shanghai was at the top, with a student mean score of 575 compared with the mean score of 502 for U.S. students. Countries in which students also performed well included Finland, Hong Kong, Singapore, Japan, and South Korea. In many of the countries, males and females showed no difference in average score. However, socioeconomic differences accounted for a significant proportion of the variability in scores in some countries, including the United States.

Schooling in High-Performing Countries

The consistently high performance of students from such countries as Finland, South Korea, Singapore, New Zealand, Canada, and Japan on international tests prompted examinations of schooling in those countries for ideas for improving U.S. public schools. Lengthening the school year was one suggestion coming from the study of schooling in South Korea, where the school year is longer than in U.S. schools. Insisting that students do more homework and struggle with challenging content before being given assistance from the teacher, as is done in many East Asian countries, was another suggestion. National school inspections, such as those which take place in Singapore and New Zealand, were also proposed as a means for improving U.S. schools, as was the use of Singapore math, which emphasizes the study of few mathematics concepts early on and the integrated study of multiple concepts at the secondary level. From the study of schools in Finland, where virtually all K–12 schools are public schools, came suggestions for greater cooperation among teachers and schools, along with an education policy that promotes educational equity over excellence and ensures that all students have the same learning opportunities regardless of family income.

A key feature of the educational systems of these high-performing countries is that they have high academic expectations for all students, not just the top achievers, and considerable independence is given to local schools to help them meet the expectations (Stewart, 2012). In addition, teachers in those countries are respected, paid a good wage, and given decision-making responsibility in schools. Mechanisms are in place to recruit and retain talented teachers, and attention is paid to helping teachers improve their understandings and skills. Japanese lesson study, a collaborative professional development model to help teachers improve their instruction, is one example of an idea for improving U.S. public schools that has been widely tried.

The explorations also revealed that culture, context, and societal factors, such as poverty, school funding, and population size and distribution, play a significant role in a nation's educational system and that these factors need to be considered in contemplating the transfer of educational policy and practices from one country to another (Stewart, 2012). For this reason, some educational leaders have recommended that low-performing school systems

FIGURE 2.3 Mean science scores of 15-year-old students in 65 countries.

Country	Mean	Country	Mean
Shanghai, China	575	Slovak Republic	490
Finland	554	Italy	489
Hong Kong, China	549	Spain	488
Singapore	542	Croatia	486
Japan	539	Luxembourg	484
Korea	538	Russian Federation	478
New Zealand	532	Greece	470
Canada	529	Dubai (United Arab Emirates)	466
Estonia	528	Israel	455
Australia	527	Turkey	454
Netherlands	522	Chile	447
Taipei, Republic of China (Taiwan)	520	Serbia	443
Germany	520	Bulgaria	430
Liechtenstein	520	Romania	428
Switzerland	517	Uruguay	427
United Kingdom	514	Thailand	426
Slovenia	512	Mexico	416
Macao, China	511	Jordan	415
Poland	508	Trinidad & Tobago	410
Ireland	508	Brazil	405
Belgium	507	Columbia	402
Hungary	503	Montenegro	401
United States	**502**	Argentina	401
Czech Republic	500	Tunisia	401
Norway	500	Kazakhstan	400
Denmark	500	Albania	391
France	498	Indonesia	383
Iceland	496	Qatar	379
Sweden	495	Panama	376
Austria	494	Azerbaijan	373
Latvia	494	Peru	369
Portugal	492	Kyrgyzstan	330
Lithuania	491		

Based on data from Figure 1.3.21, "Comparing Countries' Performance in Science," from *PISA 2009 Results: What Students Know and Can Do—Student Performance in Reading, Mathematics and Science* [Vol. 1] [Paris: OECD, 2010]. Retrieved from http://dx.doi.org/10.1787/9789264091450-en study and adopt the educational policies and practices of such states as Massachusetts and Minnesota, as well as of local schools in which students consistently score high on international tests and excel on other measures (Chenoweth, 2007; Ripley, 2010).

Stop and Reflect!

Armed with new knowledge of the changing purposes of public schooling in America and with the history of recent reform efforts in science education, what recommendations do you have for improving science education in American public schools? Write a short paragraph that summarizes your recommendations, and then tuck it away and revisit it after learning about the Next Generation Science Standards. Are your recommendations for improvement reflected in these new standards?

Room for Improvement, but U.S. Schooling Is Still Strong

From the preceding discussion, one might get the impression that the U.S. educational system is in a sad state with little hope for improvement. However, through the 1990s and into the 21st century, the United States continues to be a world leader in scientific and technological advancement. Despite recent economic slowdowns, the U.S. economy remains the envy of the world. Consequently, the prosperity of the country, up until now, has not been tied exclusively to the scientific literacy of the general public or to the number of scientists and engineers that it produces.

However, this situation could change in the future, and quickly. Much of the prosperity in the communication and technology industry has resulted from many factors, such as a democratic government, a free-market economy, global competition, and the immigration of technically skilled workers from other countries into the United States. While it is expected that these factors will continue to benefit the U.S. economy and its citizens, our nation's education system, particularly K–12 public schools, will be called up to serve as the engine for a knowledge-based economy. Recent history suggests that realizing a strong knowledge-based economy will require further reform in science education. This reform must focus on helping all students to participate in science and engineering learning experiences so that they can appreciate those enterprises and apply the knowledge and skills they learn in their everyday lives as well as in the workplace.

Let's return to a conversation between the beginning teacher, Mr. Short, and his mentor, Ms. Robertson.

Mr. Short: Learning about earlier efforts to reform science education and about the international comparisons helps me put things into perspective. Economic competitiveness has been an important driver for reform since the 1980s, but it is not the only factor.

Ms. Robertson: You're right. The standards movement of the 1990s really moved us in the right direction. Use of the *Benchmarks for Scientific Literacy* in our school system encouraged all teachers to think carefully about aligning what we were teaching from one grade to the next and about how what students are learning in middle school prepares them for studying science in high school. During that period, I attended many professional development workshops in which we unpacked standards—definitely not an easy task—and learned more about inquiry, the nature of science, and scientific argumentation. We also learned about strategies used in other countries. This was all great, but then came accountability! In our school system, accountability meant that you were judged on the basis of your students' performance on statewide tests.

Mr. Short: I heard about this from other teachers. What if you had weak students in your classes, and they didn't perform at the level expected?

Ms. Roberson: That was a problem! Because of the test, I felt that I had to cover all the topics in our course syllabus, and I wasn't able to stay on some topics long enough to ensure that students were really learning. I didn't do as many labs with students as I wanted because I felt that I had to use the time available to cover the syllabus. During those years, we continued to ask for an assessment system that tracks student growth through the grades and for further refinement of the syllabus so that we could address fewer topics and help our students master important content before moving on.

Mr. Short: Those days must have been challenging times for you as a teacher.

Ms. Robertson: Well, there is always room for improvement, and I'm excited about what's ahead. I hope these readings and our talking are helping you develop your own ideas about the purpose of science teaching.

Mr. Short: Yes. In addition to providing answers, they bring up more questions. For me, this is what makes science teaching interesting. It is wrestling with the tough questions that makes it clear to me that teaching is a profession, not simply a job.

The recent history of science education is a lived experience for Ms. Robertson, but not so for Mr. Short. His reading of documents from the 1980s, the 1990s, and the first decade of the 21st century, and his discussions with Ms. Robertson, provide him with an understanding of the reform efforts of the recent past. These activities also provide him with knowledge of the challenges that reformers were attempting to address through their work. The shortcomings articulated by critics, as well as advocates, of various reform efforts, highlight areas for further improvement. The science education reform of the 1980s, the 1990s. and the first decade of the 21st century serves as a backdrop for today's reform efforts, revealed most notably through the NGSS.

TODAY'S STANDARDS AND THEIR PROMISES FOR SCIENCE EDUCATION: 2010 AND FORWARD

Your entry into science teaching will be greatly influenced by recently developed standards—specifically, the NGSS and the CCSS—along with the assessment systems being built to support them. Informed by mediocre results of American students on international comparisons, by high rates of college remediation—both perceived by policy makers as indicators of shortcomings in the nation's education system—and by the educational policies and practices of other countries, these standards are aligned to requirements for college and career readiness. They also present a refined vision of the purpose of science education in public schools through expectations for all students that will enable them to function as scientifically literate adults.

Indeed, the intent of the new standards is that all students receive an equitable education in science, regardless of who they are. As envisioned by today's science education leaders, the standards specify that, by the end of the 12th grade, all students will "have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; [be] careful consumers of scientific and technological information related to their everyday lives; [be] able to continue to learn about science outside of school; and have the skills to enter careers of their choosing, including (but not limited to) careers in science, engineering, and technology" (National Research Council, 2012, p. 1).

The Next Generation Science Standards

The development of the Next Generation Science Standards (NGSS; Achieve, Inc., 2013) was guided by broad expectations set forth in the visionary document *A Framework for K–12 Science Education*. The authors of the *Framework* recommended that science education experiences for K–12 students be built around three dimensions:

- Scientific and engineering practices
- Crosscutting concepts that unify the study of science and engineering through their common application across fields
- Core ideas in four disciplinary areas: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science (National Research Council, 2012, p. 2).

These dimensions serve to reinforce the significance of themes present in standards and guidance documents from earlier eras, as well as to elevate the prominence of other themes.

Notably elevated to prominence in the NGSS is the study of engineering as a means to strengthen the study of science and give engineering and technology their rightful place in school science. A basic understanding of both science and engineering practices is considered essential for adults to "engage with the major public policy issues of today as well as to make informed everyday decisions, such as selecting among alternative medical treatments or determining how to invest public funds for water supply options" (National Research Council, 2012, p. 7). Among the science and engineering practices highlighted in the NGSS are "Asking questions (for science) and defining problems (for engineering)" and "Constructing explanations (for science) and designing solutions (for engineering)." In addition, the practices of "Developing and using models," "Engaging in argument from evidence," and "Using mathematics and computational thinking" receive greater emphasis than in the *National Science Education Standards* released in 1996.

Having emerged from more than 50 years of work by social scientists and historians and philosophers of science, the idea of science and engineering as a set of practices shows how science and engineering are conducted in the field and in laboratories today and in the past. Moreover, according to Fausto Morales (n.d.), the presentation of science and engineering as a set of practices is an improvement over past approaches in at least three ways.

First, attention to practices makes it less likely that science and engineering will be reduced to sets of procedures. For instance, in science, rather than focusing on procedures for identifying and controlling variables in an experiment, learning opportunities will highlight such practices as modeling, evaluating data, and communicating information.

Second, a focus on practices makes clear that there is not one scientific method, but that scientists and engineers employ multiple practices in their work and that, while there is uncertainty associated with science and engineering, there is much unquestioned knowledge.

Third, addressing the practices of science and engineering removes the focus from teaching and learning science as a process of inquiry. Although teaching science as inquiry has a long and storied history in American education, its potential as an organizing theme for science teaching and learning has never been fully realized.

Unfortunately, the lack of a commonly accepted definition of inquiry and the lack of multiple inquiry frameworks has led to a host of different teaching approaches and desired instructional outcomes that seem incompatible with the notion of common standards. Scientific inquiry "is one form of scientific practice," according to Rodger Bybee, who describes the focus on scientific and engineering practices as "not one of replacing inquiry; rather, it is one of expanding and enriching the teaching and learning of science" (Bybee, 2011, p. 38).

The NGSS crosscutting concepts have been present in guiding documents for decades. They provide an organizational structure "for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world" (National Research Council, 2012, p. 83). Regrettably, earlier standards and most curriculum documents built from those concepts did not provide sufficient guidance for incorporating them into instructional materials. If taught, they were often taught in isolation from core disciplinary ideas. Thus, most students did not develop understandings about how such concepts as "structure and function," "cause and effect," "patterns," and "stability and change" serve to connect what they learned in different middle and high school courses.

The NGSS disciplinary core ideas are what most students of science recognize as the essence of science coursework. While the core ideas are organized under the familiar headings of "physical sciences," "life sciences," and "earth and space sciences," there are significant differences from the past. The NGSS present a limited set of core ideas in order to enable instruction to focus in depth on concepts considered to be of most worth. Core ideas from across the traditional disciplines include "matter and its interaction" in the physical sciences, "heredity: inheritance and variation of traits" in the life sciences, and "earth's systems" in the earth and space sciences. Also included as core ideas are "engineering design" and "links among engineering, technology, science and society."

The science and engineering concepts that give meaning to the core ideas are sequenced on the basis of understandings of human development and how people learn, with the expectation that students will progress from novices to experts in their knowledge as they move from the elementary grades through middle school and on to high school. This coherent building of science concepts across the grade levels means that middle and high school teachers must help students develop understandings of the unique concepts to be taught each year, and they should expect that students entering their classes have learned materials scheduled to be taught in earlier grades. Finally, it is intended that students develop understandings about the core ideas not as passive learners, but by engaging in scientific and engineering practices and with crosscutting concepts each year.

Fortunately, as a beginning teacher, you will be the beneficiary of all the work that has gone into developing the NGSS. Rather than having to figure out how to incorporate the three dimensions into coherent learning experiences for students, you will receive guidance from the developers of the standards. More specifically, the developers have written rather precise learning outcome statements that weave together understandings found within each of the three dimensions set forth in the *Framework*. These statements highlight the real-world interactions taking place in science and present science as both a set of practices and a body of accumulated knowledge. Moreover, helping students engage science across the three dimensions enables them to develop understandings about the nature of science, through investigations of natural phenomena, real-world problem solving, or examining case studies from the history of science. As shown in Figure 2.4, we hope that the learning outcomes ensure that students will engage in multiple practices and crosscutting concepts as they develop understandings of core ideas each year. The learning outcome statements make clear what the students are responsible for learning and what the teacher needs to teach, but not how the teacher should teach.

It is important to note that the NGSS do not limit students' access to advanced courses. The standards should not be interpreted as indicators of the upper limit of students' science understandings. Students should be afforded the opportunity to take honors and Advanced Placement courses of interest to them, thus extending their understandings of science and engineering beyond those addressed in the standards. Moreover, a science education based on the NGSS is not specifically intended to prepare students for careers in science, engineering, or technology, but we hope that it will serve to inspire and motivate more students to followed educational pathways that lead to careers in these areas.

The Common Core State Standards

The release of the Common Core State Standards (CCSS) in English language arts and in mathematics preceded that of the NGSS by little more than a year. This timing allowed for alignment of the NGSS with the CCSS, with meaningful overlap among the standards, along with the compatible pacing of expected learning outcomes across the grade

FIGURE 2.4 Learning expectations from the Next Generation Science Standards.

HS-PS2 Motion and Stability: Forces and Interactions

HS-PS2 Motion and Stability: Forces and Interactions

Students who demonstrate understanding can:

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]

HS-PS2-2. Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]

HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. [Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields.] [Assessment Boundary: Assessment is limited to systems with two objects.]

HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current. [Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.]

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.* [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models.
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS2-5)

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-PS2-1)

Using Mathematics and Computational Thinking
Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
- Use mathematical representations of phenomena to describe explanations. (HS-PS2-2),(HS-PS2-4)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
- Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HS-PS2-3)

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.
- Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (secondary to HS-PS2-6)

PS2.A: Forces and Motion
- Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)
- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2)
- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3)

PS2.B: Types of Interactions
- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4),(HS-PS2-5)
- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (HS-PS2-6),*(secondary to HS-PS1-1)*,*(secondary to HS-PS1-3)*

PS3.A: Definitions of Energy
- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary to HS-PS2-5)*

ETS1.A: Defining and Delimiting Engineering Problems
- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary to HS-PS2-3)*

ETS1.C: Optimizing the Design Solution
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary to HS-PS2-3)*

Crosscutting Concepts

Patterns
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2-1),(HS-PS2-5)
- Systems can be designed to cause a desired effect. (HS-PS2-3)

Systems and System Models
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)

Structure and Function
- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

The section entitled "Disciplinary Core Ideas" is reproduced verbatim from A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas. Integrated and reprinted with permission from the National Academy of Sciences.

July 2013 1 of 2

levels. The timing also presents the opportunity for science to be included together with mathematics and language arts as a core component of a child's public school education. Both the CCSS and NGSS emphasize student acquisition of conceptual understanding and student development of real-world practices for college and career readiness. In fact, college and career readiness standards are intentionally embedded in the CCSS. Like the NGSS, the CCSS were designed to provide a coherent progression of conceptual understandings from the elementary grades through high school, with priorities set for grade levels.

The overlap between the CCSS and the NGSS is clearly evident. For example, the CCSS in mathematics call for high school students to "practice applying mathematical ways of thinking to real world problems and challenges" and to develop understandings of "mathematical modeling." This summons to action overlaps with the NGSS's call for students to engage in science and engineering practices that emphasize "developing and using models," and "using mathematics and computational thinking." Similarly, the CCSS in English language arts emphasize practices and understandings found in the NGSS. The CCSS call for learning experiences in which students build understandings through interacting with content-rich nonfiction, engage in writing and speaking grounded in evidence that is both literary and informational, and practice with complex text and its academic language. All of these learning experiences dovetail with practices called for in the NGSS. This overlap among the CCSS and the NGSS allows for the coordination of learning experiences for students across the subject domains of science, mathematics, and English language arts.

The CCSS include components of particular importance to middle and high school science teachers: standards for literacy in science and technical subjects for grades 6–12. These standards bring attention to the importance of reading in building science and engineering understandings and of writing as a key way of conveying experiences, thoughts, and images and presenting evidence-based arguments. The reading standards focus on students' ability to analyze science text material, make meaning from domain-specific words and symbols, and synthesize information from multiple sources, while the writing standards stress students' ability to craft text that presents clear and coherent, evidence-based arguments using discipline-appropriate language suitable for different audiences.

Middle and high school science teachers are being asked to attend to these literacy standards alongside the NGSS in their instruction and to provide evidence of their students' mastery of them. Students' mastery of the understandings and practices included in these reading and writing standards is considered an indicator of college and career readiness. Figure 2.5 shows both unique features and common features of the NGSS and the CCSS.

FIGURE 2.5 Features of related emphasis between the Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS).

Both the NGSS and the CCSS—Mathematics emphasize . . .

- Limiting the content to be studied
- Attending carefully to the content emphasized in the standard to build foundational knowledge
- Aligning learning across and within grades to enable students to build new understandings on content previously mastered
- Expecting that students will hold solid understandings of content targeted in instruction
- Devoting instructional time and resources to achieve the specified learning outcomes
- Balancing and integrating instruction across multiple dimensions of learning
  - The dimensions for mathematics are conceptual understanding, procedural and skill fluency, and the application of understandings through problem solving
  - The domains for science are scientific and engineering practices, crosscutting concepts, and disciplinary core ideas

The CCSS—English Language Arts/Literacy emphasizes supporting science learning through . . .

- Building understandings by reading information-rich, nonfiction text materials
- Comprehending and evaluating evidence-based arguments in text and oral presentations
- Gathering information from multiple sources and using the information to construct explanation and design solutions
- Constructing written and oral evidence-based arguments to assert and defend claims
- Following written multistep procedures when conducting investigations
- Devoting more instructional time to the interrogation of complex text and the academic language it contains

Based on information presented in Achieve, Inc. (2013). *Explore the NGSS.* Retrieved from www.nextgenscience.org; Student Achievement Partners. (n.d.). *Achieve the Core*. Retrieved from www.achievethecore.org); and National Research Council. (2012). *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press, pp. 23–34.

Stop and Reflect!

Examine the Standards for Literacy in Science and Technical Subjects, Grades 6–12, as you think about the science course or courses you envision yourself teaching. Write a short paragraph that explains how you might address specific facets of the reading and writing standards in your teaching. Exchange paragraphs with classmates, read the paragraphs, and then discuss them.

ASSESSMENT SYSTEMS TO SUPPORT STANDARDS

A significant limitation of past standards-based reform efforts has been the absence of assessments that measure students' achievement relative to the standards. This limitation is being addressed head-on in today's reform by two state-led consortia, supported by funding from the U.S. Department of Education. Representatives from states that compose the Partnership for Assessment of Readiness for College and Careers (PARCC) and the Smarter Balanced Assessment Consortium are building K–12 assessment systems that are aligned to the CCSS and that provide a pathway to college and career readiness by 12th grade.

The work of PARCC centers on supporting the efforts of states to build assessment systems that make use of innovative online measures and classroom-based tasks in English language arts/literacy and in mathematics that can serve both diagnostic and summative purposes. In addition, PARCC is developing tools and resources for teachers that provide guidance about the PARCC assessments and their alignment with the CCSS. The intent of this guidance is to furnish teachers with the know-how to align the curriculum students will study with both the standards and the standards-based assessments. The centerpiece of the work of the Smarter Balanced Assessment Consortium is computer-adapted testing, as an alternative to paper-and-pencil tests. By adjusting the difficulty of assessment questions on the basis of correct and incorrect responses, a more precise assessment of both an individual student's mastery of the standards and the student's growth over time can be inferred, according to the consortium leadership (SmarterBalance.org, online). An important outcome of both consortia will be high-quality assessments for the full range of CCSS.

As a science teacher, you will no doubt hear more about one or both of these assessment systems from fellow mathematics and English/language arts teachers. It is likely that your students' progress toward meeting the Standards for Literacy in Science and Technical Subjects, Grades 6–12, will be assessed with the use of measures developed through these consortia or measures built by other groups. Given the overlap and similarities between the CCSS and the NGSS, it is also likely that complementary assessments to measure student achievement relative to the NGSS will be built, also with an eye toward students' college and career readiness by the end of high school.

Much excitement surrounds today's reform in science education. It is informed by the CCSS in mathematics and in English/language arts and by the development of robust and comprehensive assessment systems that will not only measure, but also serve to guide, student learning. The purpose of science education in the context of this reform, as revealed through the NGSS, is certainly to develop a scientifically literate citizenry. However, the scientifically literate citizen of the 21st century is one who must function in, as well as contribute to, an ever-evolving information and technology-rich global society. Preparing for life in the 21st century demands a middle and high school science education that develops students' appreciation for science and engineering and their understanding of the nature of those disciplines, informs their decision-making, and readies them for college and careers. This is a lot to expect, but not inconsistent with the expectations historically placed on American public schools.

STANDARDS FOR THE PRESERVICE SCIENCE TEACHER

The NGSS, as well as the CCSS for Literacy in Science and Technical Subjects, Grades 6–12, lay out what is expected of students. In doing so, they provide insights about what teachers need to know and be able to do to help students achieve these standards. But how can you determine whether you are well prepared for the job ahead of you as a middle or high school science teacher?

Fortunately, the NSTA has developed standards that you can use to answer this question. These 2012 Preservice Science Teacher Standards (www.nsta.org/preservice) highlight understandings in science content, content pedagogy, learning environments, safety, the impact of the standards on student learning, and professional knowledge and skills expected of beginning science teachers. An overview of the standards is presented Figure 2.6. The standards are the centerpiece of nationally recognized and accredited science teacher preparation programs, and you can use them to gauge the quality of your educational experience and your readiness for beginning a career in science teaching.

FIGURE 2.6 Overview of the Preservice Science Teacher Standards from the National Science Teachers Association (Presented with permission from the National Science Teachers Association).

Overview of the Preservice Science Teacher Standards

Standard 1. Content Knowledge Middle and high school science teacher candidates are expected to have a robust understanding of science content in their fields of licensure and in supporting fields. Their understandings must reflect the expectations for student learning presented in state and national standards.

Standard 2. Content Pedagogy Middle and high school science teacher candidates are expected to be knowledgeable about current understandings of human learning. They must be able to apply this knowledge to guide and assess students' science learning.

Standard 3. Learning Environments Middle and high school science teacher candidates are expected to develop appropriate and equitable science learning experiences for all students. Development must take into consideration matters of social context, personal safety, availability of instructional resources, and fair assessment.

Standard 4. Safety Middle and high school science teacher candidates are expected to be knowledgeable about matters related to the safe storage, maintenance, use, and disposal of chemicals and equipment, as well as to the ethical treatment of living organisms associated with their fields of licensure. In addition, they must be prepared to respond to emergencies that may arise in the course of science teaching and instructional preparation.

Standard 5. Impact on Student Learning Middle and high school science teacher candidates must be able to demonstrate the positive impact of their teaching on student learning.

Standard 6. Professional Knowledge and Skills Middle and high school science teacher candidates must be able to demonstrate their efforts to continually improve their science content and content pedagogical understandings and skills, and to engage in actions that reflect well on the science education community.

More information about these standards, the research that supports them, and their role in the national recognition and accreditation of science teacher preparation programs can be found at the National Science Teachers Association website (www.nsta.org/pd/ncate/docs/2012NSTAPreserviceScienceStandards.pdf).

YOUR PURPOSE IN TEACHING SCIENCE

In concluding this chapter, let's return to the question asked by Mr. Short in the opening vignette: "So, then, what *is* the purpose of teaching science in public schools today?" As you've learned, the purpose of public education in the United States has evolved over time, and with it, the purpose of science teaching in public schools. As expressed in today's standards, the purpose of science teaching continues to be the preparation of a scientifically literate citizenry. Unlike the way we thought in the past, we must now think about our students as future adults functioning in a knowledge-based economy, stoked by advances in science and technology that make information instantaneously accessible and make possible what was considered impossible just a few years ago. The charge of guiding students as they construct understandings and skills that will enable them to function as scientifically literate adults in this milieu comes with much responsibility.

A teacher must help students develop an appreciation for science and engineering and an understanding of the nature of those disciplines both to enhance their decision-making abilities and to ready them for college and careers. While this purpose for science teaching does not specifically target the preparation of students for careers in science, engineering, or technology, it is not incompatible with this outcome. Learning experiences that serve the purpose of preparing a scientifically literate citizenry will surely inspire and motivate a good number of students to follow educational pathways that lead to careers in these areas.

Your attending to major science education themes and fundamental attributes and abilities shared by successful science teachers will go a long way toward enabling you to teach in ways that support this purpose of science teaching.

As shown in Figure 1.1 in Chapter 1, science education themes that deserve your attention include the practice of science and engineering, student diversity, and human learning, as well as testing and accountability. Moreover, fundamental teacher attributes and abilities that you will want to develop fall within the categories of professional traits, teaching functions, teaching skills, instructional strategies, and learning techniques. Your growing understanding of the concepts nested under these major themes, in addition to your ever-developing professional teacher attributes and abilities, will enable you not only to survive, but also to thrive as a teacher of science. Happy science teaching!

Assessing and Reviewing

1. Describe in two or three paragraphs how expectations for public schooling in America have changed from pre-Revolutionary times through the 1960s. Address in your description how the national context has tended to drive expectations for public schooling.
2. What factors led to the development of the Next Generation Science Standards? Answer this question by constructing a table that presents (a) challenges associated with recent science education reform and (b) indicators of the need for further reform. *Hint:* Consider Project Synthesis and the sets of standards generated by three prominent organizations in the 1990s, as well as reports of educational quality from the first decade of the 21st century.
3. What are the three dimensions of science education featured in the Next Generation Science Standards? How do these dimensions compare with features highlighted in past standards documents?
4. Reflect on what you now know about the Next Generation Science Standards, the Common Core State Standards, and the NSTA Standards for Science Teacher Preparation. How do you expect these standards to affect your work as a beginning middle or high school science teacher?
5. What is the purpose of science teaching in public schools today? On the basis of your understanding of the purpose, describe in two or three paragraphs how you would organize a science course, unit, or lesson for today's middle or high school students.

Resources to Examine

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. 2012. Washington, DC: National Academies Press. Available online at www.nap.edu/catalog.pjp?record_id=13165#

The *Framework*, which sets forth a new vision for K–12 science education, served as the genesis for the Next Generation Science Standards. Discussed in depth in this report are the three dimensions of the framework—scientific and engineering practices, crosscutting concepts, and disciplinary ideas—along with challenges inherent in integrating the three dimensions into a coherent science education program. The report also offers recommendations for implementing new standards in classrooms and in teacher professional development, as well as for addressing matters of equity and diversity in science education in concert with new standards.

Common Core State Standards. 2012. The standards can be accessed electronically at the Common Core State Standards initiative website: www.corestandards.org/the-standards

Presented at this website is an overview of the Common Core State Standards development process and of the key points of the English language arts and mathematics standards, along with news of state implementation of the standards. Of particular interest to middle and high school science teachers are the Reading and Writing Standards for Literacy in Science and Technical Subjects, Grades 6–12. These specialized standards, in addition to the English language arts and mathematics standards, can be downloaded as PDF documents from the site.

National Science Teachers Association **Standards for Science Teacher Preparation.** 2012. These standards can be accessed electronically at the National Science Teachers Association website: www.nsta.org/pd/ncate/docs/2012NSTAPreserviceScienceStandards.pdf

This document provides a detailed description of the six standards for science teacher preparation and how they should be applied in a science teacher preparation program. The standards emphasize the importance of beginning teachers having mastery of science content, content pedagogy, and science classroom safety, along with being able to establish a learning environment that encourages and enhances student learning of science.

Next Generation Science Standards. 2013. These standards can be accessed electronically at the Next Generation Science Standards website: www.nextgen-science.org/next-generation-science-standards

Found at this website are the standards, along with a host of supporting information. In addition to presenting information about the three dimensions that compose the framework, the site has links to details about the structure of the standards, to appendices that address such topics as the nature of science, to course maps for middle and high schools, and to the Common Core State Standards.

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Chapter

3

Planning for Science Teaching

Planning is essential for effective science teaching and student learning.

Michael Graff was hired to teach biology at Johnson County High School in August, just a few days before the start of classes. And, as required by school system policy, Michael joined 11 other new teachers from high schools across the county in the system's induction program specially designed to aid inexperienced science and mathematics teachers. The program brought the 12 together after school, every other week, under the direction of veteran teacher Shannon Martin. She had taught science and mathematics in the school system for years and took the job of induction program leader very seriously. To fulfill the induction program requirement that each new teacher demonstrate proficiency in developing lessons plans and in teaching lessons, the group agreed to serve as students for peers to test their newly prepared lessons.

The week before Michael was to teach his first lesson to peers, he met with Mrs. Martin to receive feedback on his plan. Let's listen in on their conversation.

Mrs. Martin: Hi, Michael. Please come in and have a seat.

Mr. Graff: Well, am I good to go? Is my lesson plan okay? I spent much time preparing it, and I intend to use it with my biology students as part of my unit—that is, after testing it on my peers in our induction session next week.

Mrs. Martin: Overall, your lesson plan is quite good, but let's examine each part in turn to highlight your plan's strengths and areas where improvement is needed. Let's begin with your statement of purpose.

Mr. Graff: OK. I really gave this some thought and considered how my lesson fits in with other lessons in my unit about energy flow in organisms. I used the structure presented in *A Framework for K–12 Science Education* to guide my thinking.

Mrs. Martin: You did a nice job here. You succinctly describe the purpose of the lesson in the context of how organisms obtain and use the matter and energy they need to live and grow, and you highlight why high school students—and your peers—should have a basic understanding of the process of photosynthesis. More specifically, your lesson zeros in on evidence which indicates that photosynthesis involves two reaction systems—one independent of light and one dependent on light.

Mr. Graff: What do you think of the title of my lesson? I tried to align it with my statement of purpose.

Mrs. Martin: "Photosynthesis: The Light and Dark of It," is a catchy title for your lesson. It is indeed aligned with your lesson's purpose, and you can use your title to focus students' attention at the beginning of the lesson. You may wish to ask your peers what they know about photosynthesis and what light and dark might have to do with the photosynthetic process. Those who teach biology may know quite a bit, but those who don't may not. Similarly, some of your high school students may have learned something about the light-dependent and light-independent reactions of photosynthesis in middle school, but others may not have.

Mr. Graff: Yeah, I planned to introduce my lesson with a series of questions about photosynthesis, including "What is the evidence for a separate, light-independent reaction system?" In my plan, you saw other questions I'll ask, along with a description of the learning experiences that I'll use.

Mrs. Martin: I particularly like the graphs that you propose to use, which depict the findings of Blackman and Matthaei's investigations with cherry laurel at Cambridge University in the early years of the 20th century. These graphs and your questions should help students to better understand that the rate of photosynthesis is influenced by temperature under strong light and varying CO_2 concentrations, but that the rate of photosynthesis is *not* influenced by temperature under low light and excess CO_2.

Mr. Graff: By the end of my lesson, I want students to infer that, if photosynthesis consisted of only a reaction to light, then the rate of photosynthesis should be the same no matter what the temperature, since light-activated chemical reactions are independent of temperature. And to close my lesson, I want students to construct a diagram showing inputs and products of photosynthesis, as well as variables associated with light, water, carbon dioxide, oxygen, and carbohydrates. Further, I want students to learn that photosynthesis involves both light-dependent and light-independent reaction systems. We'll get into aspects of the reaction systems in later lessons, and I will encourage some students to read Blackman's 1905 article, "Optima and Limiting Factors," found in volume 19 of the *Annals of Botany*.

Mrs. Martin: Well, I'm impressed with all that you are proposing to do in your lesson. Your graphs represent models recommended in the Next Generation Science Standards and present informative data about photosynthesis. Your questions will help guide students to identify significant features and patterns in the data. However, the description of what you want students to be able to do at the end of your lesson highlights a part of your teaching plan that needs to be modified.

Mr. Graff: What do you mean?

Mrs. Martin: Well, let's take a look at the instructional objectives that you've written for this lesson. How do they match with what you just said that you want students to know and be able to do at the end of the lesson? You said that you want students to infer an explanation about the reaction systems of photosynthesis from the graphs and to construct a diagram showing photosynthesis involving two reaction systems—one independent of light and one dependent on light. Is this what your objectives indicate that students will learn from your lesson and how they should demonstrate their learning?

Mr. Graff: OK, I see what you mean. I need to rewrite my objectives so that they specify the learning outcomes I want for my students in terms of their performance, a criterion, and, where applicable, the conditions under which the learning outcomes will be assessed. I guess I also need to check my end-of-lesson assessments to make sure that they match my instructional objectives.

Mrs. Martin: Michael, I think that with the modifications you just described, your lesson plan will be ready to go! I look forward to observing you teach the lesson to your peers during our next induction session.

This excerpt from the conversation between Mr. Graff and Mrs. Martin reveals that lesson planning involves careful thinking about the science content that will be the focus of the lesson, the alignment of all components of the teaching plan, and the interactions between teacher and students during the lesson. It also involves clearly articulating what students will learn from the lesson and positioning the lesson in a unit that is one of many units constituting a high school or middle school science course. An understanding of the planning process and the ability to plan lessons that engage students and help them learn are critical to one's success as a science teacher. The content of this chapter will help you develop an understanding of how to plan coherent science instruction and how to use feedback about your planning and teaching to improve your lessons, your teaching effectiveness, and, most importantly, your students' learning. By helping you to become a good instructional planner, the material in the chapter will enable your teaching to help your students learn science well.

CHAPTER OBJECTIVES

Use the following learning outcomes to guide your thinking and learning about planning for science teaching:

1. Describe in one paragraph the importance of planning for effective science teaching.
2. Define the terms *teaching skills*, *instructional strategies*, and *learning techniques*, and list, as well as recognize in practice, at least five examples of these critically important dimensions of the teaching and learning enterprise.
3. Initiate the unit planning process by identifying the learning outcomes for a unit, stated as instructional objectives, and describe how the learning outcomes might be assessed with the use of one or more culminating assessment tasks.
4. Write clearly stated instructional objectives that specify learning outcomes in terms of a *performance*, a *criterion*, and, where applicable, the *condition* under which the learning outcomes are assessed.
5. Construct a detailed, long-form science lesson plan for a class period that includes the following elements:
   - (a) lesson title;
   - (b) one or more paragraphs that describes the lesson's purpose;
   - (c) list of materials and/or equipment, along with handouts (attached), required for student engagement;
   - (d) precisely stated instructional objectives describing what students will learn from the lesson;
   - (e) lesson introduction that grabs students' attention and elicits their prior knowledge;
   - (f) detailed description of the lesson's learning experiences, along with teacher questions and desired student responses;
   - (g) lesson closure that enables students to review and make sense of key understandings;
   - (h) assessment of learning that matches the lesson's instructional objectives; and
   - (i) handouts or other teaching aids.

A MOST IMPORTANT TEACHING FUNCTION

It has been argued that planning is the most important teaching function because it provides a "game plan" for what to teach and how to teach. The process of thinking through a science course, its units, and the lessons nested within each unit gives you opportunities to sequence instructional events that hold the potential to initiate and sustain learning. Architects use blueprints, conductors follow music scores, and teachers use unit and lesson plans to guide their performance. All teachers plan. However, some plans are more carefully and thoroughly conceived than others.

Those who plan well will likely be more effective in helping students learn than teachers who do not. Teachers who plan well will be in a better position to specify learning outcomes that their students can achieve. They will be prepared to manage a learning environment in which students are expected to be more responsible for their own learning. Further, teachers who plan well can teach for student understanding rather than for rote memorization.

A critical ingredient in planning is *time to plan*. Without taking the time to think individually or collaboratively about a unit or lesson, it is unlikely that a teacher can orchestrate a coherent set of experiences that will engage most students in learning. In our busy, hectic society, many beginning as well as experienced teachers are overwhelmed by the multitude of after-school responsibilities that demand their time. Some teachers have a second job, church activities, young children to care for, coaching duties, cheerleading practice, and so on, all of which compete with one's time to plan.

Further, there are in-school tasks that add to a teacher's instructional planning responsibilities, as well as those which steal precious planning time. Special arrangements must be *provided* and *documented* to show that each student with special educational needs is being accommodated by plans that will aid his or her learning. This additional planning also is required for students who are developing English language skills as they learn science. Moreover, the amount of testing and the necessity of reporting student progress have become burdensome. The list of noninstructional tasks that teachers face is large and growing. For example, teachers may need to use their designated planning time to meet with parents, write reports, or cover the classes of sick colleagues. Regardless of the circumstances that make planning a challenge, we cannot overemphasize the importance of being prepared when the bell rings to begin class.

An experienced teacher can play an important role in providing a beginning teacher with emotional support and ideas for successful planning and teaching. Veteran teachers have developed ideas about course organization and unit and lesson sequencing with an eye toward achieving student learning outcomes that reflect state and national standards. To this end, they have collected and built unit and lesson plans that incorporate laboratory exercises, simulations, demonstrations, videos, textbooks, websites, reviews, tests, and so on. It is important for an individual who is new to science teaching to access and incorporate such curriculum resources as these into his or her planning. It is not unusual for a new, or even an experienced, science teacher to feel isolated (Guarino & Watterson, 2002). Therefore, it is necessary for new teachers to reach out to those who have been teaching for many years and ask for their assistance with planning.

The remaining sections of this chapter will help you think about some fundamental aspects of science unit and lesson planning. As you explore the fundamentals of planning, it is important that you keep student learning in the forefront of your thinking. Planning for effective teaching is what enables student learning. Consider the following questions to guide your thinking about planning:

- What will you teach?
- Whom will you teach?
- How will you teach?
- How will you manage the science learning environment?
- How will you assess student learning?

What Will You Teach?

"As a result of your teaching, what should students know and be able to do?"

Only your consideration of the students who will populate your classes is more central to the planning process than is your answer to this question. When you have decided what students should know and be able to do as a result of your teaching, you are well on your way to effective planning. But your answer to the question is highly dependent on your views of the purpose of general education in the United States.

If you think that the purpose of your teaching is to train all students to become scientists or engineers, then you will probably aim to teach a high-powered science course, covering large amounts of subject matter and requiring students to understand the content as a scientist or engineer might, down to the smallest details. If you think that the purpose is to educate all students so that they understand certain fundamental science concepts and develop an understanding of the scientific enterprise, then your planning will involve the careful selection of subject matter and skills for students to master.

As a beginning teacher, your first instinct may be to plan units and lessons that will cover a large number of abstract science concepts, perhaps similar to what you experienced in college science courses. In fact, the planning efforts of many beginning teachers tend to be guided by their past science learning experiences rather than a consideration of the adolescent learners that populate their classes. This approach is not surprising, since the experiences of beginning science teachers have been, not with adolescent learners, but with science content. However, the chances are high that the students in the classes you will be assigned to teach will have a large range of abilities.

Following are some common statements from beginning science teachers regarding the abilities of their students:

- "What did they teach these kids in the earlier grades? They can't read the information presented in the textbook."
- "I overestimated the ability of my students. I thought they could use fractions and construct graphs."
- "Most of my students failed the first test, and I thought I made it so easy."
- "My students are not able to write a coherent paragraph."

In addition to overestimating the abilities of students who will populate their classes, many beginning teachers hold somewhat naive notions of what counts as science learning. The tendency is to view science learning as students memorizing facts and reproducing information, in contrast to a more contemporary view of science learning in which students are expected to meaningfully understand, organize, and retrieve science concepts and to use their science understandings to solve problems in novel situations (Abell & Volkmann, 2006). Without a doubt, student ability, as well as your own view of what counts as science learning, must be taken into account in planning science units and lessons.

While we do not wish to paint a bleak picture of students and teaching in middle and high schools, we wish to encourage you to think about the primary purpose of science education at this level of schooling and its bearing on instructional planning. It is our hope that people going into science teaching today will seriously consider the fundamental purpose of science education in American schools and its relationship to their planning efforts. Even with students who are enrolled in advanced classes or attending private schools, you will likely find those who need help to develop understandings and skills considered necessary for further learning. Keep in mind that *you are teaching science for all Americans*.

Those who are preparing to become science teachers today must understand the assumptions that undergird the Next Generation Science Standards (NGSS; Achieve, 2013) in order to be able to help students realize the expectations for science learning conveyed in these new standards. In addition to recognizing students as born investigators, beginning science teachers must focus their planning to help students learn core ideas through engaging in scientific and engineering practices that will enable them to shift from novice to expertlike in their thinking.

Moreover, the planning efforts of beginning teachers must acknowledge that science learning involves the development of both knowledge and practice. This fact means that guiding students to build arguments from evidence and to function as a member of a learning community is as important as understanding facts, theories, and methods for collecting and analyzing data. In addition, planning must consider how units and lessons can connect to students' interests and experiences, as well as ensure equitable opportunities for all students to learn science.

Equally important, beginning middle and high school teachers must make sure that, before and after the classes they teach, their planning efforts are in concert with teachers of other classes that their students will take. All teachers must understand students' proficiency in science as "following the logic of learning progressions" (National Research Council, 2012, p. 33). Research-based learning progressions provide guidance for teacher planning because they outline how students' ability with regard to core science practices, concepts, and ideas may develop over multiple grades. The document *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012) is a good source of information about learning progressions for some understandings that you may wish to have students develop as a result of your instruction.

Now let's consider how this discussion of "what are you planning to teach" might play out in a block schedule, in which four courses consisting of approximately 90-minute class periods are taught in the fall semester and four courses are taught in the spring semester. A teacher might choose to organize the course into four units, with about 4 weeks devoted to each unit. One unit may focus on the structures and processes of life, with respiration and photosynthesis as prominent conceptual features. Strategically nested within this unit could be a lesson on the two reaction systems of photosynthesis, similar to the one discussed by Mr. Graff and Mrs. Martin in the vignette that opened the chapter. This lesson might be preceded by a laboratory exercise in which students test the effect of light intensity and temperature on the rate of photosynthesis and followed by exercises in which students investigate the processes of respiration and then contrast the processes of photosynthesis with those of respiration.

Figure 3.1 presents an abbreviated plan for a lesson on the two reaction paths of photosynthesis and illustrates how the lesson might be situated in a high school biology course unit on the structures and processes of life.

FIGURE 3.1 Abbreviated lesson plan situated in a unit within a biology course.

Introductory High School Biology is organized into four units, each addressing a number of ideas:

Unit 1 Structures and Processes of Life	Unit 2 Inheritance and Variation	Unit 3 Ecological Relationships	Unit 4 Biological Evolution
• cell structure and function • growth and development • function of organic molecules • photosynthesis • cellular respiration • organisms' responses to stimuli	• sexual and asexual reproduction • Mendelian genetics • DNA and RNA processes • chromosomes and mutations • biological resistance	• organisms, populations, communities, etc. • food chains, energy pyramid • cycling of nutrients • influence of human activity • adaptation to environmental conditions	• natural selection • adaptation of plants and animals • fossil and biochemical evidence • biodiversity • common ancestry

Lesson Plan
Lesson Title
Photosynthesis: The Light and Dark of It
Purpose
To engage students in an argument from historical evidence that enables them to construct explanations about the processes of photosynthesis—specifically, that photosynthesis involves both light-dependent and light-independent reaction systems.

Instructional Objectives
As a result of participating in the lesson, students will be able to do the following:
1. Describe, in a paragraph, the evidence that photosynthesis consists of both light-dependent and light-independent reaction systems.
2. Construct two diagrams that show what was known about photosynthesis before and after experiments conducted by F. F. Blackman and others early in the 20th century. Include the inputs and products of photosynthesis (i.e., light, water, carbon dioxide, oxygen, and carbohydrates) in your diagram.

Lesson Introduction
In the lab during the last couple of days, you investigated the effect of temperature and light intensity on the rate of photosynthesis. Also, you read in your textbook that the process of photosynthesis includes light-dependent (or, simply, light) reactions and light-independent (or dark) reactions. Given your reading and lab work, what evidence can you present showing that photosynthesis does in fact include these two kinds of reactions?

Abbreviated Description of Learning Experiences
1. Describe what was known about the process of photosynthesis at the end of the 19th century. [It was known that plants exposed to light could make carbohydrates by using water and carbon dioxide and that oxygen was released as carbon dioxide was consumed.]
2. Tell about the investigations conducted by Blackman and Matthaei at Cambridge University. They grew cherry laurel under varied conditions of carbon dioxide concentration, light intensity, and temperature. Display digital images of graphs that approximate the results of the experiments conducted by Blackman and Matthaei.

   Graph 1 shows that the rate of photosynthesis is influenced by temperature under strong light and varying CO_2 concentrations.

(*continued*)

FIGURE 3.1 (*continued*)

Graph 2 shows that the rate of photosynthesis is *not* influenced by temperature under low light and excess CO_2.

3. Ask students to carefully examine the graphs, discuss what they see with classmates, and draw conclusions about the results of the experiments.

   [Aid students by telling them that light-activated chemical reactions are independent of temperature.]

Desirable student response: When temperature increases under excess light intensity, the rate of photosynthesis increases. If photosynthesis consisted only of a light reaction, the rate of photosynthesis should be the same regardless of the temperature, since light-activated chemical reactions are independent of temperature.

Graph 3 shows that the rate of photosynthesis levels off as light intensity increases at a constant temperature.

Desirable student responses: If there were only a light-activated reaction, the rate should continue to increase.

4. Ask students to relate their recent laboratory experiences to those associated with the data reflected in the graphs presented in the lesson. Also, ask students to speculate how easily the data reflected in the graphs would convince early 20th-century scientists that photosynthesis is a two-reaction system.

Lesson Closure:
Review the inputs and products of photosynthesis (i.e., light, water, carbon dioxide, oxygen, and carbohydrates) with students by helping them to construct diagrams to represent their understandings from the lesson. Also, guide the students in constructing and explaining their own graphs that would and would not support the conclusion that photosynthesis includes both light-dependent and light-independent reactions.

Assessment

1. Ask students to describe, in a paragraph, the evidence that photosynthesis consists of both light-dependent and light-independent reaction systems.
2. Ask students to construct two diagrams that show what was known about photosynthesis before and after experiments conducted by F. F. Blackman and others early in the 20th century. Tell the students to include the inputs and products of photosynthesis (i.e., light, water, carbon dioxide, oxygen, and carbohydrates) in the diagram.

Materials
Graphs showing the rate of photosynthesis under varying carbon dioxide concentrations, light intensities, and temperatures as described earlier.

From F. F. Blackman (2005, April), Optima and Limiting Factors? *Annals of Botany*, *19*(74), 279–295.

As you examine the contents of the figure, use the following points to guide your own thinking about what you should teach:

- Seek out print and online sources of information about science content and instructional strategies for planning courses, units, and lessons.
- Plan instructional units that include multiple ways of teaching core ideas and practices of science.
- Plan individual lessons that support the unit plan and that articulate the purpose of the lessons to students.
- Guide all elements of the lesson, using instructional objectives based on standards.
- Create the lesson introductions to engage students' interest and elicit their prior understandings about the topic.
- Provide opportunities for students to make sense through the construction of evidence-based explanations.
- Ensure that lesson assessments are aligned with instructional objectives and learning activities.