Teaching Secondary School Science
Strategies for Developing Scientific Literacy

Bybee Powell Ninth Edition

Pearson New International Edition

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Becoming a Science Teacher

If you are reading this sentence, you are in the process of becoming a science teacher. As with other important issues in your life, you no doubt struggled with this decision. While deciding, you probably gathered information on the options—you might have explored the science major, talked to friends and parents, conferred with your college advisor, and even visited your high school science teacher. With all the facts in mind, you decided to become a science teacher. Thinking all was settled, you went to work on your science major and began taking education courses. For a time, most aspects of your career choice seemed resolved. Now you are taking a course to learn about science teaching; soon you will be student teaching; in the foreseeable future, you will have your first job as a science teacher.

All of this is exciting, but now you have an entirely new set of questions about your career: "How do I teach science?", "Am I qualified to teach science?", "What do I need to know about science and technology?", "What science do I teach to middle school or high school students?", "What is science teaching like?", "What are the problems facing science teachers today?". Constantly emerging questions and concerns regarding science teaching are part of becoming a science teacher.

Some of your questions have answers; others depend on your specific talents, personality, knowledge, enthusiasm, and other important, but elusive, qualities. Obviously, we cannot answer all of these questions in this chapter or in this book, but we can provide some information and direction. We can suggest activities to help clarify your strengths and weaknesses and the realities and possibilities of science teaching. The best way you can begin is by completing Activity 1–1: How I See Myself As a Science Teacher, at the end of this chapter.

Am I Qualified to Teach Science?

This question is difficult to answer with a simple yes or no, because of the adjective *qualified.* Traditionally, persons have qualified as science teachers by completing a set of educational requirements. Legislation passed in 2002, called "No Child Left Behind", defines highly qualified teachers as those who obtain full state certification or pass the teacher licensing examination. In addition, the law indicates that secondary teachers must demonstrate content competence through either a college major, graduate degree, or comparable coursework, or by passing a "rigorous state test" in the subject (Berry, 2002; U.S. Department of Education, 2004).

In this sense, most individuals can be qualified for teaching. A science teacher, however, must do more than fulfill a set of requirements and be able to talk about science. Certain dimensions of science teaching addressed in Activity 1–1, are identifiable in the following discussion.

Understanding Science and Technology

You should have a background in science, including both a broad general knowledge and a specific knowledge in your major. These statements may seem obvious. In today's world, however, you also will need an understanding of technology, because our society and the experiences of your students are extensively based on technology. You should be aware of the many relationships between science and technology. In the past, science teachers and textbooks presented technology as *applied science;* that is, the enterprise of science resulted in knowledge that was applied to human problems.

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Although this statement still is partially accurate, in some cases scientific advances must wait until technology is developed. Technology can also be viewed as an area of study. As with science, technology also has products and processes that form the basis of study.

In addition to having scientific and technological knowledge, you should apply this knowledge in new situations, use basic science concepts to analyze problems presented by students, and synthesize knowledge so that you can answer students' questions accurately.

Understanding the Purposes of Science Teaching

Most individuals in the science education community use the term *scientific literacy* to express the major purposes of science education. The term also refers to your role in advancing individual development of students and achieving society's aspirations within the context of your classroom. Although scientific literacy expresses the highest and most admirable purposes of science teaching, as science teachers, we must be a little more concrete and practical.

What do you think the scientifically and technologically literate person should know, value, and do—as a citizen? As you think about this question, recognize that the final phrase—*as a citizen*—is an important orientation for your answer. An answer that focuses on acquiring knowledge about biology, chemistry, physics, and the earth sciences should be mediated by the question, "What is it about the knowledge from these disciplines that is important for citizens?" How do you justify that knowledge in terms of your student's future role as a citizen? What about values and skills? What values, attitudes, and habits of mind does your teaching of science and technology help students develop?

A close connection exists between the purpose of developing scientific literacy and the various books you will encounter. Both the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (AAAS, 1993) address the question of exactly what is meant by scientific literacy. We discuss these and other reports in later chapters. For now, think about the following statement on the purpose of science teaching.

> Science teaching should facilitate students' learning about science and technology as they need to understand and use them in their personal lives and as future citizens. Science teaching should sustain students' natural curiosity; develop their skills in inquiry and design; improve their scientific explanations; help them develop an understanding and use of technology; contribute to their understanding of the role, limits, and possibilities of science and technology in society; and inform the choices they must make in their personal and social lives.

Indeed this statement about science teaching is tightly packed with ideas. As you proceed through this book, we will provide many ideas for you as a science teacher.

Organizing Science Instruction

You should be well prepared, thoroughly organized, and have a clear direction in your teaching. There is no substitute for a well-prepared lesson. At one time or another, most science teachers have tried to teach without preparation. More often than not, the lesson was less than effective. As you begin organizing your science program, try to establish the "big picture" by determining your

Students should be actively engaged in science.

program for the year. You may wish to divide the year into units, and the units into coherent sequences of lessons. This simple procedure will give you an overall organization; but you require still more knowledge and skills to be an effective teacher.

Effective science teachers have a variety of instructional methods, choosing the best for each lesson. Keep in mind the following simple questions: "What do I want my students to learn?, How will I know when my students have learned?, What experience will best help my students learn?". The answers to these questions will direct you to different teaching methods. We recommend completing Activity 1–2: The What and How of Science Lessons, at the end of this chapter.

Understanding Student Learning

Imagine that you are ready to begin your first science lesson. The students are sitting at their desks, waiting for you to teach them. Do the students in front of you already understand any science concepts? The answer is probably yes. The students you will be teaching have lived 12 to 18 years. Through formal and informal experiences, the students already have developed ideas about the natural and designed world. They also have placed labels on many of the events, objects, and organisms in the world. In this regard, three points will help you: (1) Students have explanations and concepts about their world, (2) many of these concepts are inadequate when compared to scientific explanations or concepts, and (3) students' current concepts of the natural world influence what and how they learn science (Novak, 1988). David Ausubel (1963) summarized this when he wrote: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."

It is interesting to note that the ideas from Novak and Ausubel have stood the test of time. In 2000, the National Research Council published a synthesis of research about how people learn. The three major points from this synthesis are as follows:

- All learners come to the classroom with prior knowledge. This knowledge must be engaged if learning is to occur.
- The facts of a discipline must be taught in the context of a larger framework so learners can understand the connections among ideas.
- All learners need practice with metacognitive skills such as setting goals and assessing their progress toward those goals.

Many science teachers approach instruction as though students are empty vessels to be filled with facts, information, and concepts about the world. This perception of how students learn generally is inaccurate. Perhaps a different metaphor is appropriate. Students have packed a suitcase for a trip, but many garments are out of fashion, inappropriate for the climate, and inadequate because the student has grown. The science teacher's task is to help students improve their "intellectual wardrobe." Students construct their explanations of the world through a personal process in which sensory data are given meaning in terms of prior knowledge. In order for learning to occur, the adequacy of students' current conceptions must be challenged, and in appropriate time and with opportunities, students can reconstruct newer and more adequate explanations. Ways to facilitate this learning process will be explored in later chapters. How is this process of learning different from what you currently understand about student learning? Review your response to Activity 1–2.

Recognizing Personal Meaning in Teaching and Learning

Imagine two middle school lessons about the life cycles of organisms. In the first lesson, the students individually read about mealworms. In the second, small groups of students each receive a container of mealworms and are asked to observe the tiny organisms. The students exclaim, "Ooh," "Ahh," "I can't touch this," "It squirmed," "Look at my worm back up!" and other utterances that indicate their feelings about the experience.

The second lesson provides an experience that is physically close, less abstract, and emotionally connected to the subject. This exercise easily could be extended into areas such as experimental design, reaction to stimuli, and the life cycle of mealworms. Both lessons convey the material; however, the second probably would be more effective in teaching the concepts, because it offers physical and psychological involvement and social interactions, all of which contribute to personal meaning for the students.

Many contemporary science curricula are inquiry oriented. For the most part, the inquiry centers on science facts and concepts; physical involvement with materials through laboratory activities provides the primary teaching method for presenting these facts and concepts. The next step in the teaching task is discovery of the personal meaning of these facts and concepts. Obviously, learning science is easier when students are interested and involved. For example, you have been motivated to read this chapter because it has some personal meaning. You are becoming a science teacher and you want to be as effective as possible. What is said in this book likely has personal meaning for you.

Personal meaning has three aspects: (1) the physical closeness of the materials, (2) the psychological

interest the individual has in the materials, and (3) the social relevancy of the material or topic. To state this idea succinctly: Learning science is enhanced when students have personal involvement with materials and organisms that have some direct importance to them. Usually, science teachers have started lessons with content and assumed that personal meaning would emerge. This progression, as it turns out, may or may not occur. Science teachers engage learners by beginning with interest, motivation, and personal meaning, and structure the content on these experiences while still teaching scientific concepts.

Personalizing Science Teaching

The effective science teacher realizes the importance of interpersonal relations. An important finding in regard to helping others is that objectivity has a negative correlation with effectiveness; that is, if students are treated as objects, the teacher is less successful with students. No one becomes significant to someone else—whether student, fellow teacher, or friend—by making the other person feel insignificant. You become significant to others by treating them with integrity, sincerity, and openness (Combs, Avila, & Purkey, 1978). The best science teachers make a conscious effort to regard all students positively, to understand them as human beings, and to help them advance academically, personally, and socially. In these situations, students learn science; in fact, they probably learn more science because of the interpersonal rapport. If you become a significant person to your students, the final reward is yours.

Personalizing your relationship with students can include developing a keen understanding of the pupils, devising different tasks for different students, making individual assessments, and using varied questions or different materials and equipment. The idea of effective communication covers, in one way or another, most of the important aspects of personalizing science teaching.

Talking and listening to adolescents is a subtle and important way of recognizing their growing need for identity. It also enhances the learning relationship and increases your efficiency in facilitating their understanding of science.

Managing the Classroom and Maintaining Discipline

When beginning teachers talk about managing the classroom, they usually mean managing students in various activities of science teaching. For example: How will students form groups for laboratory? How will they handle materials and equipment safely? How do you get students to change from one type of activity to another? Such concerns are realistic, but soon you will find that most students respond to directions. Several chapters include detailed information to help you manage the classroom. Following is some initial advice:

- *Preparation will resolve many problems.* Be sure to have materials ready, know the size of groups and how you want to form them, understand your expectations for behavior and learning outcomes, and give clear and simple directions for effective classroom management.
- *Recognize the need for transition between activities.* Making a transition, for instance, from laboratory work to a class discussion, takes several minutes. Students will have to adjust to the different class structure. Plan for the transition time—it should not be long, because this is a time when some students are apt to cause a conflict. Some teachers expect the new norms of behavior to emerge instantly. A visible signal, such as turning on an overhead projector, may help complete the transition.
- *Try not to panic in nonpanic situations.* Things happen in science classrooms. We cannot tell you what they will be, only that something unexpected will happen. Our advice is to stay calm, quickly think about the situation, and act decisively on a proposed solution. If it doesn't work, try another.

The second topic of the section concerns classroom management, a concern of most teachers. Conflicts between your goals and some student behaviors are inevitable. Most management issues in science classrooms are resolved quickly and with little difficulty. We tend to refer to management issues as *conflicts* instead of *discipline problems,* because the definition—the activities or behaviors of two (or more) individuals that are incompatible—suggests that you, as a teacher, have goals, and that part of your responsibility is to achieve those goals. Avoiding or resolving educational conflicts is key to managing your classroom or maintaining discipline. It is more productive to think and act in ways to avoid or resolve conflicts than to engage in discussions of the appropriateness or fairness of rules, policies, or expectations of behavior. Chapter 20 discusses classroom management in general, and conflicts and their resolution. Following are a few initial suggestions:

- Center attention on avoiding or resolving the conflict, as opposed to defining who is right or wrong.
- Establish clear communication and agreement on the issues, rules, or expectations that define the conflict.
- Use cooperative problem solving. Because of your position as a science teacher, you have the responsibility for resolving classroom conflicts cooperatively and constructively.

Realizing Decisions Determines Effective Science Teaching

Imagine that you are about to begin a chemistry lesson on pollution. Your plan is to demonstrate how the common air pollutants sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are produced when coal and oil containing sulfur are burned. You then plan to show how sulfur trioxide can react with water vapor (H_2O) to form sulfuric acid. You have some sulfuric acid on the demonstration desk so that you can show the students the corrosive power of this acid. As you begin your demonstration, you accidentally knock over the beaker containing the acid, which spills onto papers and books. Take a moment and think about the situation. What would you do?

Suppose you have just finished an activity investigating the effects of continental glaciers. You begin showing a DVD on the subject. As soon as you turn off the lights, you hear funny noises and muffled comments. You are fairly certain that Steven, the class clown, is the one making the noise. Take a moment to think about this situation. What would you do?

You could consult this textbook for answers. You could call your methods instructor or ask the science supervisor in your district for answers. You could do any number of things, most of which would help only if the same situation recurred. The one certainty in all such classroom situations is you will have to decide what to do and respond in the best way possible. Your role as a science teacher will be to combine your knowledge and perceptions of classroom situations with your understanding of the students, and then to decide on appropriate action. Many science teachers do not realize this central role of decision making. You must adapt the textbook, the curriculum, and the inquiry method to the events that occur in actual teaching situations.

Look back to the opening question, "Am I qualified to teach science?" This question still cannot be answered with a simple yes or no, but you have begun thinking about what it means to become a science teacher. How well do you understand science? How do you incorporate the purposes of science education? How are you at organizing instruction in science? What ideas do you have about student learning? Can you personalize science teaching? How can you include personal meaning as a part of science lessons? Do you realize what your role will be as manager and conflict resolver in the science classroom? These questions and many more will emerge as you continue the process of becoming a science teacher.

WHAT IS SCIENCE TEACHING REALLY LIKE?

Most individuals entering the teaching profession are concerned about daily happenings in the school. In one form or another they inquire, "What is science teaching like?" When asked to further clarify the question, they want to know what the science programs are like, what teachers talk about, what it is like actually being in front of a class, and the concerns of other science teachers. If you complete Activity 1–3: A First Lesson, at the end of this chapter, some of these questions will be answered. In addition, the next sections give glimpses into different schools, science programs, and science teachers. We have adapted these vignettes from case studies funded by the National Science Foundation (NSF) and completed as part of a larger evaluation of science education. The case studies were originally completed by individuals who spent time at different schools, observing and participating in the various activities of science teachers (Stake & Easley, 1977). Our adaptations have maintained themes from the original case studies while updating ideas, language, and issues of contemporary science teaching. Although we realize that schools, science programs, and teachers differ, the case studies present perspectives of actual science programs, glimpses of teacher conversations, and insights about science teaching.

Middle School Science Programs

This section characterizes two middle school science programs from the same science district. The district is located in central California (Western City is the name used in the case study), a region where much of the population is involved in agriculture. Due to the large African American and Hispanic American populations, student backgrounds and interests are diverse. This comparison of middle school science programs points out how differently science can be taught at the same grade level and within the same district (Serrano, 1977).

Case Study 1

Science instruction at both schools is offered at the discretion of the building principal. If the principal has no interest in science, the science program at either school will wane. As a consequence, the science program is a minimal program and only as complete and thorough as the teachers who instruct in the program. The following observations (made during site visits) tell the story.

> At Middle School I, the "science room" is almost bare. The bulletin boards have a few items about earth tacked on them. The storeroom is badly supplied with three microscopes in semioperable condition, a few unlabeled chemicals, pieces of broken glassware (thistle tubes, test tubes), a Fisher burner, and a Bunsen burner. There is no evidence of any packaged kits (such as Introductory Physical Science [IPS]) or other equipment to indicate the students have experience with hands-on materials. The desks and a few tables are available for use in the room. The principal is making a great effort to upgrade this area.

> The "science room" at Middle School II is not in the same condition as the one at Middle School I. Although the walls are still relatively bare, the closets are filled with old, unused materials. Ample supplies of glassware, hardware, and chemicals normally used in a middle school science class are visible. The collection of rocks and minerals is minimal, as is the preserved animal collection. In reality, the science room is much better supplied and organized at Middle School II than at Middle School I.

The science program at Middle School II has been well established by the instructor, who has been teaching there for three years. He follows a course of study that he has developed over the years, and he continues to modify it. His counterpart at Middle School I appears to flounder in the science area. Students at Middle School I spend a considerable amount of time studying earthquakes. ("Since we live in an area that is earthquake-prone, I feel the students should spend some time studying earthquakes.") Besides earthquakes, there is not much evidence of other science topics being discussed, nor is there any evidence of students having an opportunity to get their hands on any equipment.

Because the science program at the middle school level is determined by science teachers at individual schools, these teachers use a wide range of areas and approaches. A great number of science teachers in the district are not aware of contemporary science curricula and their packaged equipment and, as a consequence, do not use them.

When asked about their major concerns regarding the science program at their respective schools, the teachers responded as follows:

> *Middle School I*
> The students lack discipline. They make little or no effort to learn. They would rather talk and delay the teaching process. They are the ones who will suffer the most.
>
> *Middle School II*
> The biggest problem at the school is absences. The students don't seem to care. They would much rather be somewhere else. Discipline is not as much of a problem here as is the lack of supplies and equipment. I always have to be on the lookout for equipment.

Other teachers in the same schools have voiced concern about lack of the following:

- Administrative support
- Supplies and equipment
- Current books
- Student motivation
- Parental interest
- Adequate facilities

When the science teachers were asked to describe a typical day in their science classes, they replied with this summary:

> The kids come into class as soon as the bell rings. We check their homework (this is done for purposes of reinforcement). We present a short lecture (at least 20 minutes) on a given topic. We make an assignment for the following day. On Fridays, we schedule quizzes based on the last four days of work.

What are your reactions to this summary?

High School Science Programs

This case study was completed in a small city on the plains east of the Rocky Mountains. The name used for the school was Fall River (Smith, 1977).

Case Study 2

The high school science program consists of 18 courses. Despite lenient graduation requirements, enrollments are high. The courses are staffed with an impressive group of teachers, most of whom have advanced degrees in the disciplines and have attended summer programs.

The biology program has the largest enrollment and staff. All students who elect biology take a one-semester introductory course, after which they can choose one or more follow-up courses in ecology, plant structure and function, social biology, microbiology, heredity, and animal anatomy. Some students fail or opt out of biology after the introductory course. An advanced placement course in biology is also offered.

The content of the introductory course is largely the same, regardless of who teaches it. The text used is from the Biological Sciences Curriculum Study (BSCS). The instructional methods are largely lectures, laboratory investigations, review sheets, and occasional films and guest speakers. Although the BSCS text emphasizes developing students' interest and heuristic inquiry, the classroom instruction at Fall River High tends to be formal, didactic, and organized. Almost the entire text is covered. This is a large quantity of material for one semester, but it provides the background needed for the more specialized follow-up courses. In the ecology course, for example, the students review the relevant BSCS chapters and then go on to more specialized texts. They participate in simulations on DVDs designed to show the relationship between values and environmental processes. Topics covered include ecology and the law, mountain ecosystems, and the food chain. Laboratory investigations are conducted on photosynthesis and chromatography, as are field investigations in small ecosystems near the school building. The students conduct independent research on biomes.

Although the other follow-up courses are not so directly related to the environment, a strong environmental

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WHO ME?! A SCIENCE TEACHER?

"Teaching science? Me? You've got to be nuts." This would have been my reaction a few months ago; however, today my response is just the opposite: Science teaching is a plausible career for me. Why the change of opinion in such a short time? The answer is simple: After seriously evaluating my interests and goals, with respect to possible careers, I found that teaching would allow me to incorporate and use more of them. The next step was to discover what education is and what methods are used. This step was achieved through a science methods course where I actually observed and participated in various teaching activities of a class at a local school. The career experience in this field has had an important positive effect on my knowledge and opinions of the educational system, besides showing me some of the realities of science teaching.

I have always been interested in helping people learn; my past working experience as a camp counselor, recreational leader, and YMCA swimming instructor and coach is evidence of this interest. However, teaching in the educational system did not appeal to me; I felt that I would become very bored with teaching the same thing to several classes year after year. Yet, with my recent finding that education was a career possibility and that many of my goals and interests could be combined with it, I began to take a new look at education and saw it as a challenge as long as I could eradicate my adolescent biases toward the educational system.

I entered the education program still unsure of what teaching science entailed. I soon found out that my preconceived biases toward the educational system, based on my own public school experiences, were not universally true. The elimination of these biases was the major factor in altering my opinion of the system. Now, instead of looking at the system as hopeless, I see myself as an agent of change: I can set an example and hope others will follow. I can challenge myself to improve, change, and alter lessons, activities, and methods to counteract any boredom in myself and in the students, and to communicate with more students.

Through a science methods course, I learned about education, the variety of methods that can be used to attain objectives, and some of the realities of teaching. From these new views, I can see that teaching can be a much tougher occupation than I had previously expected. It involves many time-consuming activities, such as developing new units, changing lesson plans, improving activities, keeping up to date on recent developments in the specific area of science, and keeping enthusiasm at a high level. Yet, it is through these same time-consuming processes that the rewards of teaching are to be found, for example: communicating with those who previously did not understand or care, introducing students to new and interesting ideas and techniques, developing within the students an enthusiasm for continued learning, and watching them develop as individuals.

consciousness pervades the entire department and has been adopted by many of the students. When asked about the principles behind the program, three teachers made the following statements:

- The purpose is to make them better citizens, help them understand the issues in society that are related to science, and help them make better decisions. For example, I ask them how the price of gas affects their driving? I don't try to impose my own view on them, but I do try to make them think.
- You can't separate our values and science anymore. When we talk about population growth or genetics, issues come in. I tell them they should learn the material, if only so they can determine their own future.
- A person just can't be an effective citizen unless he can read and understand political issues that have scientific overtones. . . . The average citizen must have the awareness and appreciation of how his actions affect the environment and what is likely to happen, depending on the choices he makes now.

In addition to the idea of developing environmental consciousness, the teachers believe their purpose is to provide a strong and diverse academic experience that

puts the students in touch with the major body of knowledge in biology and the processes used to gain the knowledge. One teacher reported, "Any systematized body of knowledge is part of the foundation of civilization. It's part of their responsibilities as citizens to be aware of it. Science has applications in all their lives." What do you think about these perspectives?

The biology program is not without its rough edges. Students in the introductory course fail in higher proportions than in other courses. Most teachers are determined to hold to their standards, however. Based on previous experience, teachers are convinced that students will take the easiest possible path, dilute the content of the course, and make the follow-up course structure impossible. The teachers believe that any student who makes the effort can pass.

Another serious problem is lack of space and facilities. The school has two well-equipped laboratories, but sometimes four sections must share them in a single class period. Therefore, the teachers have to coordinate classes so that while one section is doing lab work, the other teacher must lecture in a classroom designed for physics. No space is available for advanced laboratory preparations. They look back wistfully on the year they had a teacher's aide. "Not having the facilities lowers my interest and energy and influences what I teach. The situation has discouraged every bit of open-ended inquiry I've got. A question comes up from the class and I think of an investigation that would be related, but there we are in the physics room, so I lecture."

About 40 percent of each graduating class goes to college. A greater proportion of students follow a traditional college preparatory course of study. Most of this group take chemistry in the junior year. The chemistry classes are packed, but whether the high enrollment is due to students' scientific curiosity, the genial personality and showmanship of the teacher, or the abundance of A grades is unclear. Although some of the best students complained that the class "wasn't tough enough . . . didn't go too deep into chemistry," the instructor primarily wants them "to be interested in science and to master the basic material in the field. I feel like anybody can learn at the level I teach them. The kids who are really interested then can go off on their own and learn more."

The text *Modern Chemistry* is used, and the approach is traditional. The greatest amount of class time is spent in lectures and laboratory experiments. The laboratory areas are well equipped for a basic program, but the teacher longs for materials that would support more advanced work. The laboratories are terribly overcrowded, and the teacher worries that someone will be injured in an accident.

The physics course is taught by a man with experience and impressive credentials—advanced degrees in physics and math. His laboratory is well equipped, and under his leadership the science program has always received a healthy share of the school budget.

In answering a question about the purpose of science education, the physics teacher spoke of his own philosophy.

> In recent years, I've wondered if you could justify it. Earlier I would have said that physics was a part of cultural knowledge, something enormously practical, like all science having something philosophically to offer the public, and intellectual integrity which would carry over into politics and society.
>
> Now I don't know. We live in a technological society, so it is necessary to propagate information to some parts of the society. But for the general person in high school who will eventually go into business or become a homemaker they really don't need to know about physics, except in a very superficial way. If you want a kid to know how to change a tire, you teach him about levers. . . . I'm a good sailor and I apply my knowledge of physics, but other people are better sailors and have no physics background.
>
> That is too pessimistic. Let me state it this way. Everyone deals with nature. Every high school student knows a great deal of physics, and the teacher merely encourages him to abstract his knowledge to form more general and sometimes more useful patterns of thought. If the student can deal with ideas in the abstract, he learns this before going to college and can thereby make a sounder choice of careers. He may not do better than another competent college student, but he has had the benefit of guidance and proven academic discipline. Finally, and this is important for all ability ranges of students, a sense of being at home in the universe must be transmitted. The physical world and the technology of man must be dealt with as an important part of the total culture he is to inherit.

In addition to the more traditional track of three courses, the science program includes a great variety of offerings: astronomy, archaeology, geology, conceptual physics, electronics (less mathematical than the physics course), introduction to chemistry (a student-centered laboratory program using discovery techniques and emphasizing the process of science), and space science (a rather easy course for students who have a previous failure or little interest in science).

The science teacher responsible for several of these courses is a former geologist who runs his classes very informally, trying to structure each one around the interests and questions of the students. Environmental consciousness appears to be a strong focus in his course as well. In the course description for geology, he writes

> Our study of geology will be centered around the following concepts: Geology, the study of the earth, is essentially an environmental science. . . . Man . . . must learn to function in harmony with the earth environment. . . . Citizen roles dictate an understanding of the environmental problems confronting man, solutions to these

problems, and the responsibilities of citizens and government to work toward their solutions.

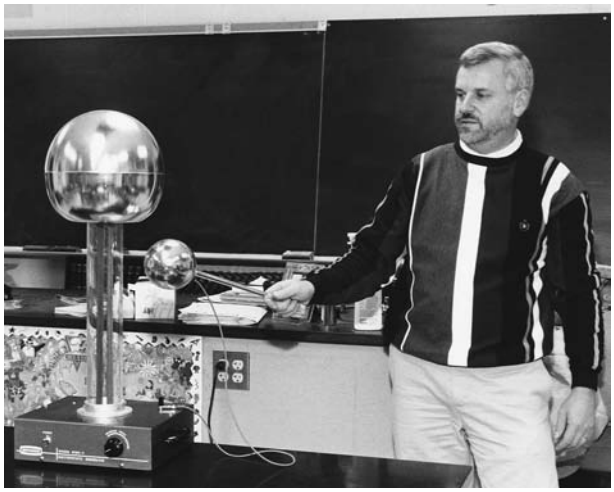
During his classes this philosophy is never far off, injected even into a presentation on the physical properties of minerals.

In his courses, perhaps more than those of others, the methods of science are given prominent attention. One of his science courses centers on the following objectives:

> Demonstrates an understanding of the process of identifying and defining a scientific problem or question to be investigated . . . of proposing a logical test of a hypothesis . . . of testing the effects of variables and controlling relevant variables . . . the ability to synthesize data from several sources to arrive at generalizations or conclusions . . . withhold judgments or conclusions until adequate information has been validated.

The following is a second view of high school science. This program is from a large high school in a major city in the Pacific Northwest. The name used to identify the school is Hardy (Welch, 1977).

> The natural science program at Hardy is strong. It is paced by an active biology program, team-taught by three full-time and one part-time teacher. Currently 472 students (93 percent of the sophomore enrollment) are enrolled in a laboratory course led by the department chairman. The classrooms are filled with science artifacts (birds, weather maps, rocks, specimens, snakes, etc.), and the spirit of the group can be portrayed by two episodes: an open session with students one day after school to discuss the implications for science of the presidential election and a weekend assault on the walls separating the three biology rooms, resulting in open portals that central administration had stalled on for nearly two years.
>
> Probably 80 percent of the class time is spent by students working on experiments, and three tracks (developed locally) are provided, depending on student ability. The course is patterned after college science courses and seems difficult for many of the students. However, teacher enthusiasm and interest seem to rub off on students, and they rate the course as very good. Marine biology, human physiology, mushrooms, and wildflowers are other courses offered as part of this strong program. Exactly which courses will be offered during a given semester depends a great deal on student interest. A college-style registration procedure is used, and if a given course doesn't fill (i.e., isn't selected by more than 25 students), then it may not be offered. Conversely, sections are added if student interest is high.
>
> During the semester following the site visit, the life science enrollment was as follows:
>
> Biology II 250
> Molecular Biology 29
> Marine Biology 53
> Wild Flowers/Edibles 34
> Human Physiology 53



An experienced science teacher uses interesting examples of natural phenomena to engage student interest.

> Apparently, some of those students in the first semester of biology opt for more specialized courses the second semester.
>
> The first year of chemistry is currently taken by 146 students (27 percent of the junior enrollment) and is taught as a laboratory science. The five sections of chemistry are handled by the physics teacher and a chemistry teacher who also teaches biology. The course is viewed by students and teachers as primarily a college preparatory course. A third semester of general chemistry and a semester of organic chemistry are offered if enough students register for these courses.
>
> Physics may be taken in either the junior or senior year, and currently 68 students (13 percent of the senior enrollment) are enrolled. About half of the group consists of girls, which is seen by students and teachers as a result of changing female roles. Counselors, parents, and friends are changing their attitudes and beliefs that advanced science is only for boys. The course has some laboratory components, but in general is taught more like a mathematics class; that is, explain concepts, assign problems, correct problems, and discuss difficulties. This routine is interrupted occasionally by exams or experiments, but the doing of problems is predominant over the doing of science found in the other classes. The class is clearly for the academically talented, and the teacher sees no need to try to increase enrollments.
>
> An adjunct to the science program is a popular horticulture program offered in the technology education department. In a temporary building and greenhouse located about two blocks from the main building, 113 students were enrolled in environmental horticulture. The course meets the state requirements for a laboratory science, but although it is considered a strong program by the science teachers, there seems to be very little interaction between it and the rest of the science program. It has grown through the efforts of an active teacher whose academic home is technology education.

The science program is strong and surviving, but it is being subjected to many challenges: transfer of teachers, declining budgets for texts and equipment, and competition from the basics. It may be seriously affected if subjected to many more problems.

How do you respond to these descriptions of science programs? Do the descriptions align with your original perceptions?

Conversations with Science Teachers

In this section, comments from the teachers' lounge are used to point out some issues in science education. The observations are from a case study made in a greater Boston high school (Walker, 1977).

Role of the Experiment in Science Teaching

STEVE: (looking through a workbook of experiments David has been using in his class): The trouble with a lot of this stuff is that it is so obvious. Even when you have done the experiment, you only know what you knew already.

DAVID: Maybe it's obvious to you, but it isn't always obvious to these kids. To some of them maybe, but not to all of them. Sometimes they do know what is going to happen in the experiment, but they only know it vaguely; they haven't really thought it out. Like this morning we were talking about that experiment where you float a cork in water, then push an upturned glass down on top of it. They did the experiment and saw what happened. When I asked why the cork went down, one girl just said "gravity." Well, you can see what she means; it does involve gravity, but that's not an explanation of what you see happening.

STEVE: Yes, but you can't say that's exciting. Floating corks in water. I want to get these kids interested in science. I want experiments you can do that set them all off saying, "Wow! How did that happen?" Something that really challenges and excites them. (looking at the book) Finding out 20 percent of the air is oxygen, that's no challenge. Why not just tell them? You shouldn't just have to do an experiment for everybody, only if it excites them or triggers them off.

DAVID: But before you can work on these dramatic experiments they have to know scientific procedures and appreciate the methods. All this week I've been emphasizing the five stages of writing a lab report and getting them to appreciate the difference between observation and explanation. You have to do it several times, and it takes practice. And for most of them, writing a scientific report is not something they are used to doing; in fact, some of them have gotten so used to multiple-choice tests that it is an effort for them to write complete sentences.

STEVE: Maybe you are right. I think teaching them rigor and method is a useful thing to do. The danger, though, is that you end up just pacifying them. The science that is going to affect their lives isn't the five stages of writing a lab report. It is nuclear power, pollution, recombinant DNA research. Those are the things I want them to know about, and I want them to be able to pursue things for themselves, not just because they are in a course or a textbook.

Strategies and Methods of Science Teaching

CIVICS TEACHER: I feel constrained by the forty-minute period and the pressures of working in a building that is really only a heap of classrooms. I'd like to be able to get out more with the students and get to do more things.

SCIENCE TEACHER: I don't agree. I think almost the most important thing for the students to learn is the discipline of working in the classroom. When they come here at the beginning of the year, they are all up in the air and we have got to bring them down. You've got to get order and discipline before you can give it up.

CIVICS TEACHER: By this time of year [March], they should have learned some sort of classroom discipline. The problem is that enforcing it starts to become an end in itself. You begin to forget about what you are trying to teach and just think about keeping a neat, orderly class.

SCIENCE TEACHER: I don't just think of discipline as keeping an island of sanity in my class, whatever happens in the rest of the school. I don't think you can separate discipline in class from the discipline of the subject. In science especially, where you have expensive equipment and valuable things around, you have to learn certain ways of behaving, and learning those ways of behaving are [sic] part of learning the subject.

SECOND SCIENCE TEACHER: I'd like to get out of the classroom more because there are a lot of things I want to do that you can't very easily do in school. I think really the only way to get students to appreciate the significance of things like environmental pollution is to get them out of the classroom [and] looking at it.

ENGLISH TEACHER: My classroom is important to me. I can't imagine a better place for doing the kind of teaching I want to do. Going outside the classroom on some occasions might have advantages. I'd like to have students going out to interview people, for example. But what they do in the classroom (which is mainly writing) has got to remain at the center of everything else for me.

CIVICS TEACHER: Sometimes I feel limited by the expectations the students have of me as their teacher. For most of them, the range of things they will allow in

a teacher is very limited, and this makes it very hard to start anything new or different. The experience I have had in the past of working a lot outside school has shown me that you can have quite a different kind of relationship with students once you get them out of the school building.

ENGLISH TEACHER: I don't want a different kind of relationship. I want to be the kind of teacher I am.

A Conclusion About Science Teaching

People in schools are conscientiously doing the jobs they have defined: tutor, scholar, but also at times, counselor, steward, custodian, and social director.

Teachers must juggle the expectations of the invisible, distant, and mostly impersonal profession of science education and the local, powerful, and relentless demands of teaching. The two roles do not necessarily conflict, but the latter usually overpowers and preempts the former.

We recommend completing Activity 1–4: An Interview with a Science Teacher.

How Can You Become an Effective Science Teacher?

We assume that you have the normal concerns of beginning teachers. We also assume that you are motivated to become an effective science teacher. Three things that will help reduce these concerns and increase effectiveness are preparation, time, and experience. Remember that this is only the beginning of your career as a science teacher and you cannot accomplish everything you wish, learn everything you need, or do everything you would like during the science methods course or even during the first year of teaching.

You can do something specific and immediate to help reduce your concerns and develop your effectiveness. *Be prepared.* This message is crucial. Some teachers equate preparation with knowledge of their scientific discipline. Although this is essential, preparation is key. We have mentioned some ideas, such as understanding the purposes of science teaching, organizing science instruction, understanding student learning, and managing the classroom.

Becoming an effective science teacher takes time. The corollary to time is experience. There is no substitute for the actual experience of teaching science. The one sure way that you will detect strengths and weaknesses in yourself as a teacher is through experience. You will learn more about yourself and science teaching in the first year than you can now imagine. It will not be easy, but it will be interesting and challenging. Every day will involve you in experiences that contribute to your effectiveness. Many of these are the other topics of this book.

For now, let's look at your concerns, apprehensions, and needs concerning science teaching, by completing Activity 1–5: My Concerns, at the end of this chapter.

Becoming a Science Teacher: Closing Reflections

One premise of this book is that you can become a better science teacher. Students entering science teaching and those already in the profession are concerned about improving the quality of instruction in science and increasing student learning. Your own concerns and activities in studying this book and taking the methods course have already demonstrated your willingness to learn more about science teaching. Once you obtain a teaching position, professional development in the form of workshops, curriculum revision, and continuing education courses will be available. Participation in all of these programs indicates a desire to become a better science teacher.

A second premise is that you are the one person who best knows what is necessary for you to become an effective teacher. This is the reason for the self-evaluation exercises. Your college supervisor, methods professor, and perhaps classroom teachers also will provide you with feedback. This feedback will help, especially when you combine it with your own insights and act on the information. In other words, you have many personal choices in the process of becoming a science teacher.

The responsibility for becoming an effective science instructor is yours. Many individuals and an abundance of programs are available to aid you. Ultimately, however, you are the person who must combine all of the elements to facilitate science education for your students.

We now look at goals related to your professional growth. Becoming a science teacher means you continually demonstrate the following:

- *An adequate understanding of scientific knowledge*—This goal includes an in-depth understanding of specific disciplines, as well as a broad understanding of science in general. It also includes a comprehension of the role of science in our society.
- *An adequate understanding of scientific inquiry*—Specifically, this understanding includes the attitudes and abilities of inquiry and the application of scientific philosophies to classroom instruction.
- *An adequate awareness of educational foundations and the place of science education as a discipline in the larger realm of education*

- *An adequate understanding of and ability to use teaching methods appropriately*—This goal includes the ability to plan and organize activities for the classroom, to carry out standard classroom procedures, to use a variety of techniques and equipment in teaching science lessons, and to assess student progress.
- *Adequate interpersonal relations and an enthusiasm for working with all students*
- *The synthesis of these five goals into the practice of teaching science in the secondary school*

SUMMARY

The experience of becoming a science teacher is identifiable through the questions one asks. Here we assumed you might ask, "Am I qualified to teach science?" Although this is impossible to answer, several activities were presented, each allowing you to investigate the question. We also described several attributes essential for science teaching: understanding science, understanding students, organizing materials for science instruction, personalizing your interaction with students, recognizing personal meaning as a part of learning, managing the classroom and maintaining discipline, and very important, realizing your own role as decision maker in the science classroom.

After discussing the first question, we turned to a second: "What is science teaching like?" To answer this we used a variety of vignettes drawn from case studies of schools from all over the country.

Next, we addressed the question of becoming an effective science teacher. The question seems to be a part of the natural sequence of questions asked by students as they enter teaching. Once the initial anxiety of becoming a science teacher is overcome, individuals turn to the problem of becoming a better teacher. Time, experience, and preparation contribute to the increasing effectiveness of the beginning teacher. One way of helping to overcome apprehension is to identify concerns and act on reducing them. We recommended completing a self-examination by responding to the question, "What are my concerns?"

The chapter ends with some goals related to the process of becoming a science teacher. The goals are summarized as demonstrating an understanding of scientific knowledge and inquiry, of science education as a discipline, and of teaching methods; forming adequate interpersonal relationships with students; and synthesizing these goals into the teaching of science in the secondary school.

INVESTIGATING SCIENCE TEACHING

ACTIVITY 1–1
HOW I SEE MYSELF AS A SCIENCE TEACHER

The statements in this exercise allow you to examine your self-perceptions as a science teacher. The exercise is designed for your personal knowledge and need not be shared with others. Read the statement and decide if you strongly agree, moderately agree, agree, are neutral, slightly disagree, moderately disagree, or strongly disagree. Then place the appropriate number in the space to the left of the statement.

Strongly agree	*Moderately agree*	*Slightly agree*	*Neutral*	*Slightly disagree*	*Moderately disagree*	*Strongly disagree*
7	*6*	*5*	*4*	*3*	*2*	*1*

_____ 1. I am well informed about science and technology.
_____ 2. Students can generally take care of themselves.
_____ 3. I identify with people.
_____ 4. My task as a science teacher is one of assisting students to learn.
_____ 5. The meaning of science and technology for our society is more important than the facts and events of science and technology.
_____ 6. Science and technology are meaningful in my personal life.
_____ 7. For the most part, other people are friendly.
_____ 8. Basically, I am an adequate science teacher.
_____ 9. I see my purpose as concerned with larger issues of science, technology, and society.
_____ 10. I try to understand how my students perceive things.
_____ 11. I have a commitment to the field of science and technology.
_____ 12. Students have their own worth and integrity.
_____ 13. I am a dependable and reliable science teacher.
_____ 14. I usually do not conceal my personal feelings and shortcomings from students.
_____ 15. Teaching science is best done by encouraging personal development of students.
_____ 16. Science and technology are essential in our society.
_____ 17. People are basically trustworthy and dependable.
_____ 18. Students generally see me as personable and likable.
_____ 19. I am personally involved with my students.
_____ 20. I am accepting of individual differences in my students.
_____ 21. My understanding of science and technology is adequate.
_____ 22. Students are important sources of personal and professional satisfaction for me.
_____ 23. As a science teacher, I am worthy of respect.
_____ 24. The process of learning science is important for our culture.
_____ 25. My orientation is toward people more than things.

The items in this list are keyed to five important dimensions of science teaching as a helping profession. If you would like to see how you perceive yourself on these dimensions, complete the following section. Add your response for the items in the left column. Divide that number by five. The result should be a number between seven and one for each of the dimensions of science teaching listed. The numbers give some indication of your self-perceptions as related to the different categories.

Items		*Average*	*Dimensions of Science Teaching*
1, 6, 11, 16, 21	÷ 5	_____	Perceptions about science subject matter
2, 7, 12, 17, 22	÷ 5	_____	Perceptions of students
3, 8, 13, 18, 23	÷ 5	_____	Perceptions of yourself as a science teacher
4, 9, 14, 19, 24	÷ 5	_____	Perceptions of your purpose as a science teacher
5, 10, 15, 20, 25	÷ 5	_____	Perceptions of the teaching task

ACTIVITY 1–2
THE WHAT AND HOW OF SCIENCE LESSONS

In this activity you are presented with a teaching situation on the left and asked to match a method from the right to achieve your teaching goal. In each case you should give a rationale for your choice of method. Complete the activity alone. Then share your responses with several other students in the class.

What you want to accomplish—the goal	*How you would accomplish your goal—the method*
1. Introduce the concept of acids and bases.	_____
2. Clarify the effects of air pollution.	_____
3. Summarize the effects of erosion.	_____
4. Show the interrelationships of organisms in a community.	_____
5. Evaluate students' understanding of pulleys.	_____
6. Differentiate the phylum Echinodermata from the phylum Chordata.	_____
7. Realize the ethical decisions involved in scientific research.	_____
8. Introduce the structure of DNA.	_____
9. Show the dynamic qualities of weather.	_____
10. Expand students' understanding of the systems.	_____
11. Review the concept of force.	_____
12. Teach students to handle the microscope correctly.	_____
13. Outline safety procedures for the chemistry laboratory.	_____
14. Introduce students to careers in science.	_____
15. Help students understand the role of science and technology in society.	_____

Methods of teaching

a. Bulletin board
b. Demonstration
c. Discussion
d. Field trip
e. Video
f. Internet
g. CD-ROM
h. Guest speaker
i. Laboratory investigation
j. Library research
k. Lecture
l. Projects
m. Questioning
n. Quiz
o. Analyzing data
p. Role playing
q. Presentation using video images
r. Simulation game
s. Television
t. Test
u. Chalkboard
v. Computer simulation concept
w. Calculator (handheld)
x. Records

ACTIVITY 1–3
A FIRST LESSON

It is strongly recommended that you teach a short science lesson early in the methods course. Preferably, this lesson should be taught in a local science class; however, it may be taught to your peers in the methods class. An important objective of this lesson is to help you answer two questions: "Can I teach science?" and "What is science teaching like?" There is no better way to answer these questions than to actually teach a science lesson.

Here are some guidelines to help you prepare your first lesson.

1. Keep the lesson simple. Try to present a single concept, process, or skill.
2. What do you hope to accomplish by the end of the lesson? What should the students know or be able to do that they could not do before the lesson?
3. What experiences will best achieve the goals and be interesting and motivating for the students?
4. What is the most effective way to organize the materials or experiences of the lesson? What is its conceptual structure and instructional sequence?
5. Use the following format as the basis of your lesson plan.

Self-Critique of Your First Lesson

1. Rate the following:

	Poor	*Fair*	*Good*	*Excellent*	*Comments*
Voice quality and articulation	_____	_____	_____	_____	_____
Poise	_____	_____	_____	_____	_____
Adaptability and flexibility	_____	_____	_____	_____	_____
Use of English	_____	_____	_____	_____	_____
Procedure	_____	_____	_____	_____	_____
Enthusiasm	_____	_____	_____	_____	_____
Continuity	_____	_____	_____	_____	_____
Maintenance of good class control	_____	_____	_____	_____	_____
Provision for individual differences	_____	_____	_____	_____	_____
Ability to interest students	_____	_____	_____	_____	_____
Ability to involve students	_____	_____	_____	_____	_____
Ability to ask questions	_____	_____	_____	_____	_____
Ability to answer questions	_____	_____	_____	_____	_____
Use of instructional methods	_____	_____	_____	_____	_____
Provision of adequate summaries	_____	_____	_____	_____	_____
Budgeting of time	_____	_____	_____	_____	_____
Organization of the lesson	_____	_____	_____	_____	_____
Knowledge of subject	_____	_____	_____	_____	_____

2. Did you achieve your goals?

3. What were the strengths of the presentation?

4. What were the weaknesses of the presentation?

5. What would you change if you were to teach this lesson again?

ACTIVITY 1–4
AN INTERVIEW WITH A SCIENCE TEACHER

One way to find out what science teaching is like is to interview a science teacher. Tell the teacher the reason for the meeting and the general topics of discussion. If at all possible, make arrangements to observe a class period before the interview. This visit will give you some insights concerning the teacher's style and approach to science instruction. It will also provide some bases of discussion. You may wish to ask the following questions to get the conversation started.

1. What is the science program in your school?
   How many courses are offered?
   What is the enrollment in life science? Earth science? Physical science? Which textbooks are used?
   How is educational technology incorporated into each course?
   How does the science program in your school relate to the rest of the science program in the district?
   Do you offer any special science courses?
   Has the science program changed in the last five years?
2. What do you see as the important trends and issues in science teaching?
   Have enrollments in science increased? Decreased? Has the science budget increased? Decreased? How much do you use the laboratory in science teaching? Do you introduce any science-related social issues?
3. What are your concerns as a science teacher? Are your facilities adequate? Do you have materials for your program? Is student interest high? Low? Is maintaining discipline a problem?
4. What are your greatest rewards as a science teacher? Seeing students learn? Helping other people? Working with interesting and exciting colleagues? Contributing to the public's scientific literacy?
5. Why is science important?

ACTIVITY 1–5
MY CONCERNS

Listed below are several statements commonly expressed by students entering teaching. Indicate your present concern about the problem by placing an X in a space provided on the continuum: Number 1 indicates little concern, number 9 indicates a high degree of concern.

1. Developing short- and long-term purposes, goals, and objectives for science instruction
2. Understanding scientific inquiry
3. Motivating students to learn science
4. Designing programs to increase the learning of science
5. Recognizing and responding to different developmental levels of students
6. Understanding the dynamics of student groups
7. Adapting to the special needs and abilities of students
8. Designing programs for the individual needs of students
9. Knowing about science curriculum programs and instructional materials
10. Incorporating other disciplines, such as mathematics or social science, into the science program
11. Understanding and using different instructional strategies
12. Planning and organizing science activities
13. Evaluating student progress
14. Handling problems of classroom management, pupil control, and student misbehavior
15. Preparing for practice teaching
16. Budgeting time and judging the flow of science lessons
17. Handling routines such as making out reports, attendance, and keeping records
18. Lack of an adequate background in science
19. Lack of self-confidence to teach science
20. Presenting science demonstrations, questioning, and guiding student discussions
21. Adapting to the unique problems of school facilities, materials, and equipment
22. Understanding and using special school services such as counseling and testing
23. Knowing how to obtain a science teaching job
24. Understanding the place and importance of science education
25. Other concerns

These statements constitute a personal inventory of concerns. Many of them are addressed in this book and will be included as part of the methods course. Identifying and clarifying your concerns will better enable you to direct your work, study, and activities during this preparation for science teaching.

Beginning Your Instructional Theory

This chapter introduces some practical aspects of science teaching. Chapter 1 focused on questions, such as, "Am I qualified to teach science?" and "What is science teaching like?" The questions for this chapter include: "What do I have to know in order to teach science?", "What do I have to be able to do to teach science?", and "How do I put it all together for effective science teaching?". To answer these questions, we use the idea of an *instructional theory* to help you formulate ideas about science teaching. Further, we have you begin developing an approach to science teaching.

Teaching science requires continual decision making. One way to characterize the decision-making process is through questions. How do I respond to students' misconceptions in science? The LCD projector does not work—what should I do? Where should I use this new piece of software? How can I use the Internet with my class? Is this laboratory safe? Indeed, you will have to consider many variables during the school day. Effective science teachers act efficiently and respond constructively to numerous classroom situations. Before continuing in this chapter, you should complete Activity 2–1: What Would You Do?

Why Develop an Instructional Theory?

Scientific theories guide the research of scientists and help them develop new insights into the intricacies of nature. A theory is an effective intellectual tool that integrates many observations and helps scientists make predictions. Recall that in science, a theory is an empirically substantiated explanation of some aspect of the natural world. A theory is based on evidence and it incorporates facts, inferences, tested knowledge, and laws. Scientific theories have several fundamental attributes. They (1) guide scientific inquiries, (2) organize observations and data, (3) provide explanations for phenomena, and (4) help predict events and therefore provide direction.

An instructional theory should provide well-substantiated explanations for aspects of teaching and learning in science classrooms. Your instructional theory should be based on evidence—observations and research—not prevailing beliefs about students and teaching. As a science teacher your effectiveness can be enhanced by your ability to organize observations of students, explain behaviors, and predict what will happen as a result of your activities and actions in the classroom. Although an instructional theory may not have the power and utility of a scientific theory, it will certainly help you bring consistency to the decisions you make as a science teacher.

What Are the Foundations of an Instructional Theory?

One essential foundation is your understanding of the purposes of science education. Other foundational elements include principles of learning, motivation, development, and social psychology, as well as attitudes and values of the scientific enterprise, curriculum materials, and instructional techniques. Individual science teachers combine all of these elements in unique ways.

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ANTICIPATING STUDENT TEACHING

As I anticipate my student teaching placement in the fall, I am beginning to formulate my definition of a successful teacher. The ideal teacher is organized, energetic, and confident. He or she uses subject matter as a means of helping students to develop an appreciation of themselves, others, and society. During my student teaching placement, I hope to develop the skills of an "ideal" teacher. As I work toward my goal, student teaching will have a dual purpose for me. I want to help my students appreciate their own abilities, and I hope to learn more about myself as a science teacher.

To recognize students' abilities, I will need to become acquainted with them and their interests. As I search for topics that interest them, I will hope for interesting moments and sparks of thoughtful questions. It will be necessary to appreciate diversity. Some students will have trouble with analytical skills, but they may demonstrate the ability to lead others, to communicate, or to be creative. To provide each student with the opportunity for success and enthusiasm, I will have to include a broad range of activities.

As I envision activities for students, I recognize one of the causes of my own enthusiasm. I believe that science classes provide a means of understanding the earth and its resources. Such understanding is essential if we hope to protect and improve the environment. The science courses I most enjoyed were those that increased my awareness of the environment and my perceptions of change. As a teacher, the opportunity to select materials and topics will be very important to me. I hope to teach about general principles by providing a background of specific examples. I plan to infuse a good deal of environmental education in my classes, and I hope that my enthusiasm for science will be shared.

As I try to share my interests and concerns with others, I also will be learning about myself. A cooperating teacher will probably provide both criticism and praise. Students' actions and reactions in the classroom will challenge my assumptions as well as my creativity. There will be times when I cannot select the exact subject matter I would like to teach. Unless I demonstrate my willingness to take risks and correct mistakes, however, I will not learn the ways in which I need to change. To succeed as a student teacher, I will need to be persistent, open, and energetic. I want to help others value their own abilities and, by doing so, I hope to become better acquainted with myself.

CHARACTERISTICS OF AN INSTRUCTIONAL THEORY

In 1968, Jerome Bruner outlined the characteristics of an instructional theory in a book entitled, *Toward a Theory of Instruction*. According to Bruner, a theory of instruction is *prescriptive*. It gives direction and provides guidelines for effective instruction and enables the teacher to evaluate teaching techniques and procedures. A theory of instruction also is *normative;* it is general rather than specific. For example, a theory of instruction would give some criteria for a chemistry lesson on acids and bases but would not give specific guidelines for the lesson.

What help does a theory of instruction provide? What questions will it answer? An instructional theory has five important characteristics. It should help you specify the following:

1. *The most acceptable evidence that students have learned*. This first and most valuable aspect of an instructional theory identifies what counts as learning.
2. *The most effective experiences to enhance learning.* An instructional theory helps you answer the question, "What activities will encourage learning?"
3. *The most effective way in which knowledge can be structured to enhance learning*. An instructional theory helps you answer the question, "What is the best way to structure the knowledge and skills of my lesson?"
4. *The most effective sequence in which to present material*. An instructional theory helps you answer the question,

"How do I present the lesson so all students will develop their understandings of science?"

5. *The most effective processes for feedback and evaluation*. An instructional theory helps you answer the questions: "How and when should I give feedback?", "When should instruction be assessed?", "What is the most appropriate form to obtain and return feedback?", and "How should I modify instruction?".

One important condition for learning is *active participation by students*. Science teachers often ask, "How can I motivate students?" You will slowly accumulate ideas and activities that encourage a predisposition toward learning. Engaging the learner is difficult for even the most experienced science teacher. Consider your own response to the problems in Activity 2–1. Ideally, the problems engaged your interest. One response you could have made was the exploration of alternative solutions to the problem. Another was a curiosity concerning details of the situation. Both of these responses originated in the uncertainty and the ambiguity of the problems. There is an optimal level of uncertainty and ambiguity: too little and the problem is easily resolved; too much and there is confusion, anxiety, and lack of resolution. Part of your task as a science teacher is to help learners stay within the optimal range of their interest and curiosity.

Once you have engaged the learners, they must continue to work on the problem. To stimulate continued interest, the rewards of the exploration must be greater than the risks. Was this true with your work on the problems in Activity 2–1? Giving or receiving instruction should increase rewards and decrease risks; if such is not the case, your instruction is not as effective as it should be.

Finally, you need a direction or goal. From the alternatives provided, you were asked to resolve the classroom problems in the best way possible. The question—What would you do?—helped define the direction and goal.

A second condition for effective instruction is the *optimal structure of knowledge*. In the best cases, this condition is provided by well-designed instructional materials. The body of knowledge should be presented in a form simple enough to be understood by the learner. The fact that the material is in a textbook means that the science teacher will have to adapt the structure of knowledge to accommodate students' needs and interests.

A third condition for learning is the *optimal sequence of knowledge*. As science instruction progresses, teachers present and draw students' attention to relationships among ideas, processes, and skills. The instructional sequence should increase the probability that at each step the learner understands, transforms, and applies these ideas, processes, and skills. Here again you may encounter the problem of steps that are too small, resulting in students' boredom, or steps that are too large, resulting in frustration. In part, the purpose of your instructional theory is to help you bridge the gap between the structural and sequential logic of the curriculum and the social and psychological needs of the students.

A fourth condition is your ability to receive, respond, and give *feedback in the teaching environment*. Motivating, structuring, and sequencing of instruction are contingent on your ability to receive and respond to cues from the students. Student feedback should in turn influence your instruction and your response to student achievement.

PURPOSE, GOALS, AND OBJECTIVES

Like any journey, in science teaching you have to know where you are going. What is it that you perceive as the destination for your students? What do you see as the stops along the way to this final destination? In the first chapter, we suggested that the term *scientific literacy* expresses the destination for all students. Translating scientific literacy into concrete goals of knowledge, skills, and values of curriculum and instruction is an important process for science teachers, because the translation has to be fairly consistent with the overall purpose. Finally, the specific objectives of lessons have to be consistent with the purpose of developing scientific literacy. Separate chapters are devoted to these topics. Before continuing, complete Activity 2–2: My Aims and Preferences. You should review your responses on this investigation after completing the chapter.

The *National Science Education Standards* (NRC, 1996) also provide purpose, goals, and objectives for science teaching. They give a valuable description of your destination, and outline the territory for your travels. They do not have specific, detailed maps for the trip, so you will have to create your own maps for using curriculum, instruction, and assessment. Your instructional theory will be invaluable for this process.

LEARNING AND TEACHING

Research on student learning has long been an important factor in any teacher's instructional theory. In the 1960s and 1970s, science teachers looked to Jean Piaget's theory of cognitive development (Bybee & Sund, 1982). The research focused on two major features of Piagetian theory. First, Piaget proposed that learning occurs through an individual's interaction with the environment. This interaction is described as a student assimilating new information and ideas from various educational experiences and then accommodating the new information with previously held information. This method establishes a consistency between the

individual's cognitive structure and everyday experience. Second, each individual passes through different stages of development, each characterized by the ability to perform various cognitive tasks.

The most relevant stages for science education are concrete reasoning and formal reasoning. A concrete reasoner requires tangible objects and experiences and their observable relations to reason logically. A formal reasoner can manipulate abstract ideas.

Piaget's notion of learning as an interaction with the environment has been generally supported (Luzner, 1986; Renner, Abraham, & Birnie, 1986) and, in fact, was a foundation for contemporary constructivist explanations of students' conceptual understanding and change. The concept of stages of concrete and formal reasoning, however, has been criticized and revised. Studies (Chiapetta, 1976; Renner, Grant, & Sutherland, 1978; Wavering, Perry, & Birdd, 1986) have demonstrated that, as measured by performance on cognitive tasks, the majority of secondary students are at the concrete stage of reasoning. There is also evidence that performance on such tasks is strongly influenced by context, mode, language of task presentation, and subject matter (Golbeck, 1986; Brandwein, 1979). Other studies have demonstrated that even young children are capable of abstract thought in certain situations (Chi & Koeske, 1983).

Because most secondary students engage primarily in concrete reasoning, be careful about introducing tasks that primarily require abstract thought. For example, many texts of secondary science implicitly assume that the reader can reason at the formal level. A statement about where students *are* in their reasoning ability does not, however, mean they cannot learn and develop more sophisticated levels of reasoning. Students much younger than secondary students are capable of reasoning and logical thought under certain conditions. Appropriate contexts and experiences that progress from concrete to abstract could foster the reasoning abilities necessary for understanding many science concepts.

In recent years science educators have used a model termed *constructivism* to help understand students' learning. The theoretical basis for constructivist research comes from several sources, including David Ausubel (1968). We have introduced the essence of Ausubelian theory (Ausubel, Novak, & Hanesian, 1978) earlier: A learner's prior knowledge is an important factor in determining what is learned in a given situation. L. S. Vygotsky (1968) is a second important source for constructivism. He wrote of student and teacher conceptions, and how students and teachers might use similar words to describe concepts, yet have different personal interpretations of those concepts. Vygotsky's work implies that science instruction should take into account the differences between teacher and student conceptions and should provide a great deal of student–student interaction so that learners can develop concepts from those whose understandings and interpretations are closer to their own.

Early work in constructivist research focused on identifying students' conceptions about scientific phenomena and how such conceptions differ from accepted scientific conceptions. Student conceptions have been referred to by various unfortunate labels, such as misconceptions, alternative conceptions, alternative frameworks, and naive theories. We think it is much more useful to simply recognize students' *current* conceptions and emphasize your role in changing those conceptions so they are more aligned with those recognized as scientific. Several good reviews of this research exist (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1983; Duit, 1987). We especially recommend that you review *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, & Cocking, 2000), and *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005).

In the constructivist model, students construct knowledge by interpreting new experiences in the context of their current conceptions, experiences, episodes, and images. Students' construction of knowledge begins at an early age so that by the time they encounter formalized study of science, they have developed stable and highly personal conceptions for many natural phenomena. Given this view, one goal of your instruction must be to facilitate change in students' conceptions of the world. Researchers (Posner, Strike, Hewson, & Gerzog, 1982; Smith, Carey, & Wiser, 1985) have likened this process of conceptual change to the process by which scientific theories undergo change and restructuring. In fact, studies have demonstrated that student beliefs and conceptions often parallel early scientific theories, dating back to Aristotle and Lamarck (Caramazza, McCloskey, & Green, 1981; Champagne, Klopfer, & Gunstone, 1982; Wandersee, 1986). However, other research cautions against drawing too strong a parallel between student conceptions and the history of science, largely because student conceptions are not nearly as comprehensive as, say, Aristotelian theories.

Posner and others (1982) have proposed four conditions for conceptual change that should be recognized as you formulate your instructional theory. First, in order for students to change their conceptions of a given phenomenon, they must be *dissatisfied* with their current conception. This dissatisfaction presumably comes about through repeated exposure to experiences they cannot explain by using current conceptions. Second, the new conception must be *intelligible* in terms of prior experiences and knowledge. Third, the new conception must be *plausible* in that it can explain a number of prior experiences and observations. Finally, the new conception must be *fruitful,* opening up new areas of inquiry, primarily through predictions about future events.

Constructivist research also suggests other strategies to promote conceptual change. You should be aware that students have conceptions of the world and that they often do not differentiate concepts (Trowbridge and McDermott, 1981). Students need time to make their ideas explicit, and they should have a chance to apply their conceptions of the world in different contexts (Minstrell, 1989).

Contemporary research associated with cognitive sciences and constructivism has had an important influence on science teaching. We recommend reviewing *Learning Science and the Science of Learning,* a publication prepared specifically for science teachers (Bybee, 2002).

When considering your approach to instruction, recognize that your students may have explanations or conceptions for many objects, events, and phenomena. Stated another way, your students are not empty vessels into which you can pour scientific facts, information, and concepts. Your challenge as a science teacher is to help students realize the inadequacy of their current conceptions and provide the time and opportunity for them to construct more scientifically accurate concepts. In later chapters, we return to your role in providing linkages between students' explanations and scientific explanations.

EFFECTIVE RELATIONSHIPS WITH STUDENTS

For many years psychologists have investigated the characteristics of effective helping relationships, including teaching. Their research indicates that a teacher's perceptions of self, students, and the teaching task are critical to effective instruction.

Effective teachers perceive other people, particularly their students, as able, friendly, worthy, intrinsically motivated, dependable, and helpful. In the same manner, effective teachers see themselves as good teachers who are needed and trustworthy, and who relate well to other people.

Better teachers see themselves assisting and facilitating rather than coercing and controlling. They identify with larger issues, are personally involved with issues, problems, and other people, and view the whole process of education as important. In addition, they tend to be altruistic and self-revealing. Effective teachers see their task as helping people rather than dealing with objects; and, generally, they try to understand the perceptions and backgrounds of their students.

These studies delineated the perceptions of effective teachers. What about the students' perceptions of the science teacher? Years ago, one author conducted research on the perceptions of the ideal science teacher (Bybee, 1973; 1975; 1978). The results of these studies are summarized in Table 2–1. Note that adequate personal relations with students, and enthusiasm in working with them, consistently rank as the most important characteristics for science teachers. With only one exception, these two categories ranked first or second by all the groups studied. Although this research indicates that personal qualities are perceived as important dimensions of science instruction, knowledge, personal relations, planning, enthusiasm, and methods are all important for effective science teaching. An instructional theory should incorporate these elements, adapting them individually and *in toto* to the situation in the science classroom.

TABLE 2–1 Science Educator's Grand Mean Ranking Compared with Other Population's Data Reported by Rank

Category	Science Educators N = 172	Inservice Teachers N = 76	Preservice Elementary Majors N = 58	High School Students Average N = 44	High School Students Disadvantaged N = 106	High School Students Advantaged N = 31	Elementary School Children Grade 6 N = 25	Elementary School Children Grades 4, 5, 6 N = 18
Knowledge of subject matter	4	4	4	3	4	3	3	3
Adequate personal relations with students	1	1	1	1	1	2	1	1
Adequate planning and organization	5	5	5	4	3	4	5	4
Enthusiasm in working with students	2	2	2	2	2	1	2	2
Adequate teaching methods and class procedures	3	3	3	5	5	5	4	5

EFFECTIVE INSTRUCTION

Lee Shulman of Stanford University reported the role and development of teachers' knowledge in relation to teaching. Shulman (1986) identified three categories of content knowledge: (1) subject matter, (2) pedagogical, and (3) curricular.

For science teachers, *subject matter* is more than information and facts about a discipline. Content knowledge of a subject includes what Joseph Schwab (1966) called the "substantive and syntactic structures" of a discipline. That is, substantial knowledge is an understanding of the different ways the basic concepts and principles of a discipline are organized. What are the major conceptual schemes in your discipline? If you had to organize the information and facts of physics, chemistry, biology, or the earth sciences, what major ideas would you identify as basic structures of these disciplines? In biology, for example, one can use the levels of organization approach, studying biology from the smallest particles to larger domains, and explaining living processes in terms of molecular activities. One also can use an ecological approach in which the ecosystem is the basic level of study and individual activities are studied in terms of the systems in which they live and interact. Using either of these structures you can develop basic conceptual schemes of biology, such as energetics, genetics, diversity, and evolution.

The syntax of a discipline is the set of ways scientists establish the truth or falsehood, validity or invalidity, of new or extant knowledge claims. Science teachers' use of inquiry introduces students to the processes of obtaining new knowledge, such as observation, hypothesis, and experimentation. Students also gain the understanding that knowledge must be evaluated. By what criteria do biologists, geologists, or astronomers evaluate the worth of different theories?

Pedagogical content knowledge describes the depth and breadth of knowledge a teacher has about teaching a particular subject. Pedagogical content knowledge is the capacity to formulate and represent science in ways that make it comprehensible to learners. Examples of pedagogical knowledge include forms of representing concepts such as use of analogies, examples, illustrations, and demonstrations. Effective science teachers have a variety of ways and means of representing such ideas as ionic bonding, density, recombination of DNA, or stellar evolution.

Another dimension of pedagogical content knowledge is the understanding of what makes a concept easy or difficult for a learner to grasp. What misconceptions might students have about phenomena, such as heat and temperature, position and velocity, or living and nonliving? What preconceptions do students have for objects and events in the natural world? The science teacher's instructional theory helps establish links between new concepts and the students' current understanding.

Next we consider *curricular knowledge*. One goal of this book is to introduce you to the many methods and materials used in science teaching. The science curriculum includes a full range of materials with which science teachers should be familiar. Materials are designed for a particular subject, at a particular level, to be used with particular students. Each discipline has its own textbooks, kinds of laboratory equipment, and educational software.

In addition to knowledge of curricular materials and how best to use them, curricular knowledge extends to science teachers' abilities to relate topics of study to the curricula their students may be studying in other disciplines.

INSTRUCTIONAL DECISIONS

The discussion of teacher knowledge as it relates to content, pedagogy, and curriculum is obviously important, even essential, but you will need more than an adequate knowledge base for your instructional theory; as we have mentioned, you will also have to make many instructional decisions. David Berliner (1984) reviewed research on teaching and provided valuable insights about these decisions, using the categories of preinstructional decisions, instructional decisions, and postinstructional decisions.

First, we introduce *preinstructional decisions*. Before you begin teaching a science lesson, be aware of the effect of certain decisions on student achievement, attitudes, and behaviors. You must make *content decisions*. What is the content of your science lesson? You must consider not only national standards and state and local standards and assessments, but also your judgments about issues, such as the effort required to teach a subject and the problems that you perceive the students will have with the subject. Finally, you must take into account the subjects you enjoy teaching. Which are the areas within your discipline that you really like? Are you excited about introducing students to the nature and history of science? Do you think it most important to have students recognize science-related social issues?

Science teaching involves groups of students. *Grouping decisions* are part of your preparation for a lesson. What is the best size of a group? How much laboratory equipment do you have? Who should (or should not) work together? Should you use cooperative groups? What criteria do you have for forming a particular group? Whether you lecture to the entire class or work in the laboratory, you will usually make grouping decisions. Even when assigning individual work on

projects, experiments, and tests, a group in some sense still exists.

Finally, you will have to make *decisions about activities*. Laboratory work, for example, has specific functions; that is, it is used to achieve certain goals. In a laboratory, students may learn to design an experiment, manipulate equipment, and use computers. Operations—the rules or norms of conduct for the activity—are also important. Is it okay to be out of one's seat? What type of conversation is acceptable? What rules *must* be followed for safety reasons?

The importance of these kinds of decisions cannot be overstated. Just reading this section should make you aware of the many and varied decisions you must make *before you begin teaching even the simplest lesson*.

Next is the importance of *instructional decisions*. Once you begin teaching a lesson, numerous factors determine what your students learn. The amount of time students spend on a task—*engaged time*—is directly related to how much students will learn. Recognize that *engaged* can mean physically (hands on), mentally (minds on), or both. Although this seems obvious, the amount of engaged time varies from student to student and class to class. Be aware of the amount of time students are actually working. Engaged time is especially important for students who are under achievers and of low ability. These students will benefit most from time *on task,* but they also are the students who are most likely to be *off task*.

The *success rate* of students is related to continued achievement. Success in the early stages of learning new concepts or skills is especially important for students of low ability and those who have traditionally been unsuccessful. If students do not experience some success in the early stages of lessons, their frustration and lack of understanding can contribute to low achievement.

Decisions you make about *questioning* will also influence your teaching effectiveness. Science teachers in particular should ask many questions—questions about the natural world are the foundation of science. The first thing to consider is the cognitive level of the question. Most teachers ask low-level questions, such as: "What do the letters DNA stand for?", "What is the second law of thermodynamics?", or "What is a silicon oxygen tetrahedron?". Although questions of this nature have some benefit, remember that higher level questions facilitate thinking and learning. Questions that require students to analyze and synthesize will produce higher levels of student achievement. You could, for example, provide data in graph form and ask the students to analyze the results and form an explanation based on the evidence. Or, you could provide information from two separate but related experiments and ask students for their predictions of possible outcomes.

Another point about questioning concerns the importance of *waiting* after you have asked a question. Research by Mary Budd Rowe (1974) confirms the importance of wait time. Longer waits (most teachers wait less than one second after asking a question) result in increases in the appropriateness, confidence, variety, and cognitive level of responses. A two- to three-second adjustment in your teaching style can result in a much higher return for you and your students.

Finally, you will make *postinstructional* decisions. Now that the lesson, unit, or semester is over, how much did the students learn? Science teachers usually arrive at an answer through the assessments, grades, and feedback given to students.

Assessment is not the central issue. In fact, we propose that planning the assessment should exactly correlate with your aims and should have been designed *before* developing the instructional sequence and providing students opportunities to learn. Although this may seem backwards, it is designing school science instruction so it is coherent (Wiggins & McTighe, 2005).

Grades motivate students to achieve; however, the overuse of grades or their use as coercion can have detrimental effects. Corrective feedback, if properly given, results in positive achievement and attitudes on the part of students. Your decisions to give praise for correct work, recognition for proper behavior, and personally neutral criticism (as opposed to sarcasm) for incorrect responses all can influence student learning.

It is easy to feel overwhelmed at the number of decisions that go into science teaching. We think the early introduction of these ideas will prepare you for the topics and activities to come. For the time being, only an awareness of these decisions is necessary.

RESEARCH ON EFFECTIVE TEACHING

Research on good teaching provides insights that may help you synthesize the ideas in this section. After reviewing the research on good teaching, Andrew Porter and Jere Brophy (1988) concluded that the concept of good teaching is changing. In the past, teachers sometimes were viewed as technicians who had to apply how-to lessons, or as weak links in the education system who had to be circumvented with a teacher-proof curriculum. Such approaches did not work. The current concept of effective teaching deals with empowering teachers. How are teachers empowered? A brief answer is through the application of research on teaching, and a longer answer involves the continuous development of an instructional theory. Our discussion assumes that student learning within science classes requires good teaching, and good teaching requires science teachers who make appropriate decisions about how to educate students.

A contemporary image of the good teacher is that of a thoughtful professional who works purposefully

toward educational goals. According to Porter and Brophy (1988):

- Effective teachers are clear about their instructional goals. They inform their students of these goals and keep them in mind as they design lessons and communicate with students.
- Effective instruction provides students with strategies they can use for their own learning.
- Effective instruction creates learning situations in which students are expected to learn information, solve problems, and organize that information in new ways.
- Effective teachers continually monitor student understanding and adjust instruction accordingly.
- Effective teachers frequently integrate other subjects and skills into their lessons.
- Effective teachers design instruction so that what is learned can be used in the future.
- Effective teachers are thoughtful and reflective about their instruction.

Figure 2–1 summarizes these points.

Effective science teachers continually develop and improve their approach to instruction—what we call an instructional theory. The feature that mediates the instructional theory and teaching practice is decision making as it applies to different teaching situations.

METHODS OF FORMING INSTRUCTIONAL THEORY

When science teachers use the Internet, show a DVD, take a field trip, have students work in the laboratory, or guide a discussion, they are using instructional methods that they assume will develop understanding, skills, or values relative to science and technology. The assumption underlying an instructional method is, it is the most effective, efficient, and appropriate means of facilitating learning.

In this section, we introduce a variety of teaching methods. They are listed in alphabetical order, with a brief description and guides for effective use.

Assessment

Purpose: to provide feedback to both the students and teacher about student understanding of concepts and ability to use skills

Predominant Learning Modes: visual, kinesthetic

Group Size: individual, occasionally small

Tests, quizzes, performance-based assessments, and portfolios used frequently in science classes should be

Good teaching is fundamental to effective schooling. From the studies of the Institute for Research on Teaching and from other studies conducted over the last 10 years, there is a picture of effective teachers as semiautonomous professionals who

- are clear about their instructional goals,
- are knowledgeable about lesson content and strategies for teaching it,
- communicate to their students what is expected of them—and why,
- make expert use of existing instructional materials in order to devote more time to practices that enrich and clarify lesson content,
- teach students metacognitive strategies and give them opportunities to master them,
- address higher- as well as lower-level cognitive objectives,
- monitor students' understanding by offering regular and appropriate feedback,
- integrate their instruction with that of other subject areas,
- accept responsibility for student outcomes, and
- are thoughtful and reflective about their practice.

FIGURE 2–1 Highlights of Research on Good Teaching
(*Source:* Andrew Porter and Jere Brophy, "Synthesis of Research on Good Teaching: Insights from the Work of the Institute for Research on Teaching," *Educational Leadership* [May 1988]: 75.)

designed to provide accurate feedback concerning student progress. Appropriate and effective use of assessment includes the following:

- Assess the opportunities students have had to learn science.
- Use performance-based assessments to evaluate the processes of scientific inquiry and technological design.
- Provide students feedback about their understanding of concepts.
- Use questions and situations that require critical thinking and problem solving at different cognitive levels; that is, recall, comprehension, application, analysis, synthesis, and evaluation.

Chalkboard or Marker Board

Purpose: to illustrate, outline, or underscore ideas in written or graphic form

Predominant Learning Mode: visual

Group Size: small to large

Chalkboards or marker boards are used extensively in science classrooms. Most science teachers use the chalkboard or marker board with some skill. Here are a few helpful hints:

- Say what you are going to write before writing it.
- Use key words or concepts.
- Write legibly and spell correctly.
- Stand to the side of the material so the students can see the board and you can see the students.
- Erase the board before writing a new concept, idea, or diagram.

Debate

Purpose: to allow students to gain information, discuss different sides of an issue, and resolve conflicts

Predominant Learning Mode: auditory

Group Size: medium—10 to 15 students

Debate is an effective way to introduce different sides of science-related issues. The debate can continue over several days and involve several teams in various aspects of a topic. Students will have to understand information concerning their position and develop the skills of analysis and evaluation concerning their opponent's position. Here are some guidelines for using debate:

- Be sure the debate topic has clear pro and con sides.
- Use teams of three to four students per side for an issue.
- Set clear time limits for opening statements, rebuttals, and closing statements.
- Make it clear that there are to be no interruptions while a speaker has the floor.

Demonstrations

Purpose: to provide students the opportunity to see a phenomenon or event that they otherwise would not observe

Predominant Learning Modes: visual, auditory

Group Size: medium to large

Demonstrations can be used to teach concepts or skills directly, or to prepare students for work in the laboratory. Demonstrations are often used due to safety concerns or lack of equipment. The best demonstrations have a dramatic quality and usually deal with something that is puzzling to the students. Here are a few helpful hints:

- Present demonstrations so students can see them and hear you.
- Do the demonstration *before* trying it in class.
- Take all necessary safety precautions.
- Plan your demonstration so it clearly shows the intended concepts or skills.

Discussion

Purpose: to promote an exchange of information and ideas among members of a group or class

Predominant Learning Mode: auditory

Group Size: small to medium—two to eight students

Discussions are used frequently in science instruction. The teacher must plan the discussion so that information is accurate and students stay on the topic. Some suggestions follow:

- Think carefully about the initial questions.
- Prepare students for the discussion through reading or a laboratory experience.
- Provide a sheet of topics and/or questions that help guide the discussion.
- Facilitate discussions through planning, questioning, and summarizing.

Educational Software and Computers

Purpose: to allow students the opportunity to review, record, model, and acquire concepts and skills

Predominant Learning Modes: visual, auditory

Group Size: individual to small—two to four students

Examples of this technology in the science classroom include word processing, computer-assisted instruction, microcomputer-based laboratories, HyperCard, simulations, and modeling. Suggestions for use of software include the following:

- Select software aligned with the learning task.
- Use software as part of the planned instruction.

Field Trips

Purpose: to provide a learning experience that is unique and cannot be accomplished in the classroom

Predominant Learning Modes: kinesthetic, visual, auditory

Group Size: large

Field trips can be an exciting complement to the science program. They also can be a disaster. The difference between a learning experience and a disaster lies in the preparation for and appropriateness of the trip. As a science teacher, you will have to decide the appropriateness of the timing and destination of the trip in the instructional sequence. Concerning preparation, here are some guidelines:

- Take the trip yourself before making the trip with students.
- Prepare the students for the trip by informing them of the objectives, activities, and expected behaviors.
- Make sure transportation arrangements have been made and are safe and adequate.
- Confirm any prior arrangements for admission and guides at your destination.
- Obtain permission slips from parents.
- Arrange for additional adults (teachers and/or parents) to go on the trip.

Video/CD-ROM/DVD

Purpose: to present information in an interesting and efficient manner

Predominant Learning Modes: auditory, visual

Group Size: small to large

Most students are interested in video. Science teachers need to use media in a manner that will attain the established objectives. Placement of a video in the instructional sequence is critical. Following are recommendations for effective use of videos:

- Preview the video before showing it.
- Decide where the video can best fit in the curriculum.
- Prepare and distribute questions to the students.
- Identify one or two places to stop the video and have a discussion.
- Conduct a discussion after the video. You can evaluate the students' understanding of key concepts. Answer questions and make connections between the content presented and students' knowledge.

Games

Purpose: to give students an opportunity to learn in an enjoyable, stimulating manner

Predominant Learning Mode: kinesthetic

Group Size: small to medium

If used wisely, games can be valuable for developing concepts and ideas not generally conveyed by other methods. Here are some guides for using games:

- Consider the difficulty of the game.
- Consider the appropriateness of the game for your objectives.
- Provide clear rules for the game.
- Conduct pregame and postgame discussions.

Inquiry and Design

Purpose: to give students experience so they develop knowledge, skills, and values related to science (inquiry) and technology (design)

Predominant Learning Mode: kinesthetic

Group Size: individual to small

Methods related to use of inquiry and design include asking questions, using technology, designing experiments, analyzing data, formulating explanations, thinking about the relationship between evidence and explanation, and communicating explanations and methods. Here are some introductory guides:

- Select the inquiry activity that best illustrates the concepts or skills you have as objectives.
- Be sure materials are available and functional.
- Check equipment to be sure it works.
- Give clear, succinct directions including safety precautions, how to handle equipment, where to obtain materials, assignment of groups, and your expectations of conduct and reporting.

Internet

Purpose: to provide students with opportunities to gather information from a wide range of sources

Predominant Learning Mode: visual

Group Size: individual to small—two to four students

The Internet is an effective educational resource. Students can access the Internet for data and information about various topics.

- Connect use of the Internet with current activities and topics.
- Review the quality of information.

Laboratory Report

Purpose: to have students formalize their experiences and make connections between prior and present knowledge

Predominant Learning Mode: visual

Group Size: individual to small

Laboratory reports can be valuable means to bring different ideas into focus, to have students consider the context of concepts, and to reflect on the meaning of the laboratory experience. For the laboratory report to be effective, we recommend the following guidelines:

- Provide a purpose for the report.
- Outline your expectations in terms of content, length, and format.
- Have all members of groups sign the report, indicating they contributed.

Lecture and Direct Instruction

Purpose: to present a large body of information in an efficient manner

Predominant Learning Mode: auditory

Group Size: large

Lecture is used more often than it is effective, especially for middle school students. Here are some suggestions for effective lecturing:

- Use an outline and either distribute it before the lecture or place it on the overhead projector.
- Supplement the lecture with slides, overheads, or charts to illustrate concepts and ideas.
- Monitor student attention and understanding.
- Talk clearly and in a manner that identifies key points and facilitates note taking.

Oral Reports

Purpose: to allow students to demonstrate their understanding of a subject

Predominant Learning Mode: auditory

Group Size: individual to small

Oral reports are the students' equivalent of the teacher's lectures. Students—individually or in small groups—research information, organize material, and present a report. In effect, students teach other students. Here are some helpful hints:

- Presentations should align with the science program objectives.
- Allow students to report on topics of interest to them.
- Organize presentations as if they were to take place at a professional scientific meeting.
- Help students with audiovisual aids.
- Set clear time limits for the preparation and presentation of reports.
- Provide a formal evaluation in advance.

Problem Solving

Purpose: to give students experience in identifying and resolving a problem

Predominant Learning Mode: visual

Group Size: individual to small

The basic method is to place students in a situation where they must take action that is not immediately obvious. Problem solving provides opportunities for students to encounter concepts such as criteria, constraints, costs, risks, benefits, and trade-offs. Since students usually have not had much experience in problem solving, it is helpful to do some of the following:

- Identify general problems for study and resolution.
- Help students narrow their problems.
- Provide an opportunity to brainstorm possible solutions to the problem.
- Select and test reasonable solutions for the problem.
- Evaluate the tested solutions.
- Prepare a formal report using the protocol of professional papers.

Projects

Purpose: to give students knowledge, skills, and understanding related to a unique problem

Predominant Learning Mode: kinesthetic

Group Size: individual to small

Many science teachers like to have students work on projects and participate in local or regional science fairs. We believe projects are a wonderful way to give students a real sense of science. Here are some things to consider:

- Develop a list of project ideas for students.
- Provide written guidelines concerning the purpose and nature of the project and the final product.
- Provide time and assistance as the students work on their projects, particularly in locating resources.

Multimedia Projects

Purpose: to provide an opportunity to demonstrate understanding of a concept visually to a large group

Predominant Learning Mode: visual, kinesthetic

Group Size: individual to small

Multimedia techniques such as the use of slide show, hypermedia, and video clips provide means for students to put together in creative ways their ideas about a science concept. The use of computers with multimedia capabilities, including presentation software, has been shown to positively influence student achievement.[37] If considering the inclusion of multimedia projects in your classroom, consider the following:

- Be sure to provide options so that all students have access to appropriate technology and software, not just those with equipment at home.
- Provide a nontechnology alternative for completing the project so that the mechanism for demonstrating understanding doesn't overshadow the actual concept learned.

Questioning

Purpose: to stimulate thinking by engaging the learner

Predominant Learning Mode: auditory

Group Size: individual, or small, medium, and large

Questioning is a primary means teachers use to engage learners. Asking questions can be an effective and efficient means of stimulating students to think about the topic. Here are some suggestions on questioning:

- Use both convergent and divergent questions.
- Provide time for students to think about the answer.
- Use questions that require thinking at different levels; that is, recall, comprehension, application, analysis, synthesis, and evaluation.

Reading

Purpose: to present information that is uniform and consistent

Predominant Learning Mode: visual

Group Size: individual

Reading is central to effective instruction. Though reading should be used in science classes, it should not be the exclusive learning method. We also encourage reading of materials other than the textbook. Some guidelines follow:

- Use reading materials that are appropriate to the students' abilities and your program objectives.
- Assign a variety of readings (e.g., textbook, science books, popular magazines, and articles or tracts of historical significance).

Simulations

Purpose: to increase students' abilities to apply concepts, analyze situations, solve problems, and understand different points of view

Predominant Learning Modes: visual, auditory

Group Size: small to medium—5 to 15 students

Simulations provide teachers with a means of presenting situations, concepts, and issues in a condensed and simplified form. Simulations are especially useful for involving students in science-related social issues. Use of simulations can be enhanced by doing the following:

- Select a problem or issue of interest to the students.
- Include key issues and concepts in a realistic way.
- Make procedures clear, including expected behaviors, roles to be played, and time limits.
- Use lifelike materials and situations.
- Conclude the simulation with a discussion of different perceptions of the issue, how the students felt about the issue, how the conflict was resolved, and what actions might be taken in the future.

Computer-Based Learning

Purpose: to provide course content and interactive instruction in a variety of forms using the computer.

Predominant Learning Mode: visual, kinesthetic

Group size: individual, small group, whole class

Drill and practice, a repetitive approach emphasizing rote memory, was an early form of computer-based learning. Through enhanced motivation and ample practice afforded by drill-and-practice programs, learners improve their abilities to solve the type of problems presented. Software design has now gone well beyond the drill-and-practice stage; this form of computer-based learning is rarely emphasized today.

Programming advances and the use of the Internet have greatly changed the face of computer-based learning options for the science classroom. Simulations provide a computer model of the attributes, concepts, and relationships in the real world. In simulations, the student plays an active role in manipulating various factors in the computer simulation to better understand real-world phenomena. Through the variation of various factors, the computer generates creative, perhaps even