WELCOME TO

MINDS ON *SCIENCE*

O N L I N E

INQUIRY	CONTRUCTIVISM	LEARNING

A Web Course on the Art of Teaching Science
by Jack Hassard, Georgia State University

Department MSIT
Georgia State University
Atlanta, Georgia 30303 USA
404/651-2518
Website

Chapter 1

MINDS ON SCIENCE:

A Reconnaissance

"The most important discovery made by scientists was science itself," said Jacob Bronowski, a mathematician, philosopher of science, and teacher. What about science teaching? Is there a comparable discovery made by science educators about science teaching? Perhaps the discovery approach to learning itself is one candidate? Or perhaps the discovery that students don't learn science through direct instruction, rather they construct their own knowledge from formal and informal experiences on their own. Or perhaps that all students are cabable of learning.

There are many candidates for important "discoveries" that have been made by science educators. If you are interested in finding out about the world of science teaching, and fascinating discoveries made by science teachers and researchers about learning, curriculum, instruction, then *Minds on Science* is for you.

We'll start our exploration of science teaching with a reconnaissance of the field. Just as a scout goes out ahead and looks around to get a view of the scene, so it is with this chapter. You'll look ahead by examining and comparing some of your ideas about science teaching with those of other science teachers. Before you know it, you'll be teaching and participating in science lessons prepared by and taught to your peers. Then you'll investigate some conceptions about the nature and philosophy of science, and relate this to approaches to science science teaching such as inquiry and cooperative learning.

We'll then introduce you to some students via brief vynettes designed to capture the intensity, personal dimensions, and wholistic character of the students you'll teach. Finally the chapter will close with some insights and wisdom about teaching by hearing from a high school teacher who has been involved with secondary school students for over twenty years.

PREVIEW QUESTIONS

- What are your current views about science teaching? How do these compare with the views of professional science teachers?

- What are some major conceptual ideas about science teaching?
- Why do you want to be a science teacher?
- What do science teachers like most about teaching?
- What are some of the important characteristics of science?
- Is inquiry teaching a valid method in secondary science classroom? Are there other valid approaches? What fosters inquiry?
- Do scientists and students represent two cultures? If so, how can these cultures be bridged?
- Who are the students we teach? What are they like?
- What characterizes an effective science teacher?

Chapter 1

1.1 Introduction and Goals

"The most important discovery made by scientists was science itself," said Jacob Bronowski, a mathematician, philosopher of science, and teacher. What about science teaching? Is there a comparable discovery made by science educators about science teaching? Perhaps the discovery approach to learning itself is one candidate? Or perhaps the discovery that students don't learn science through direct instruction, rather they construct their own knowledge from formal and informal experiences on their own. Or perhaps that all students are cabable of learning.

There are many candidates for important "discoveries" that have been made by science educators. If you are interested in finding out about the world of science teaching, and fascinating discoveries made by science teachers and researchers about learning, curriculum, instruction, then this online book is for you.

We'll start our exploration of science teaching with a reconnaissance of the field. Just as a scout goes out ahead and looks around to get a view of the scene, so it is with this chapter. You'll look ahead by examining and comparing some of your ideas about science teaching with those of other science teachers. Before you know it, you'll be teaching and participating in science lessons prepared by and taught to your peers. Then you'll investigate some conceptions about the nature and philosophy of science, and relate this to approaches to science science teaching such as inquiry and cooperative learning.

We'll then introduce you to some students via brief vynettes designed to capture the intensity, personal dimensions, and wholistic character of the students you'll teach. Finally the chapter will close with some insights and wisdom about teaching by hearing from a high school teacher who has been involved with secondary school students for over twenty years.

PREVIEW QUESTIONS

Scan these questions to get a feel for the content of Chapter 1. What questions pique your curiosity?

• What are your current views about science teaching? How do these compare with the views of professional science teachers?

• What are some major conceptual ideas about science teaching?

• Why do you want to be a science teacher?

• What do science teachers like most about teaching?

- What are some of the important characteristics of science?
- Is inquiry teaching a valid method in secondary science classroom? Are there other valid approaches? What fosters inquiry?
- Do scientists and students represent two cultures? If so, how can these cultures be bridged?
- Who are the students we teach? What are they like?
- What characterizes an effective science teacher?

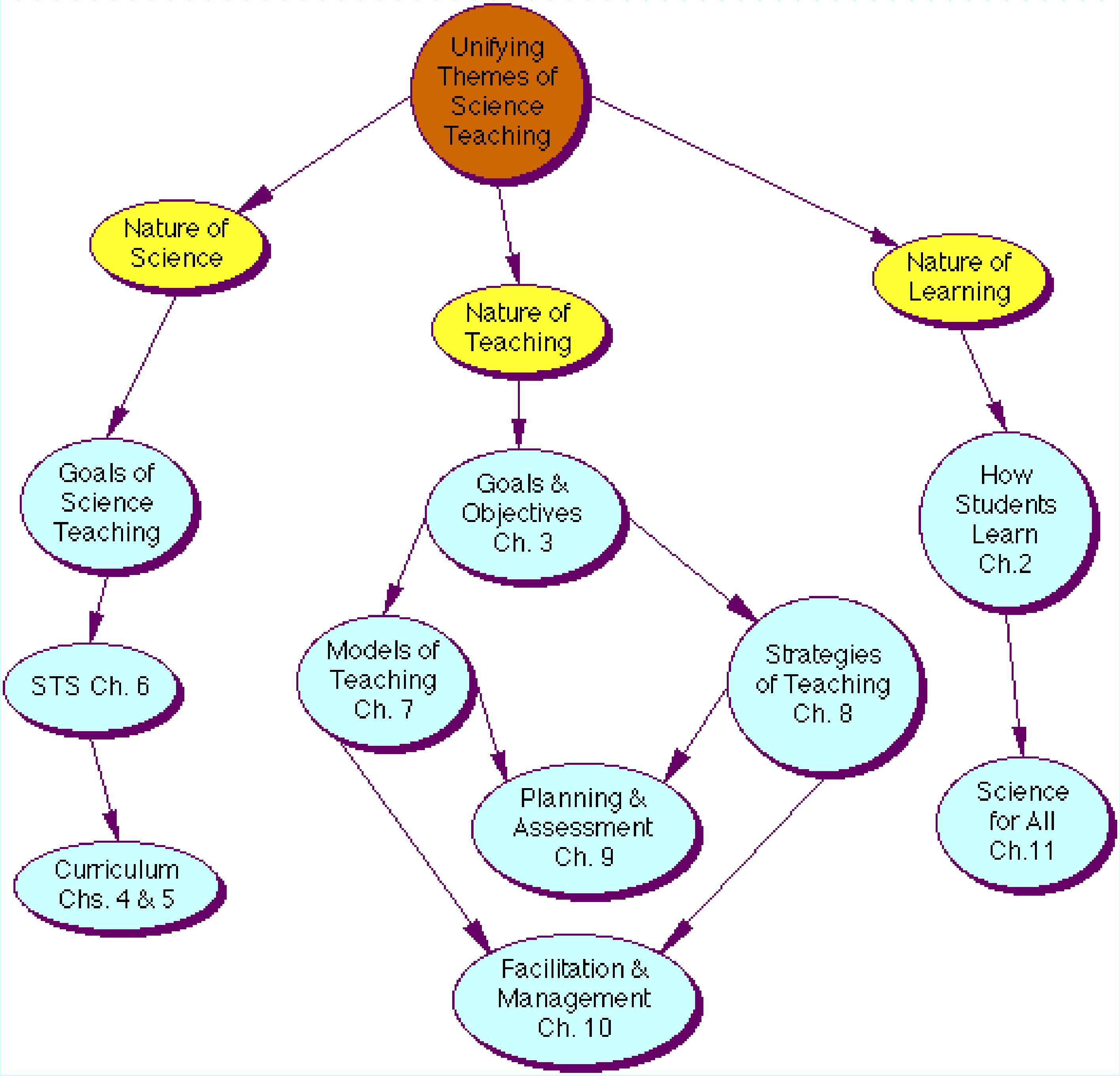
Chapter 1

1.2. Unifying Themes

What knowledge do you need to become a science teacher? To help you in this quest the content in the book has been organized around a set of unifying themes of science teaching, that taken as a whole, consititute a partial answer to the question: What does a person need to know to be a science teacher? Some science educators refer to unifying themes as conceptual themes. A conceptual theme is a big idea---a unifying notion---an organizational structure. The conceptual themes that been have chosen are well documented in the literature, they make sense to the practicing science teacher.

The themes are clustered into three organizers: the nature of science, the nature of teaching, and nature of learning and the learner (Figure 1.1).

Figure 1.1: The Themes of Science Teaching



The conceptual themes should be recognizable to you, and furthermore, you come to this course with knowledge and ideas about these conceptual themes. I suggest that the place to begin your study of science teaching is to evaluate your present views about teaching, learning, students and the curriculum---in short, what do you bring to this course in terms of knowledge, attitudes and appreciatioins about science science teaching.

1.3. SCIENCE TEACHING: YOUR CAREER CHOICE

For a variety of reasons, you've chosen to be a secondary science teacher. In studies to find out why people choose a career in science teaching, interest in the subject-matter field is rated as the most important. Is this true for you? Other reasons why people choose a career in science teaching include such factors as:

• they feel their abilities are well suited to teaching;

• they like the opportunities to work with young people; and

• teaching contributes to the betterment of society

You may also have a made a choice between middle school/junior high and high school level teaching. Perhaps you are interested in working with early adolescent students in either a middle school or a junior high school. Or, you've decided that you want to work with older students, and have geared your preparation to high school science teaching. In either case, being a science teacher will require you to blend knowledge of science, pedagogy and how students learn. How can this be done so that students learn and develop an appreciation for science, and you perceive science as a rewarding career? What will this entail?

As you begin your study of science teaching, keep in mind that these conceptual themes will be helpful organizational ideas for you, but nonetheless, you should also acknowledge that having a theoretical base for these notions will not insure your success in the classroom. Teaching requires an integration of theory and practice. So you will find in this book a number of practical, laboratory oriented activities designed to help you translate some of the theoretical ideas into practice. There is a good chance that the course you are taking will also involve some practical work in a middle school/junior high or a high school. These opportunities during your teacher preparation experience are important as you develop your own professional outlook on science teaching. To gain more insight into your career choice, read what some practicing science teachers have to say about the rewards of science teaching.

1.4. Wisdom of Practice

In preparation for *Minds on Science*, I interviewed a number of practicing middle and high school science teachers because I wanted to include their ideas---their wisdom-of-practice, if you will--as we explored science teaching. I wanted these teachers to report to you how they deal with the main concepts and ideas of science teaching. In this chapter I will introduce you to these teachers---all of whom are real practicing science teachers. The teachers are

Ginny Almeder, a biology teacher from Georgia

Bo Miller, a biology teacher from Texas

Jerry Pelletier, a junior high science teacher from California.

John Ricciardi, a physics and astronomy teacher from Nevada

Dale Rosene, a middle school science and computer teacher from Michigan

Mary Wilde, a middle school science teacher from Georgia.

In subsequent chapters, these wisdom-of-practice interviews will be found in the *Science Teacher Gazette* under the section entitled "Science Teachers Talk." The comments made by the teachers are brief, but candid, and are here to give you some insights into teaching from a practitioners point of view.

Many teachers report that science teaching can be a very rewarding career. What do science teachers like most about teaching? Surely this will give us some insight into the profession of science teaching, and help you formulate your own goals and strategies for making your choice of science teaching a successful and positive one.

Science Teachers Talk

MOS: "What do you like most about teaching?"

John Ricciardi: What I like most about science is that I can be myself, which is being part of a body of teenagers. Their spirit, ambience and energy can become the self that is mre and who I am becomes naturally part of them. For me, teaching science is becoming myself by becoming one with all that "sciencing" is in my students.

Ginny Almeder: Science is my way of questioning the universe, a pursuit we appear compelled to follow by our human nature. Teaching high school provides me with an opportunity to share my love of science with young people. Students are generally enthusiastic and open-minded about their world. It is a good time to introduce them to the joys of science. I appreciate having the opportunity to help young people realize their potential especially in the area of science. It is gratifying to observe students improving their skills, becoming more questioning, and developing a healthy self concept.

Jerry Pelletier: I am fascinated by science. It encompasses a myriad of subjects and experiences and is an every changing and developing field. Some ideas have remained unchanged for hundreds of years while others have changed many times through the centuries. I find that my excitement for the subject of science can easily be transmitted to the students. I enjoy observing students interacting while trying to understand and solve scientific concepts. Science lends itself to the inductive method of teaching. Students are constantly questioning themselves and their observations. In essence science is fun for students as well as myself.

Mary Wilde: What I like most about teaching science are the variety of ways and techniques one can use to teach a particular concept. You can prevent yourself from becoming "burned out" because there are always new demonstrations, activities and experiments to incorporate in your curriculum that can explain old concepts. It is very exciting to be part of the new discoveries, new theories, and new conceptual ideas that take place in the scientific world. What is even more "thrilling" is the sharing of these new theories and discoveries with our young people. The teaching of new scientific principles or old scientific principles in new ways, stimulates a curiosity and creative desire within the student. Thus, for me, science is a very successful tool to help the student develop creative skills, thought process skills, and problem solving skills while learning factual content and conceptual theories that explain how this world "ticks." Science is the "why" and "how," and isn't that what everyone wants to know?

These teachers believe that science can be fun for students, that they enjoy interacting with students, that it provides an opportunity to introduce students to the joys of scence. Let's begin our study of science teaching by visiting a high school classroom where science content, pedagogy, students and teachers meet---the science-teaching interface.

1.5. ON THE NATURE OF SCIENCE TEACHING

"What are these?"

"Where did they come from?"

"How old are they?"

"Where did you get them?"

"Are they all the same?"

"What are they used for?"

Questions asked by the the teacher? No! These are questions asked by students in a ninth grade teacher's physical science class at Southside High School in the Atlanta Public Schools. The teacher, one of thousands of new science teachers in the United States, began the first day of school with a very brief activity. He gave each student a fossil crinoid stem, placing one in each students' hand, and telling them they could not look at the object until he said they could. The students were instructed to explore the object without looking, and to write down observations of the object, and to make a small drawing of it as well. Still without looking, the teacher asked the students to call out some of the observations (hard, breaks easily, gritty, grainy, cylindrical, about 2 cm in diameter, grooves along the side, a hole in the center). Then the teacher provided each student will play doe, and asked each student to make a replica of the crinoid (still without looking).

Finally the teacher asked the students to guess what they thought it was (rock, bone, dog biscuit, pottery) and then to look at the object. Without telling the students very much, he asked the students if they had any questions about the object. Their curiosity led to several questions as shown above, and then to a discussion of these 400 million year old fossils from Silurian rock beds of North Georgia. The next day, the teacher divided his students into groups and assigned a different task to each group. Later in the lesson a student from each group reported their results to the class.

The teacher began his class by actively engaging his students with natural materials, having them work in groups, and encouraging them to use their observation skills and creative abilities to solve problems and participate in interesting tasks.

However, this lesson and the way hiw students feel about science is in stark contrast with what is known about science teaching in the United States and other countries around the world. In general, students see science class as dull, no fun, and a place where they do not wish to be. Students do not like the typical or traditional science classroom. Although studies about science teaching reveal that there are many factors that seem to make science teaching more interesting and result in high achievement (these will be discussed in the next chapter), one factor that seems to be very important is engagement. What this refers to is the active involvement of students in the learning process. Students were engaged in handling, operating or practicing on or with physical objects as part of the lesson.

Perhaps the one metaphor about science teaching that has become a password for "good science teaching" is that science teaching should be *hands-on*. In recent years, however, this metaphor has been enriched and expanded with the use of the phrase "minds on science". These metaphors seems like a simple and logical step in the teaching process, but the evidence from science education research studies is quite the contrary.:

1. The predominant method of teaching in science is recitation (discussion), with the teacher in control. We will call this the delivery mode of teaching, contrasting it from the engagement mode described above.

2. The secondary science curriculum is usually organized with the textbook at the core, and the main goal of the teacher is to cover (or deliver) all the content in the book.

3. The science demonstration ranks second as the most frequently observed science "activity." Two out of five classes perform demonstrations once a week. And, please note, that in most demonstration, students are typically passive observers.

4. Student reports and projects are used about only once a month or more in half the classes.

5. Because of the anxiety to cover the text, the use of inquiry techniques is discouraged, and is rarely observed. Instead activities are generally workbook

exercises in following directions and verifying information given by the textbook or teacher.

A great controversy exists in the field of science education surrounding the issue of engagement versus delivery. Which model is more effective? Which is more efficient? How do students react to these models? Which model helps most students understand science? Which model do you prefer?

Let's explore the differences between the delivery and engagement models of science teaching in order to develop a better notion of the nature of science teaching. To do this you will plan and teach two lessons using a microteaching format. Microteaching is a scaled down version of teaching in which you present a short lesson (usually 5 - 15 minutes in length) to small group (5-7) of peers or secondary students, video tape the episode, and evaluate the lesson, and then make recommendations for possible changes. You will find more details on microteaching in Chapter 9.

1.6. THE NATURE OF SCIENCE

You are entering the science teaching profession at a time when many science educators, scientists, and the general public are calling for new directions in science education. Because of the growing impact of science and technology on societal and individual affairs, people from many sectors of society have expressed the desire that science education be reappraised and that new direction be charted. Paul DeHart Hurd suggests that the science curriculum of the future be based on interrelationships between human beings, natural phenomena, advancements in science and technology, and the quality of life. He suggests that science teachers examine closely the nature of science, especially the multidimensional changes in science, technology and society. He and other educators criticize the content of the present science curricula as being remote from human needs and social benefits, reflecting the concern that science is alien and separate from individual and public interests. To make science understandable and useful to people, it is essential that the nature of science be communicated to students in the science curriculum.

What is Science?

One scientist who had an effect not only on the scientific community, but the nonscience community as well was Richard Feynman, a theoretical physicist and popularizer of science. In his book *"Surely Your're Joking, Mr. Feynman,"* he said, "Before I was born, my father told my mother, 'If it's a boy, he's going to be a scientist,'" Not only did he become a scientist, he also was a winner of the Nobel Prize. Feynman saw science as an attempt to understand the world. To him understanding the world was analogous to understanding the rules of a game, like chess:

> "We can imagine that this complicated array of moving things which constitutes "the world" is something like a great chess game being played by the gods, and we are observers of the game. We do not know what the rules of the game are; all we are allowed to do is to *watch* the playing. Of course, if we watch long enough, we may eventually catch on to a few of the rules. *The rules of the game* are what we mean by *fundamental physics.* Even if we know every rule, however... what we really can explain in terms of those rules is very limited, because almost all situations are so enormously complicated that we cannot follow the plays of the game using the rules, much less tell what is going to happen next. We must, therefore, limit ourselves to the more basic question of the rules of the game. If we know the rules, we consider that we "understand" the world" (Feynman, 1963).

Another scientist, a chemist named Michael Polanyi explored the nature of science and said that there was a "republic of science," a community of independent men and women freely cooperating, collaborating and exchanging ideas and information. This community cuts across national boarders and brought scientists from over the globe together as a cooperative global community. Polanyi also claimed that to be a scientist, one had to be inducted into the profession by working with a master as an apprentice. Interestingly, he also believed that the practice of science was not a science, but rather an art to passed from one scientist to another.

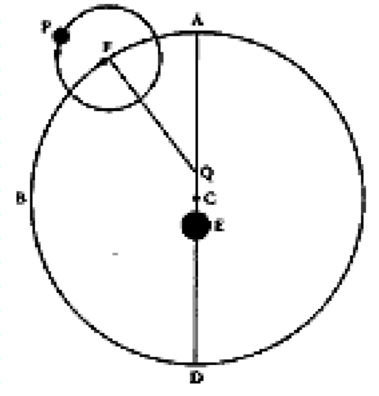
If you look up the word science in a dictionary, the usual definition is "knowledge, especially of facts or principles, gained by systematic study; a particular branch of knowledge dealing with a body of facts or truths systematically arranged." Yet prominent scientists, like Carl Sagan define science as a way of thinking much more than it is a body of knowledge. Sagan says this about science:

> "Its goal is to find out how the world works, to seek what regularities there may be, to penetrate the connections of things---from sub-nuclear particles which may be the constituents of all matter, to living organisms, the human social community, and thence to the cosmos as a whole. Our perceptions may be distorted by training and prejudice or merely because of the limitations of our sense organs which of course perceive directly but a small fraction of phenomena of the world... Science is based on experiment, on a willingness to challenge old dogma, on an openness to see the universe as it really is. Accordingly science sometimes requires courage---at the very least the courage to question the conventional wisdom".

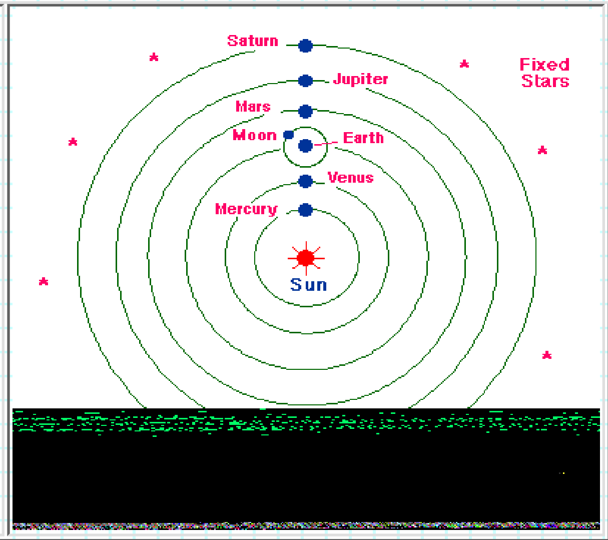
Exploring the nature of science a little further, and relating it to the views of Feynman, Polyani and Sagan, we might consider several relationships, as described below.

Science and Courage.

One human quality that is important in science is courage. If we put this in terms of one's willingness, as Sagan said, to question conventional wisdom, then we are a led to an important notion: questioning all things is a fundamental value underlying thinking in science. For example, Nicholas Copernicus, the 16th century Polish scientist, questioned the conventional wisdom of the Ptolemaic, earth-centered universe. His questioning of an old idea led to a new one---that the sun was the center of the solar system and the planets revolved around the sun rather than the earth. About a hundred years after the publication of Copernicus's book, Galileo Galelei narrowly escaped the rack of the Holy Inquisition by recanting his support for the Copernican concept of the Universe.



Ptolemaic system showing the epicycle movement of a planet with the Earth in the center of the systme.



Questioning well established ideas, or proposing a radically different hypothesis to explain data is a courageous act. Quite often people who propose such ideas are shunned, considered crazy, or rejected by the "establishment." For example, in 1920, Alfred Wegener, a German meteorologist, proposed that the continents were not stationary masses but moving platforms of rock that had drifted apart over millions of years of geologic time. At the time his idea was considered farfetched and crazy. Physicists and geologist pointed out that there were no forces within Earth to move billions of kilograms of rock. Fifty years later, most geologists supported the theory of plate tectonics, that the earth's crust is composed of large plates which move about colliding, spreading apart and sliding past each other.

A more recent example of courage is the case involving Dr. Frances Oldham Kelsey. In a book entitled, *Women of Courage*, Frances Kelsey is referred to as "the doctor who said no." After earning a Ph.D. in pharmacology (an infant field of science at the time she earned her degree), and then a medical degree from the University of Chicago, she moved with her husband and two children to Washington, and took a job with the Food and Drug Administration (FDA) in Washington. Her job was to evaluate applications for licences to market new drugs. In the Fall of 1960, shortly after she arrived at the FDA, the William S. Merrell Company applied for a licence to market a new drug called Kevadon. Kevadon was a sleeping pill. It had been used all over the world, was very effective in relieving pregnant women from morning sickness, and was very profitable. Truman describes how Frances Kelsey showed great courage as a scientist in the case of Kevadon:

> 'While Merrell's application was being reviewed by Kelsey at the FDA, they were distributing two thousand kilograms of the drug. At the time this was a legal practice as long as the drug company labeled the drug "experimental." Merrell, in their advertising and marketing materials, informed their salespeople that they had firmly established the safety, dosage and usefulness of the drug by both foreign and U.S. laboratory clinical studies. They had not.
>
> At the FDA, Merrell's application was being reviewed. Dr. Kelsey and her research team were not satisfied with the information Merrell provided as part of their application. For example, the drug when administered to animals

showed no sign of toxicity but did not make the animals sleepy. The drug was being distributed to humans as a sleeping pill. Two days before the 60 day approval period was up, Dr. Kelsey told the Merrell Company that their application was not approved and would have to submit further information.

This initial rejection (November 10, 1960) of Merrell's application to distribute the drug was followed by a series of episodes between Dr. Kelsey and the Merrell Company. There were attempts by the Merrell Company to go over Kelsey's head and in so doing try to embarrass her in front of her superiors. This did not work. Merrell even supplied research reports supposedly documenting the safety of the drug. Upon investigation it was discovered that the researcher's name that appeared on the report did not even write it. And Merrell threatened Kelsey with a law suit saying that one of her letters to them was libelous. Through all this Kelsey stood firm and boldly held her ground. It culminated with the banning of the drug in December 1961 when thalidimide had been traced to an outbreak of deformities in new born babies by the thousands in Europe. Then in 1963, the American public was stunned when they read stories and saw the horrible pictures in their newspapers that one gallant woman doctor had stood between them and a repetition of this disaster in the United States. On August 7, 1963 President Kennedy present Dr. Kelsey the Distinguished Federal Civilian Service Medal. Kennedy applauded Dr. Kelsey's work saying she had defended the hopes that all of us have for our children. The courageous behavior of Frances Kelsey also lead to an increase in the FDA's staff and a change in the laws regulating the distribution and sale of drugs to humans" (Truman, 1978)

Science, Problem Solving and the Human Mind.

Thinking in science is often associated with creativity and problem solving. These are important aspects of the nature of science, and should be an essential goal of the science curriculum. In his book How Creative Are You, Eugene Raudsepp identifies a long list of qualities of the human that are characteristic of people who think creatively: innovative, risk-taker, mold-breaker, willing to ask questions, fearless adventurer, unpredictable, persistent, highly motivated, ability to think in images, to toy with ideas, tolerance of ambiguity, anticipates productive periods. The social implication of creative thinking is that we live in an ever changing world, impacted no less than by science and technological innovations. Many popularizers of science and creative thinking believe that all people are creative and are able to deal with change. Science courses have traditionally focused only on helping students learn scientific facts and concepts, and then stopped. Rarely are students encouraged to tackle real problems, thereby putting to use the facts and concepts they have learned. But as educators like Hurd warn, the future science curriculum should present problems to solve that are desirable to students, that is ones in which students have a stake in the solution, such as nutrition, chemical safety, space exploration, human ecosystems, drugs, population growth, ecocrises, quality of life, and others.

To solve problems, to deal with situations creatively requires the use of imagination.

Historians of scientific discovery often point out that imagery and imagination have played important roles in intellectual discoveries and breakthroughs. This fact is nicely conveyed in the title of a book by June Goodfield, An Imagined World, A Story of Scientific Discovery. The book describes the drama of scientific discovery, and sheds light on role of creativity and imagination in this endeavor. The world of imagery is safe harbor for thoughts and images, and for the mind's participation in problem solving. For example, Einstein's famous thought experiments and his images led him to many of his concepts of space and time. Indeed, he used imagery to experience what he thought it would be like to ride on a beam of light.

Jacob Bronowski believed that imagination was one of the important qualities of the mind. In *A Sense of the Future*, he said this about imagination, the human mind and science:

> "All great scientists have used their imagination freely, and let it ride them to outrageous conclusions without crying "Halt." Albert Einstein fiddled with imaginary experiments from boyhood, and was wonderfully ignorant of the facts that they were supposed to bear on. When he wrote the first of his beautiful papers on the random movement of atoms, he did not know that the Brownian motion which it predicted could be seen in any laboratory. He was sixteen when he invented the paradox that he resolved ten years later, in 1905, in the theory of relativity, and it bulked much larger in his mind than the experiment of Albert Michelson and Edward Morley which had upset every other physicist since 1881. All his life Einstein loved to make up teasing puzzles like Galileo's, about falling lifts and the detection of gravity; and they carry the nub of the problems of general relativity on which he was working" (Bronowski, 1977).

Science and Human Values.

When society acknowledges the importance of qualities of the mind such as independence in thinking, originality, freedom to think, or dissidence it is elevating them to social values. And as social values they are given special protection through laws governing society's behavior. Since science is an activity of men and women, certain values must guide their work. Bronowski claims, that because of this, science is not value free, and that the work of science is based on a search for truth. In his book, A Sense of the Future, Bronowski discusses the human values that are indeed the values that guide science:

> "If truth is to be found, and if it is to be verified in action, what other conditions are necessary, and what other values grow of themselves from this?First, of course, comes independence, in observation and thence in thought. The mark of independence is originality, and one of its expressions is dissent. Dissent in turn is the mark of freedom. That is, originality and independence are private needs of the truthful man, and dissent and freedom are public means to protect them. This is why society ought to offer the safeguard of free thought, free speech, free inquiry, and tolerance; for these are needs which follow logically when men are committed to explore the truth. They have, of course, never been granted, and none of the values which I have advanced have been prized in a dogmatic society" (Bronowski, 1977).

Sometimes the values that motivate scientists result in behavior that wouldn't hold up to Bronowski's ideas. For instance, in the 1950's the race was on to discover the structure of the DNA molecule. Horace Freeland Judson in his book, The Eighth Day of Creation said, "DNA, you know, is Midas' gold. Everyone who touches it goes mad." In this case we ask: What part does ambition, achievement, and success play in the practice of science? How does a scientist's gender effect relationships? Are women scientists left behind their male counterparts? Is it possible for a scientist to literally "go mad" in the pursuit of what be an astonishing discovery? Are scientists sometimes motivated by blind ambition? The story that follows will enable you to think about these questions.

The setting for this tale is in England about 100 years after Charles Darwin and Alfred Russell Wallace co-discovered a theory of evolution.

In the 1950s a race was on to be the first to discover and unlock the secret that would reveal the basis for life. That secret was locked away in the structure of the DNA molecule---the substance of life. Two persons emerge at first, in this story: James B. Watson, a 24 year old American born scientist fresh out of graduate school with a new Ph.D., and Francis Crick, a 38 year old graduate student at Cambridge University, England, still working on his Ph.D.

Watson and Crick teamed up and decided to go all out to discover the structure of the DNA. Their reward, if they could make the discovery before the famous American chemist Linus Pauling, would be the Nobel Prize.

The process of discovering the structure of the DNA molecule was multifaceted. A driving force in the discovery was their motivation to discover and report their findings before Pauling did. Pauling, 6,000 miles away in Pasadena, California, was working diligently on the DNA problem as well. Watson and Crick, but especially Watson, were worried that news would break from Pasadena. Watson writes:

> "No further news emerged from Pasadena before Christmas. Our spirits slowly went up, for if Pauling had found a really exciting answer, the secret could not be kept for long."

The process also involved a collaboration with Maurice Wilkins and Rosalind Franklin, both of whom were researchers at King's College, England. Wilkins was trained in physics but became interested in the structure of the DNA and had been pursuing its structure for years.

At the time that Watson and Crick entered the DNA search, Wilkins was the only researcher in England giving serious attention to the DNA problem. However, there was Rosalind Franklin. She was trained in the study of crystals and how they were aranged. She used X-rays to study the structure of crystals and she was probably one of the most competent researchers in this field at the time.

Wilkins thought of her as his assistant. Rosalind Franklin thought of herself not as Wilkins assistant, but as a bonafide researcher pursuing the DNA structure as her main line of research. She was in fact hired to work in the same laboratory, but as the head of a research group, a position equal to that of Wilkins.

Vivian Gornick writes that the relationship that Watson and Crick had "was its own double helix: all attracting opposites and catalytic joinings. These two ate, drank, slept, and breathed DNA." Rosalind Franklin did not have this kind of relationship with anyone. "If she had someone to talk to, chances are she would have gotten to DNA first, it was all there in her notes and photographs, she just didn't know what to make of what she had."

Gornick, in the introduction of her book, Women in Science, raises questions about the work of women in science: What was it like to be a woman scientist? What if a woman working in science feels it is not so accesible to her? What if a woman in science feels she must prove herself many times more often than a man does; that her work is more often challenged and less often supported?

Was Rosalind Franklin, because she was a woman not allowed in on the discussions among Watson, Crick and Wilkons. In James Watson's book, The Double Helix, some insight on this assertiion is revealed:

> "Clearly Rosy had to go or be put in her place. The former was obvriously preferable because, given belligerent moods, it would be difficult for Maurice (Wilkins) to maintain a dominant position that would allow him to think unhindered about DNA...Unfortunately, Maurice could see any decent way to give Rosy the boot. To which, she had been give to think that she had a position for several years. Also, there was no denying she had a good brain. If she could only keep her emotions under control, there would be a good chance she could really help him...The real problem, then was Rosy. The thought could not be avoided that the best home for a feminist was in another person's lab" (Gornick, 1990)

Anne Sayre, author of Rosalind Franklin and DNA finds Watson's description of Rosalind quite different than her own view. In her biography of Franklin, Sayre questions the accuracy of some of Watson's facts: She says:

> "...a question arose concerning the accuracy of some of Watson's facts, simply because he presented in *The Double Helix* a character named 'Rosy' who represented, but did not really coincide, with a woman named Rosalind Franklin...The technique used to change Rosalind Franlin into 'Rosy' was subtel, but really not unfamiliar, part ofit, at the simplest level, was the device of the nickname itself, one that was never used by any friend of Rosalind's, and certainly not to her face...For we are presented with a picture of a deplorable situation. The progress of science is being impeded, and by what? Why, by a

> woman, to begin with, one labeled as subordinate, meant---or even destined---to occurpy that inferior position in which presumably all women belong, even those with good brains...But perhaps the progress of science is also being impeded somewhat by a man as well, one too inhibited by decency to be properly ruthless with female upstarts, and so to get on with the job" (Sayre, 1975)

Rosalind Franklin's work on the DNA problem was brilliant. Had she lived until 1962 (she died of cancer in 1958 at the age of 37), she no doubt would have shared the Nobel Prize awarded to Watson, Crick, and Wilkins.

Since the time of these events, the nature of science has been influenced by the increased participation of women in the field of science. However, the participation of women and minorities in science has excaserbated by the nature of school science, and the negative effect school science has had in attracting women to careers in science. In Chapter 11 we will explore this in more depth.

Since the 1970s there has been a movement in the field of science and science education that has supported an approach to science teaching based on women's studies, methods and theories to attract women in to courses in science in middle school and high school, and encourage women to choose fields in mathematics, science and engineering.

Science and Democracy.

When science is examined as an enterprise that involves the values of independence, freedom, the right to dissent and tolerance, it is clear that as a social activity, science can not flourish in an authoritarian climate. Some philosophers of science such as Bronowski claim that science can not be practiced in authoritarian regimes. In a democratic environment old ideas can be challenged and rigorously criticized, albeit, with some difficulty because of the human desire to hold on to old ideas, especially by the original proposers. Yet it is the essence of scientific thinking to propose alternative ideas, and then to test these alternative ideas against existing concepts. As pointed out in the American Association for the Advancement of Science report, Science For All Americans, "indeed, challenges to new ideas are the legitimate business of science in building valid knowledge." The principles upon which democracy is built are the very concepts that describe the scientific enterprise. Earlier it was pointed out that Polanyi felt science was organized as a republic of science in which independent people freely cooperated to explore and solve problems about the natural world. The values of a democratic society are the values that undergird Palanyi's concept of a republic of science.

The Scientific Enterprise and Teaching.

The concepts that have been presented about the nature of science have implications for science teaching. There should be a consistency between discussions about the nature of science and the nature of teaching science. If we are trying to convey to students not only facts and information of science, but the process of science, then we are obliged to establish environments in classrooms that presume the same values that guide the practice of science. Questions that we can raise about our classrooms in this regard are as follows: To what extent are students given the opportunity to challenge ideas? Are activities planned in which there are alternative methods, answers, and solutions? Are students encouraged to identify and then try to solve problems relevent to themselves? Is it acceptable for students to disagree with ideas, and propose new ones? Do the problems that students work on have any consequence in their lives now?

Science is defined as much by what is done and how it is done as it is by the results of science. To understand science as a way of thinking and doing, as much as "bodies of knowledge," requires that science teaching emphasize the thought processes and activities of scientists. Thus we are led to explore one of the fundamental thought process in science, namely, *inquiry.*

1.7. SCIENCE TEACHING AND INQUIRY

Imagine science classrooms in which:

- The teacher pushes a steel needle through a balloon and the balloon does not burst. The teacher asks the students to find out why the balloon didn't burst.
- Students are dropping objects into jars containing liquids with different densities and recording the time it takes each object to reach the bottom of the jar. They are trying to find out about viscosity.
- Students are using probes connected to a microcomputer to measure the heart rates of students before and after doing five minutes of exercise. They are investigating the effect of exercise on pulse rate.
- Students are reading newspaper articles on the topic "toxic waste dumps" in order to form opinions about a proposed dump being established in their community.

In each case students are actively involved in measuring, recording data, and proposing alternative ideas in order to solve problems, find meaning, and acquire information. In these situations students were involved in the process of *inquiry*. The greatest challenge to those who advocate inquiry teaching is the threat to the traditional and dominant role of the teacher in secondary education. I am going to discuss inquiry teaching first because of its relationship to the essence of science, but also because of the philosophical implications siding with an inquiry approach implies. By taking a stand in favor of inquiry teaching, the teacher is saying, "I believe students are capable of learning how to learn; they have within their repotoire the abilities as well as the motivation to question, to find out about and seek knowledge; they are persons, and therefore learners in their own right, not incomplete adults." The philosophy of inquiry implies that the teacher views the learner as a thinking, acting, responsible person.

Characteristics of Inquiry

Inquiry is a term used in science teaching that refers to a way of questioning, seeking knowledge or information, or finding out about phenomena. Many science educators have advocated that science teaching should emphasize inquiry. Wayne Welch, a science educator at the University of Minnesota argues the techniques needed for effective science teaching are the same as those used for effective scientific investigation. Thus the methods used by scientists should be an integral part of the methods used in science classrooms. We might think of the method of scientific investigation as the inquiry process. Welch identifies five characteristics of the inquiry process as follows:

- *Observation*: Science begins with the observation of matter or phenomena. It is is the starting place for inquiry. However, as Welch points out, asking the right questions that will guide the observer is a crucial aspect of the process of observation.
- *Measurement:* Quantitative description of objects and phenomena is an accepted

practice of science, and desirable because of the value in science on precision and accurate description.

- *Experimentation*: Experiments are designed to test questions and ideas, and as such are the cornerstone of science. Experiments involve questions, observations and measurements.
- *Communication*: Communicating results to the scientific community and the public is an obligation of the scientist, and is an essential part of the inquiry process. The values of independent thinking and truthfulness in reporting the results of observations and measurements are essential in this regard. As pointed out earlier in the section on the nature of science, the "republic of science" is dependent on the communication of all its members. Generally is this done by articles published in journals, and discussions at professional meetings and seminars.
- *Mental Processes*: Welch describes several thinking processes that are integral to scientific inquiry: inductive reasoning, formulating hypotheses and theories, deductive reasoning, as well as analogy, extrapolation, synthesis and evaluation. The mental processes of scientific inquiry may also include other processes such as the use of imagination and intuition.

Inquiry teaching is a method of instruction, yet not the only method that secondary science teachers employ. However, because of the philosophical orientation of this book towards an inquiry approach to teaching, I will explore it first, but also highlight three other methods (direct/interactive teaching, cooperative learning, and conceptual change teaching) that contemporary science teachers use in their classrooms.

Inquiry in the Science Classroom.

Secondary science classrooms should involve students in a wide range of inquiry activities. The description of "scientific inquiry" is a general description of the inquiry model of teaching. The inquiry model of teaching presented in this book includes guided and unguided inductive inquiry, deductive inquiry and problem solving. Students engaged in a variety of inquiry activities will be able to apply the general model of inquiry to a wide range of problems. Thus the biology teacher who takes the students outside and asks them to determine where the greatest number of wild flowers grow in a field is engaging the students in guided inquiry. The students would be encouraged to make observations, and measurements of the flowers and the field, perhaps create a map of the field, and then draw conclusions based on these observations. In an earth science class, a teacher has been using inductive inquiry to help students learn about how rocks are formed, and now wants the students to devise their own projects and phenomena to study about rocks. Inductive inqiry is a teacher centered form of instruction.

On the other hand, unguided inductive inquiry is student centered inquiry, in that the student will select the phenomena and the method of investigation, not the teacher. However, this does not mean that the teacher is not involved. The teacher may gather the class together for a brainstorming session to discuss potential phenomena to explore and study, based on the class's work to date. Small teams of students are then organized. The teams discuss the list of topics and phenomena generated in the brainstorming session, and then proceed to devise a project of their own.

In both forms of inductive inquiry, students are engaged in learning about concepts and phenomena by using observations, measurements and data to develop conclusions. We might say the student is moving from specific cases to the general concept. In deductive inquiry the student starts with the big idea, conclusion, or general concept and moves to specific cases. In classroom situations, a physics teacher for instance may want the class to test the principle that light is refracted when it passes from one medium to another. The students perform a laboratory exercise in which they make observations of light as it is passed through water, glycerine, and glass. The lab is desinged to help students confirm the concept. Many of the laboratory activities that are embedded in secondary science textbooks are deductive inquiry exercises. Is deductive inquiry teacher centered or student centered? Why do you think so?

Learning how to solve problems is another form of inquiry teaching. Challenging problems such as these can be investigated by secondary students: How did life originate on the Earth? What will the consequences be if Earth's average temperature continues to rise? How can AIDS be prevented? What is the effect of diet and exercise on the circulatory system? What solid waste products are the most environmentally hazardous? What resources are most critically in short supply? Posing problems such as these brings real world problems into the science classroom and furthers students' appreciation for the process of inquiry. Teachers who use problem solving are providing a perspective for students in which they will propose solutions to problems and make recommendations toward what should be done to change, improve, correct, prevent or better the situation. Involving students in solving problems that are important to the culture and themselves is an important goal of science teaching. Paul DeHart Hurd comments that "a problem-oriented societal context for science courses provides the framework essential for the development of such intellectual skills as problem solving, decision making, and the synthesis of knowledge."

Environments That Foster Inquiry

The classroom environment has psychological, sociological, philosophical and physical dimensions affected by the curriculum, students, teachers, school, community and the nation. Yet in much of the research investigating classroom environments, the teacher's role is often seen as a powerful determinant of the classroom climate. In his book Teaching Science As Inquiry, Steven Rakow points out that behaviors and attitudes of the teacher play an essential role in inquiry teaching, and he identifies the following as characteristic of successful inquiry teachers:

1. They model scientific attitudes.
2. They are creative.
3. They are flexible.
4. They use effective questioning strategies.
5. They are concerned both with thinking skills and with science content.

Yet the overriding characteristic of the environments that foster inquiry is the attitude of the teacher toward the nature of students and the nature of science knowledge. Departing from the traditional role as primary givers of information, the science teacher that "takes-on" the inquiry philosophy is more of a facilitator of learning and manager of the learning environment. The student is placed in the center of the inquiry teacher's approach to teaching, thereby fostering the student's self-concept and development. These teachers bring to the classroom an assortment of approaches designed to meet the needs of the array of students that fill their classrooms. Although inquiry centralizes these teachers' philosophy, they look to other methods of teaching.

Inquiry and the National Science Education Standards.

The National Science Education Standards place science inquiry at the top of the list of standards. In this view, science inquiry goes beyond the teaching of science process skills (e.g. observing, classifying, inferring, etc.) and requires students to integrate process and science content to develop an understanding of science.

1.8. LIFE BEYOND INQUIRY

Just as there are more ways than one to skin a cat, there are many approaches to help students understand science, besides inquiry. There is more than one way to learn; there is more than one way to teach.

Students will come to your classroom with different learning styles, and more importantly you will develop a teaching style that should not only be congruent with contemporary research on teaching, but equally based on your personality, experience, values and goals. We will explore a spectrum of approaches in Chapters 8 and 9 to help you develop a repertoire of methods and strategies. Here very briefly are a few of these methods.

Direct/Interactive Teaching

Think for a moment about the roles and interactions among students and teachers in most secondary science classrooms. You probably can envision the teacher working directly with the whole class, perhaps presenting a brief lecture, and then engaging the students by asking questions. The students might also be observed doing seat work, sometimes on their own, at other times with a partner or a small group. Homework is assigned near the end of the class period, and students might get a head start on the assignment before class ends. Various models, sometimes refered to as direct/interactive instruction, have emerged over the past few years based on the relationship between observing teacher behavior and relating these behaviors to student learning. A large number of studies have supported a general pattern of key instructional behaviors as shown below.

Direct/Interactive Instructional Behaviors

Daily Review of Homework	Teachers review the key concepts and skills associated with homework; go over the homework; ask key questions to check for student understanding.
Development	Teachers focus on prerequisite skills and concepts; introduce new ideas, concepts using an interactive approach including examples, concrete materials, process explanations, questioning strategies; check student understanding by using a highly interactive process utilizing questions, and designing a controlled practice activity for individual or group participation; teacher also use a lot of repetition.
Guided Practice	Teachers provided specific time during the lesson for uninterrupted successful practice; teachers use a sustained pace with a lot of momentum; students know that their work will be checked by the end of the period; teacher circulates about the room, checking student work, and asking questions, as needed
Independent Practice	Teachers assigned on a regular basis a homework assignment that was not lengthy, and could be successfuly completed by the students

Special Reviews	Effective teachers conducted reviews once a week, preferably at the beginning of week. Focus was on the skills and concepts developed during the previous week; monthly reviews were conducted to review important skills and concepts.

Cooperative Learning

Cooperative learning is an approach to teaching in which groups of students work together to solve problems and complete learning assignments. Cooperative learning is a deliberate attempt to influence the culture of the classroom by encouraging cooperative actions among students. Cooperative learning is a strategy easily integrated with an inquiry approach to teaching. Furthermore, science teachers have typically had students work in at least pairs, if not larger small groups during lab. Cooperative learning strategies have been shown to be effective in enhancing problem solving and high level thinking goals. I will explore a variety of cooperative learning models in Chapter 6 that are easily put into practice.

Conceptual Change Teaching and Other Constructivist Approaches

A growing number of science education practitioners and researchers have developed an approach to science teaching that focuses on the problem of conceptual change. According to these science educators, students come to the science class with naive conceptions or misconceptions about science concepts and phenomena. Further these science educators suggest that concepts students hold are constructed; they are neither discovered or received directly from another person. In order to help students overcome their naive theories these educators suggest that teaching be organized into a series of stages of learning called the learning cycle. In most learning cycles, the first stage helps students detect and articulate their naive conceptions through exploratory activities, stage two focuses on comparing naive and "scientific views" in order to develp alternative conceptions, and the third stage provides experiences to encourage students to apply the concepts to new situations.

We will explore other approaches to science teaching. For now, however inquiry, direct instruction, cooperative learning, and conceptual-change teaching should get you started.

1.9. SCIENTISTS AND STUDENTS: TWO CULTURES?

One idea that prevailed during the curriculum reform movement of the 1960s and 1970s was that students were like little scientists: curious, imaginative, interested, and inventive. One idea that has emerged in recent years, however, is that students are quite different than scientists, and indeed come to science classes with naive theories and explanations for science concepts and phenomena. The assumption made by many science educators that scientists and students are very much alike is questionable, and perhaps has contributed to many instructional problems such as motivation, success on standardized tests, and overall performance in science.

Students in middle schools and high schools are not scientists, and we shouldn't be anxious to make them into scientists. They are adolescents, some of whom may choose to be scientists later in life, but the most will not. Let's look at some of the differences between scientists and adolescent students, and consider some of the implications of these differences.

Some Differences

For starters, most people will not become scientists or engineers. In a typical school with 1,000 students in the ninth grade, only 39 would earn baccalaureate degrees in science and engineering, five would earn master's degrees, and only two would complete the doctoral degree. A more important difference, however, appears when we examine scientist and student thinking.

Adolescents are limited in the extent to which they can reason in the abstract, whereas scientists deal with the abstractions as commonly as students deal with the concrete. As we will discuss in the next chapter, formal or abstract thinking alludes the majority of middle school and high school students. As some science education researchers point out, scientist work with concepts that have no directly observable circumstances (such as atoms, electric fields) and concepts that have no physical reality (potential energy). Students, on the other hand tend to consider only those concepts and ideas that result from everyday experience. As a result, many students will enter your classroom with misconceptions about scientific ideas, ideas that are firmly held, and very difficult to alter.

Another difference between students and scientists has to do with what we might call "explanations" of concepts and phenomena. According to Osborne and Freyberg, students are not too concerned if some of their "explanations" are self-contradictory, and do not seem to distinguish between scientific (testable, disprovable) and nonscientific explanations. Scientists, on the other hand, are "almost preoccupied with the business of coherence between theories." Osborne and Freyberg also point out that while scientists search for patterns in nature, for predictability, and the reduction of the unexpected, students are often interested in the opposite, thereby becoming interested in looking for the irregular, unpredictable and the surprise.

Students' interests, thinking processes and the way they construct meaning are also limited by their prior knowledge, experiences, cognitive level, use of language, their knowledge and appreciation of the experiences and ideas of others. Scientists' interests, Osborne and Freyberg argue, follow from their participation in the scientific community. Scientists also have available to them a wide range of technical supports enabling them to extend their knowledge base by means of computer networks and data bases, telescopes, electron microscopes, and a common language.

Students and scientists have very different attitudes about science. The more school science students are exposed to, the less is their interest in science. For example in one study, nearly two-thirds of 9 year olds, 40% of 13 year olds, and only 25% of 17 year olds reported science class to be fun. This pattern persists when students were asked whether science classes are fun, about science classes making them feel curious, successful and uncomfortable.

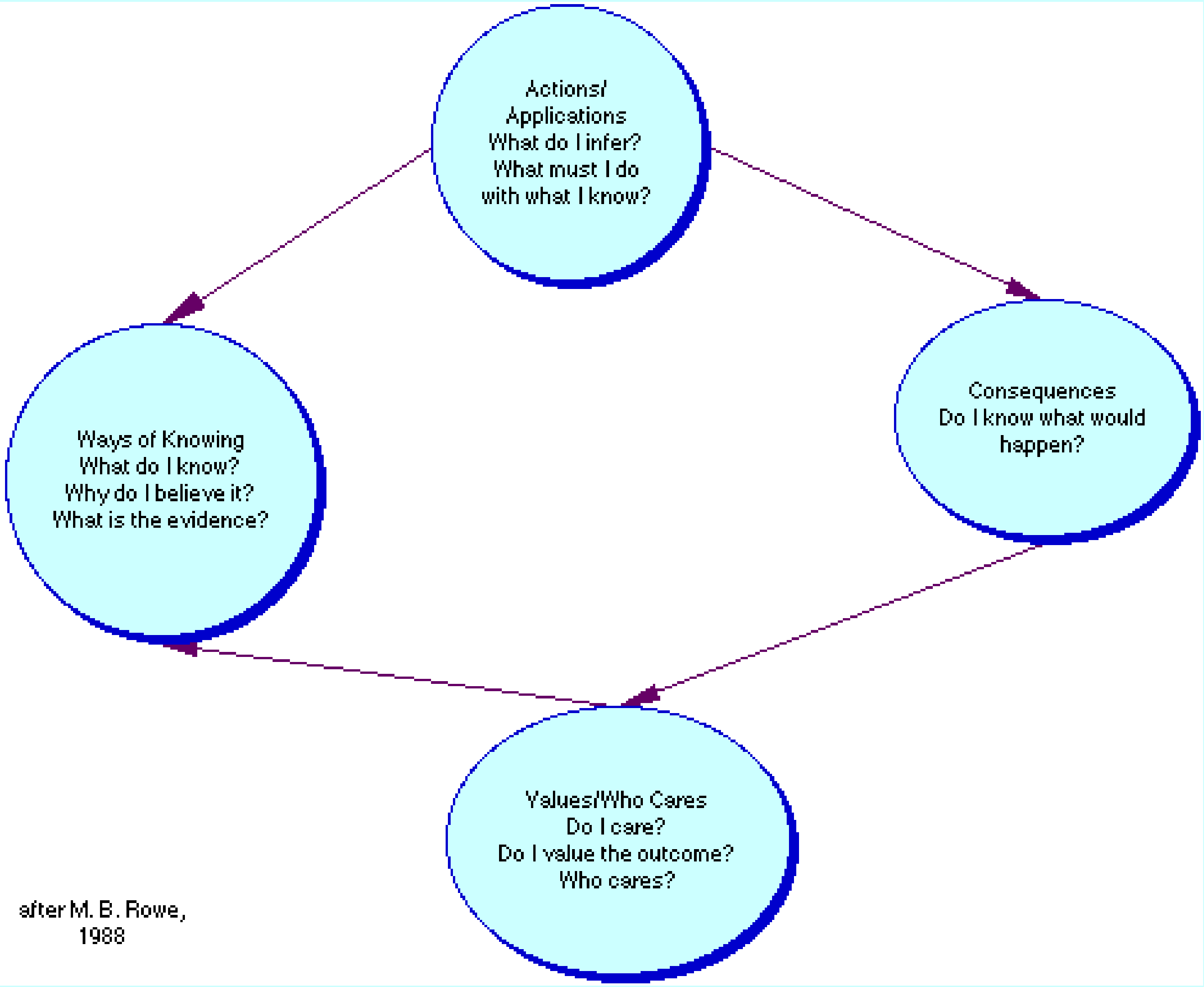
Bridging the Gap

How can science education be sensitive to the differences between students and scientists, and in such a way create science programs that nullify the negative trends in attitudes and achievement that have persisted for the past decade?

One place to begin is with pedagogy. Research study after research study has described a picture of the science classroom as a pedagogical monotone. In most classrooms a teach, text, test model prevails. For the majority of students, this model leads to disastrous results. What is needed is greater variety in pedagogy. There are many pedagogical models of teaching that place the student in an active role, as opposed to the widespread practice of students being passive receptors of information. Chapter 7 presents inquiry, conceptual change, direct/interactive, small group and individualized models of teaching, providing pedagogical varieties for the science teacher.

Science educators need to reconsider the goals of science teaching, and take a careful look at the objectives and concepts that secondary school students are expected to learn. Many science educators suggest that the humanistic and societal aspects of science should be emphasized in the science curriculum. Some suggest that science teaching---and the resulting curriculum---should help students generate ideas about the science-society interface. The interaction between science and society can lead to topics in science teaching that focus on the student interests, contemporary scientific, social and planetary issues, and help students use science concepts and methods in the investigation of these problems.

The emphasis in science teaching is on the teaching of facts and concepts. Very little emphasis is placed on the application of science knowledge to societal problems, the consequences of scientific discoveries, or the values undergirding science. Mary Budd Rowe's proposal for a shift in science education incorporates each of these components in a holistic paradigm of a science education program! The sad aspect of this is even with most of the attention given to this goal, American students have not done very well on standardized tests, especially when compared to their counterparts in other information-age societies.



As you examine this paradigm, keep in mind that Rowe suggests that for the most part, teachers and texts concentrate on the question "What do I know?" under the Ways of Knowing component. In fact, she points out that a typical high school science text averages between seven and ten new concepts, terms, or symbols per page. Making assumptions about the number of pages in the text, she estimates that students need to learn between 2,400 to 3,000 terms and symbols per science course. This translates to about twenty concepts per fifty-five minute period!

If these figures are even partially accurate, there is very little time for activities, for thinking about the applications, consequences or values implicit in science concepts and theories. The implication of this data is science lesson plans need to incorporate a spectrum of components.

Giving students a broader perspective of science will help bridge the gap separating them from the world of scientists. Most students will not become scientists, but they will become consumers of scientific discoveries and technological inventions, as well as decision-makers at the polling booths.

1.10. THE STUDENTS WE TEACH:WHO ARE THEY?

They are adolescents. According to the dictionary, the term adolescence is derived from the Latin word *adolescere*, which means to "grow up." You will teach students in either a middle school, junior high school or senior high school who will range in age from 12 - 18. According to psychologists, adolescence is the period of life that is a transition from childhood and maturity. In your pedagogical training you most likely have explored in courses on human growth and development, and educational psychology a variety of theories to explain cognitive, psychosocial, physical, sexual, and emotional development of adolescents. I will explore in the next chapter some aspects of these theories, especially as they impinge on how adolescent students learn, what motivates them, and how to get them interested in learning science. However, I think it is important to realize that each of the 100 - 175 students you will teach each day is a whole person integrating a constellation of feelings, attitudes, abilities, motivations, physical attributes, and ambitions. It goes without saying that each student is unique. At the secondary education level however, these students are taking on new roles, are influenced by peer pressure, wonder who they are, and what they will become. As a science teacher, it is easy to put subject matter first because of your love for science and your commitment to teach science, and forget that you are teaching students. If you reflect for a moment that science is the vehicle that brings you and your students together. You have an opportunity to explore such questions as: How can science teaching contribute to the development of the students we teach? How can science teaching foster the development of healthy persons with positive self-concepts? How can I give the joy I sense about science to my students?

You will come to know your students in the context of a school, some of which will be large urban high schools with student bodies approaching 5,000, to small rural schools with only 100 students in each grade. The context of school is important because the institution of the school itself plays a role in the daily life of the student. Lets look at some of the students you will teach, and the kinds of environments they will encounter so as to introduce the notion that "students are first" in any discussion of learning, science education, and the profession of teaching.

Jamie. He attends a large urban high school. He has an academic curriculum and works after school three days a week and on the weekends. He comes to school by car, usually picking up three or four friends on the way. After the half-hour ride to school, Jamie goes to his locker, talks with a few friends, and goes to his first class by 8:00 A.M. His girlfriend, Monica is in his first class, so he usually there on time in order to talk briefly with her. Jamie's first class is an ESL class, which he likes because the teacher treats all the students with great respect. The teacher told the students that he would be available after school to help with an language problems.

During math class, which Jamie does not like, yet feels frustrated, because he loved math last year, but finds that a lot of time is wasted because of a group of "trouble-makers." The teacher is constantly diverted by these students tending to their misbehaviors. In the regular English class, currently being taught by a student teacher, Jamie is asked to read a poem he wrote aloud. After reading the poem, Jamie is embarrassed and just shrugs his shoulders when asked to explain what he meant by the poem. In biology, the teacher has just begun a unit on amphibians. She announces to the class that in lab this week, lab teams will dissect a frog. Jamie is not too thrilled about this.

Pat. She is thirteen years old and her family has just moved from New York City to a small town outside a large southern city. She rides the bus to school each morning, getting up at 6:00 A.M., and riding for an hour to reach school by 7:30 A.M. The school, a regional middle school, is in its second year of operation. Pat is a student in one of three eighth grade teams, each of which is comprised of about one-hundred and fifteen students and four teachers. When she arrives at school, she goes to the cafeteria to eat breakfast before going to her homeroom. She starts the day with a bowl of cereal, a biscuit and a carton of orange juice. Her first class, a pre-chemistry course, is taught by a first year teacher who has a lot of energy, and sometimes surprises the students with a mysterious demonstration. Although she doesn't like the subject of "pre-chemistry" she loves coming to this class because her teacher encourages all the students to learn and enjoy science. Her next class is math. All the students in her pre-chemistry class move in-mass to math across the hall. She hates this class. The teacher, who is also on-the-job for the first time, embarrasses the students by pointing out their mistakes, especially when they are sent to the board to "work" problems. In interrelated arts, the teacher has invited a well-known potter to come to her class to show the students some of his work, and how he makes pots. Pat is excited and looks forward to interrelated arts today. Pat's class eats at the first lunch period, which causes her to be hungry every day around 2:00 P.M. Her science teacher has asked for volunteers to form a science club. Pat is not sure whether she will go. She decides to ask two of her friends is they are going. They say they are.

Alexis. He is the oldest in a family of five children. Both of his parents work, his mother during the day, and his father at night. Alexis usually leaves home without breakfast, but stops at the "QuickMart" for a sweet roll and a soft drink. Alexis is a very quiet student and tends to keep to himself, except for two friends that he sees each day at lunch, and briefly after school while he walks to the bus station to go to work. Alexis reads at the sixth grade level, and is having a great deal of difficulty with homework assignments in English and in U.S. History. He goes to his homeroom for attendance, and then his first class, general chemistry. His teacher explained that they are using a new book this year, and the emphasis is on chemistry in the community, and how chemistry applies to everyday life. In chemistry class, the teacher is explaining the chemistry of digestion, and as he does Alexis's stomach is rumbling. When it rumbles very loudly, a student in the next seat starts to giggle, and pretty soon the back of the class is giggling. Alexis likes school okay, but he would rather be at work. He is assistant manager of the evening shift of a pizza joint, and he feels very important in this role. He often wishes he was graduated from high school, and gives a great deal of thought to dropping out. His younger brother did.

Chris. He is a fifteen year old in the seventh grade in a junior high school. He is overweight and towers over all the students. He was retained twice in the third grade, and can't wait until next year when he will be able to drop out. Chris goes to bed late each night. He lives with his mother and two older sisters in an apartment in a high rise. Chris is a member of a gang, most of whom live in his apartment building or the ones just adjacent. His gang has not been involved in any violence, but regularly meet and smoke dope. Chris knows that his teachers and especially the assistant principal keep an eye on him and his friends. Still Chris has smoked in the boys room, and come to class many times stoned. His first class is life science, and like all the remaining classes, Chris never shows up with his textbook, pencil or paper. Chris shows up to school on an average of three or four days a week, and is forever behind in his work. Chris shows some interest when the teacher does a hands-on activity, but otherwise disdains reading the text, or doing worksheet exercises. The teacher, however, rarely does a hands-on activity, because some of Chris's friends misbehave and can not be trusted with the teaching materials.

Alicia. She is a senior at a small high school in a mid-sized city in a Western state. She, like most of the students attending the school, rides the bus. She would like to have her own car, but she can't afford one, and her parents refuse to get her one. Alicia is fond of art and language, especially French, and is a member of the drama club. This year she decided to try out for one of the the lead roles in *Romeo and Juliet*. In art class, the teacher has agreed to help the drama coach build the set for Romeo and Juliet. Alicia offers to make some quick sketches so they can get an idea of how the different plans would look. Derek sits down next to Alicia and starts talking about how bad he is going to feel when they leave school in a few months. After class, they go to the student lounge and talk for a while longer. Alicia suddenly feels sad herself and is happy to share her feelings with Derek. The conversation becomes more personal. Derek tell Alicia that he has liked her for a very long time, but has been afraid to say anything because Alicia was dating another boy. The bell rings. Alicia and Derek have to go to separate classes. Alicia goes to advanced biology where the students are giving reports. Her mind wanders to the conversation with Derek. At lunch she does her best to avoid looking at Derek. Derek finds her after school, and talks to her again. He has tears in his eyes, and tells her how much he likes her. She tries to comfort him, but nothing helps. She goes home sad, angry and flattered.

These are only a few of countless scenarios of students in secondary schools. You can add to it from your memory store. As you progress in the process of becoming a science teacher, I hope these scenarios will help you appreciate that students in your class experience a life "outside of science" that will have a significant effect their learning, just as the theories and models of learning and teaching that will be presented in this book.

1.11. THE EFFECTIVE SCIENCE TEACHER: WHO ARE YOU?

As a [science] teacher, you will have a special role in bridging the gap between the different world of science and scientists and the world of students in middle/junior and high schools. Are there characteristics common to teachers who do this effectively? There are two sources of information that will help us with this question. One is the result of the effective teaching research over the past twenty-five years, and the other comes from the insight and wisdom if-you-will of outstanding secondary teachers.

Effective Teachers

In recent years, researchers have investigated the relationship between teacher behavior (strategies and methods of instruction) and student performance (conceptual learning, attitudes). Through a technique in which a large number of research studies are synthesized, researchers have found clusters of instructional strategies and methods that are related to increased cognitive outcomes. At this stage in your study of science teaching, I assume that you have not mastered these behaviors. Instead, these characteristics will be viewed as advance organizers for our study of effective science teaching. The lists (Figures 1.19 and 1.19a) that follow have been paraphrased from Hofwolt and Borich.

Individual teachers will vary considerably in their style, and in the specific strategies they use to help students come to enjoy and learn science. However, there appears to be a clustering of broad patterns of teacher behaviors that effective teachers employ. Here are two sets of behaviors, shown side-by-side, one that appears to characterize secondary teachers in general, and the other that is more specific to secondary science teachers.

Effective Teachers: What Strategies Do They Use?

- **Clarity**: Their presentation to the class is clear and understandable. Initial explanations are clear, logical and easy to follow.
- **Variety**: Teachers who show variety use a variety of behaviors to reinforce students, ask many and a variety of questions, use a variety of learning materials, equipment, displays---in short, hands-on materials.
- **Task Orientation:** Teachers who spend more time on intellectual content rather than on procedures or classroom rules tend to have higher rates of achievement.
- **On-Task Behavior**: This refers to the amount of time that students are actually on-tasks engaged with learning materials and activities. On-task behavior is closely related to classroom management behaviors of the teacher.
- **Success Rate**: This characteristic is closely related to student self-esteem. Naturally, if students are succeeding a moderate-to-high rates, then students are going to feel good about themselves as science learners and have positive attitudes about science. A key behavior here is the teachers ability to design learning tasks

that lead to high success rates, but are not dull or repetitive, or viewed as a waste of time

- **Using Student Ideas**: acknowledging, modifying, applying, comparing, and summarizing student's comments can contribute to a positive learning environment. Teachers who use student ideas are genuinely interacting with students, thereby effecting student self-esteem.
- **Instructional Set**: This refers to teacher statements made at the beginning of a lesson, or at transition points in the lesson that help the students organize what is to come or what has happenedbefore.
- **Questioning**: Teachers can and do ask a variety of questions. Knowing what kinds and when to ask questions seems to be important to student learning. Related to questioning is the behavior of 'wait time' which refers to the amount of time teachers wait after asking students a question
- **Enthusiasm:** This humanistic behavior refers to the teacher's vigor, power, involvement, excitement, and interest during a class presentation. Enthusiasm manifests itself by the teachers use of eye contact, gesturing, movement, use of supportive and approval behaviors, variety of teaching techniques, and love of science

An Effective Teacher Speaks

There are many effective teachers in the United States. You will read in the Science Teachers Talk sections in the *Science Teacher Gazette* the comments made by several outstanding science teachers that I interviewed for this book. An eloquent spokesperson of effective teachers is Eliot Wigginton, one of the best-known high school teachers. Wigginton, who is a secondary teacher in Rabun County, Georgia, is probably best known for his *Foxfire books*, and community-based, experiential approach to teaching. In his book, Sometimes A Shining Moment: The Foxfire Experience---Twenty Years Teaching in a High School Classroom, Wigginton grapples with the question, How do we make teaching work? His response was to outline "some overarching truths" about teaching, principles of teaching which to Wigginton differentiate effective from ineffective teachers. Following are brief comments about each of these overarch truths. Wigginton acknowledges that he is constantly searching for ways to answer the question, and says that he tries new approaches, rips apart his lesson plans, and hopes for those moments when things work and his students soar. Examine his list, and compare them to the categories of behaviors that researchers have found to characterize effective teachers. Here in brief are Wigginton's overarching truths about teaching.

Wholistic View of Subject Matter. This is the characteristic that tends to get students to recall their memorable teachers. "They made the subject come alive," or She really loved her subject," are some of things students remember about outstanding teachers. Wigginton claims that effective teachers see the interdependence of their own discipline with all others. They see their subject whole. They are the science teachers who see instantly every major science related news event. Or as he says, carpet dyes and gymnasium floor waxes and cans of beer become subjects of chemical analysis, and the first spring flowers become targets of botanical scrutiny. These teachers help students relate their subject matter to the whole world, and he goes as far to say that if there is no way to help students make linkages between this course and the whole world, and relate them to the students' lives, then the course should not be offered at all.

Know How Learning Takes Place. According to Wigginton, the effective teacher understands how learning takes place, knows how to apply the principles of learning, and believes that all students can learn. To Wigginton, this last notion is at the heart of the teaching profession. Teachers who know how learning takes place understand motivation in learning. They have moved away from extrinsic motives (candy, grades, a prize) toward intrinsic motives (natural curiosity, desire for competence and mastery). They help students make connections between the information they are to learn and their own world. These teachers also know that learning takes place by doing, and that learning begins with meaningful experiences and then moves to the text or the teacher, and then on to evaluation, analysis, reflection, and a return to meaningful, hands-on experiences.

Know Their Students. Wigginton feels that effective teachers try to bring education and the lives of students together by getting to know them better. He points out that is a tricky area, because many teachers feel distance should be kept from students---and perhaps students may not want to know us. However, Wigginton believes that in order to make instruction and the curriculum relevant to the students, it goes without saying, that educators must know their students. He says, for example, "when I know students reasonably well, I know the extent of the demands I can make upon them; I know something about their talents and abilities and likes and dislike, and thus I can lead them into educational activities with reasonable hope of success."

Make Careful Assumptions. The central idea here is very simple: the best teachers never make negative assumptions about the potential of their students. Wigginton says that too often, the disease model of education is at play, wherein the student is viewed as defective, and it is the job of schools and teachers to fix them. This is in stark contrast to his view that students have a variety of strengths and abilities, and it the the job of the school and teachers to take advantage of them, and in the process turn areas of weakness around. As Wigginton says, we make cripples of students on the basis of assumptions we make about them. As a future science teacher, this is especially crucial given the negative attitudes that prevail among students toward science. The evidence from research studies (especially the famous Pygmalion effect study by Robert Rosenthal) suggests that students who receive attention, have higher goals set for them, and even more demands, often do advance academically. Students who we establish low expectations for, give less attention, do not advance academically. Teachers' attitudes and the assumptions they make about students can play as important a role in cognitive learning as all the methods, strategies and materials of teaching that we use.

Understand the Role of Self-esteem. Effective teachers know that how students feel about themselves foretells how they perceive, react to, and perform in the world. Self-esteem is especially important in science teaching, again, because of the negative connotations students have toward the study of science. One of the best remedies, and effective teachers know this, is to plan learning experiences that lead to student success, that build upon the student's dignity and self-worth.

Wigginton explores other characteristics of effective teachers. He suggests that these teachers also recognize their humanness, understand the nature of discipline and control, help students analyze and react to other adults, constantly engage in professional growth activities, and know how to avoid teacher burnout.

As you continue with your study of science teaching, come back to these characteristics---those resulting from the science of research, and the wisdom-of-practice.

ACTIVITY 1.1: EXPLORING YOUR IDEAS ABOUT SCIENCE TEACHING

Later in this book you will discover that secondary students come to science class with existing ideas about the science content that you will teach. Novices of a field of study, such as students in your future science classes, possess initial conceptions of the field, say Earth science or physics. Many of these ideas or initial conceptions are actually alternative frameworks or ways of thinking developed by students. Nevertheless, these alternative conceptions represent a good place to begin instruction. Thus, this activity is designed to help you think about, and *explore your existing ideas or your frameworks about science teaching*. It's not a pre-test, but rather an opportunity to discuss your initial ideas about science teaching from a holistic and problem oreinted vantage point.

Materials

- Index cards
- Information in Figure 1.2

Procedures

1. Read each of the situations given for the conceptual themes listed in the Figure 1.3

2. Write the themes on individual index cards. Shuffle the cards, and place them face down on a table around which four to six students are sitting.

3. Select one person to start. The person selects a card from the top of the deck of index cards to identify the unifying theme. Read the problem situation associated with the theme aloud to your group. Use the questions listed in the third column to guide your exploration of the theme. To explore the theme, you can:

a. Give your initial point of view and share it with the group. You can ask other group members if they agree or disagree.

b.. Ask each group member to write a brief statement, and then read them aloud to the group.

c. If the problem situation merits it, role play the situation with other member of your group. The person drawing the card, and selecting this method asks for volunteers and directs the role playing scene. The enactment should take no more than two or three minutes.

Minds-On Strategies

1. How do your initial ideas compare with other students in your class?

2. What is a framework? How do frameworks develop? How can they change?

3. In what ways do you think your initial ideas or frameworks about science teaching

reflect the most recent research and practice of science teaching?

Figure 1.2: Exploring Your Initial Conceptions of Science Teaching

Unifying Theme of Science Teaching	**Problem Situation**	**Assessing Your Initial Conception**
Nature of Science	Carl Sagan says that "science is a way of thinking, much more than it is a body of knowledge."	What is your view of science? Do your agree or disagree with Sagan? What are the implications of Sagan's definition for science teaching?
Learning	You overhear a science teacher explaining to her eigth grade earth science class that intelligence is incremental, not fixed. She believes that this will encourage students to try harder, especially when learning new, and difficult ideas and concepts.	What is your view of intelligence? Do you think teaching students about human intelligence might help them learn science?
Goals	According to a report on science teaching written by a prestigous group, the main goal of science teaching is to produce a scientifically literate society.	Do you agree with this? Are there other goals that are worthy, and should be an integral part of science teaching.
Curriculum	The title of a keynote address at a major conference on science teaching is, "The Science Curriculum: A Nonchanging Phenomenon!"	What is the science curriculum, anyway? Is it nonchanging, or has the curriculum changed over the years?
Science, Technology, Society	A science teacher announces at a departmental meeting that she is going to include the following topics in her survey biology class---ethics and animal rights, birth control methods, abortion, and aids counseling. One teacher objects saying, "these are too controversial, we'll have half the parents in here."	What do you think? Should topics like these be part of the science curriculum? Why?
Models	A first year teacher uses a nontraditional teaching model during the first week of school. It is a small group activity with hands-on materials. Students used meter sticks, and were asked to measure various heights and lengths with the sticks. Students were confused. How could they measure something bigger than the meter stick? Another pair of students was carving symbols and words in the meter stick, and another group couldn't decide whether the smallest marks were centimeters or millimeters.	Are nontraditional models of teaching prone to problems and the unexpected? Should they be avoided by first year teachers until they get their feet wet?

Strategies	The most common strategy used in high school science teaching is lecture and discussion. Many science teachers claim that this is an inadequate strategy for most students, and suggest other strategies.	What do you think? Isn't lecture an efficient way to teach science? Are there other strategies that might reach more students? What are they?
Planning	At a conference between a student science teacher and her college supervisor, the student expresses anger that the students didn't enjoy the lesson that she had spent three hours planning. She just can believe they were rude during a lesson she planned so hard for.	How important is planning for lessons? Does this student teacher have expectations that are too high? How would you react in such a situation?
Assessing	A teacher announces that he is going to let students work in small teams on three quizzes each term. The students will turn in one paper, and each will recieve the group's grade.	Do you think this is a good idea? Why? Would you employ such an assessment plan in your class.
Management & Facilitation	A fellow student returns from observing high school science classes with two maps drawn of the clasrooms visited (Figure 1.2).	What can you infer about the each teachers' view classroom management? How does their view of facilitating learning compare?
Science for All	A number of schools around the country with large numbers of at-risk students have adopted an approach called "integrative learning." This holistic approach appears to be successful with students who are disinterested in school, and normally end up dropping out.	How would you teach the at-risk student, the student who has had a continous record of failure in school, and clearly is prone to drop out of school? Can all students learn science?

ACTIVITY 1.2: THE CRINOID STEM AND THE NATURE OF SCIENCE TEACHING

To explore the nature of science teaching, you are going to plan at least two microteaching lessons based on the following ideas and carry them out with a group of peers or a group of secondary students. One of the microteaching lessons should be selected from the list entitled engagement mode, and the other microteaching lesson should be selected from the list entitled delivery mode.

Materials

Collection of fossils of the same species, metric rulers, crayons or marking pens, newsprint, bell caps, string and glue, and other materials and equipment to teach the microteaching lesson.

Procedure

1. Divide into groups and select a task from either the engagement or delivery mode of teaching. Your group is to prepare a ten minute microteaching lesson based on the task you selected. You can teach the lesson to either a peer group or a group of secondary students. You may want to video tape the lesson so that you can replay it.

2. When groups are finished, one member should present their group's results to the whole class.

Minds-on Strategies

1. Evaluate the lesson by comparing the engagement mode to the delivery mode of instruction by considering the following questions: Was there evidence of curiosity on the part of the students during the lesson? Did the students show their creativity? Did they ask questions? Was there an aesthetic dimension in the lesson? Which lesson model did the students (learners) prefer? Which lesson did the teachers prefer?

2. Which approach do you think is more motivational? Why?

Engagement Versus Delivery Modes of Teaching	
Engagement Mode	**Delivery Mode**

Task 1. You are a group of scientists. Make as long of a list of observations of the crinoid as your group can. When your group has completed the list, ask the instructor for the second part of your activity. Note: be sure to write your list on a large sheet of chart paper; you can use more than words! Part b. Classify each of the observations your group made according to the human sense used for each observation, e.g. F= feel, touch; T= taste; S= smell; E= sight, eyes; H= hearing, sound; O= other senses	Task 1. Lecture and carry out a discussion on the physical characteristics of the fossil. Be sure to include observations that require the use of the five senses.
Task 2. You are a group of mathematicians. Measure the diameters (in centimeters) of at least 20 crinoids. (You will have to visit other groups in order to get a total of 20 measurements. Send out four of your group to measure five crinoids each while the remaining ones measure your crinoids.) Make a population graph of the crinoids you measured. Set up the graph like this one:	Task 2. Discuss the population characteristics of the fossil. Focus attention on one characteristic, namely diameter (if you use crinoids). Explain the terms fossil, population graph and diameter to the students.
Task 3. You are a group composed of historians, anthropologists, and geologists. Use your imaginative side and draw a complete picture of what your team thinks the crinoid looks like. You only are looking at a piece of the animal. How do you think it looks as a complete creature? Does it have a head? Does it have feet? How does it move? Special note: When you draw your creature, put the creature in the context of an environment. Ask your group: Where does this creature live? Does it live alone? Or are there others about? What does it eat for food? How does it get its food? Who are its predators?	Task 3. Introduce the students to the concept of environment. Use the fossil crinoid as the species to study. Use diagrams and pictures so that the students will be able to describe the ecological characteristics of the crinoids' environment.
Task 4. You are a group of writers. Poets! Your task is to prepare several poems about the crinoid that your group will read to a group of fellow teachers. Write several poems, called Syntus, using the following formula: ● Line 1: Single word or concept such as fossil, crinoid, age, time ● Line 2: An observation of line 1 ● Line 3: An inference about line 1 ● Line 4: A feeling about line 1 ● Line 5: A synonym of line 1 Note 1: Brainstorm observations, inferences, and feelings about the crinoid. Try to think about being the crinoid, living when it lived (400 million years ago). Use the results of your brainstorming to create your syntus. Note 2: Write your final products on sheets of chart paper. Make them colorful, and easy to read from a distance.	Task 4. Give a brief lecture on the fossils so that students will be able to describe what fossils are, how they are formed, what they tell us about the earth, and what they are used for. The students should be able to write a brief essay on fossils as a result of your presentation.

Task 5. You are a group of artists. Your task is to make pendants using the crinoids, bell caps, gold or silver chain, and glue. After your group has made pendants, show other groups how to do the same.	Task 5. Deliver a lecture on the artistic and practical aspects of fossils. How are fossils used in arts and crafts? What people in the community would have a use for fossils?

ACTIVITY 1.3: SURVEYING STUDENTS' IDEAS ABOUT SCIENCE

Knowing what your students think of science can play an important role in influencing your day-to-day lesson plans. This activity is designed to help you detect and describe secondary students' view of science. Three methods are described in this activity.

Materials

Drawing paper, pencils and crayons, copies of science survey instrument.

Procedure

Choose one of the methods and survey 10 - 15 students on their view of science. After you have surveyed the students, arrange a time where you can discuss the results of the survey with the students. (Note: this activity can also be carried out with a group of your teacher training peers.)

Minds-On Strategies

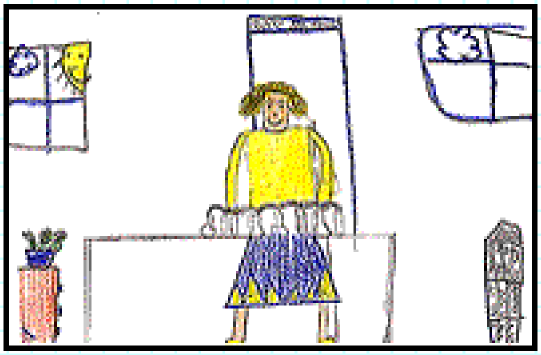
l. Summarize the results of the your method of investigation by analyzing and drawing conclusions from the drawings, perhaps by creating a poster of the drawings, or tabulating the results of the survey.

2. Compare the method you used with the other two methods. How do students view science? Do they have a positive view of science? What is their image of a scientist? How do students compare science and technology? What effect does science have on society? Society on science?

Method 1: The Essay. Have the students write an essay explaining what they think science is, and how scientist do their work. To help the students you might give them one of several sentence starters as a vehicle to begin. Some examples:

- *Science is...*
- *Scientists believe that...*
- *The purpose of science is...*

Method 2: The Drawing. Have students make a drawing of a scientist. Ask the students to show the scientist at work. You might also have the students write a brief statement explaining their drawing.



Scoring: (1 point for any of the following: lower score is a higher rating)

- labcoat
- eyeglasses
- facial hair
- symbols of research - test tubes, flask
- symbols of knowledge - books, filing cabinet
- sign of technology - solutions, machines
- captions - Eureka, I ve got it!!!
- male
- signs/labeling - Fire, Danger, Poison
- pencils and pens in pocket protector
- unkempt appearance

Method 3: The Questionnaire. Survey the viewpoints that middle and high school students hold on the following items. The items below are based on an instrument developed to survey Canadian high school students and has been modified for use here. Have a group of students respond to the items. Asterisk a different item on each student's questionnaire. Ask the student to write out reasons for their choice for that item. The purpose of each item is given in parentheses, which you do not need to include when you distribute the questionnaire to the students. The purpose of each item will be important when you analyze the results, however.

Opinions About Science

Instructions

Please check whether you agree or disagree with the following statements. If you cannot agree or disagree then check "can't tell" for the statement. For the item with an asterisk, please write the reasons for your choice.

1. In the USA, science and technology have little to do with each other. (Relationship between science and technology)

_____agree _____disagree _____can't tell

2. In the USA, technology gets ideas from science and science gets new processes and instruments from technology.

_____agree _____disagree _____can't tell

3. In order to improve the quality of living in the USA, it would be better to invest money in technological research rather than scientific research. (Science, technology and quality of life)

_____agree _____disagree _____can't tell

4. Although advances in science and technology may improve living conditions in the USA and around the world, science and technology offer little help in resolving such social problems as poverty, crime, unemployment, overpopulation, and the threat of nuclear war. (Science, technology and social problems)

_____agree _____disagree _____can't tell

5. Scientists and engineers should be given the authority to decide what types of energy the USA will use in the future (e.g. nuclear, hydro, solar, coal burning, etc.) because scientists and engineers are the people who know the facts best. (Technocratic and democratic decision making postures)

_____agree _____disagree _____can't tell

6. The US government should give scientists research money only if the scientists can show that their research will improve the quality of living in the USA today. (Mission-oriented perspective)

_____agree _____disagree _____can't tell

7. The US government should give scientists research money to explore the unknowns of nature and the universe. (The basic science perspective)

_____agree _____disagree _____can't tell

8. Communities or government agencies should not tell scientists what problems to investigate because scientists themselves are the best judges of what needs to be investigated. (Role of government and communities in the choice of research problems)

_____agree _____disagree _____can't tell

9. Science would advance more efficiently in the USA if it were more closely controlled by our government. (Government control of research)

_____agree _____disagree _____can't tell

10. Science would advance more efficiently in the USA if it were independent of government influence.

_____agree _____disagree _____can't tell

11. The political climate of the USA has little effect upon US scientists because they are pretty much isolated from US society. (Effect of political climate upon scientists)

_____agree _____disagree _____can't tell

ACTIVITY 1.4: THE STUDENT COMES FIRST!

This activity is designed to engage you in an exploration of secondary school students based on several vignettes of students. Your role is to participate with a team of peers to decide upon some strategies you think might interest the students in the vignettes.

Materials

- Student vignettes
- Chart paper
- Marking pens

Procedure

1. Working with a small team of peers, explore each student to discover some of the student's characteristics based on the vignette given here. Your role in the team is to

a). List as many characteristics of the student;

b). Identify potential activities, events, procedures you think this student will enjoy participating in;

c). Identify potential problem areas for the student. Are there aspects of science class this student may not like? What can be done to mitigate this circumstance?

2. Prepare a profile on each student by summarizing the major characteristics, potential positive activities, and problem areas on a large sheet of newsprint or similar paper.

Minds-on Strategies

1. Compare your team's analyses with other teams in your class. How do the analyses compare?

2. Are there any at-risk students in this group; that is students who you think potentially would drop out of school? How can teacher make science be a positive influence in this person's life?

Vignettes

Pedro. He attends a large urban high school. He has an academic curriculum and works after school three days a week and on the weekends. He comes to school by car, usually picking up three or four friends on the way. After the half-hour ride to school, Pedro goes to his locker, talks with a few friends, and goes to his first class by 8:00 A.M. His girlfriend, Monica is in his first class, so he usually there on time in order to talk briefly with her. Pedro's first class is an ESL class, which he likes because the teacher treats all the students with great respect. The teacher told the students that he would be available after school to help with an language problems.

During math class, which Pedro does not like, yet feels frustrated, because he loved math last year, but finds that a lot of time is wasted because of a group of "trouble-makers." The teacher is constantly diverted by these students tending to their misbehaviors. In the regular English class, currently being taught by a student teacher, Pedro is asked to read a poem he wrote aloud. After reading the poem, Pedro is embarrassed and just shrugs his shoulders when asked to explain what he meant by the poem. In biology, the teacher has just begun a unit on amphibians. She announces to the class that in lab this week, lab teams will dissect a frog. Pedro is not too thrilled about this.

Mary. She is thirteen years old and her family has just moved from New York City to a small town outside a large southern city. She rides the bus to school each morning, getting up at 6:00 A.M., and riding for an hour to reach school by 7:30 A.M. The school, a regional middle school, is in its second year of operation. Mary is a student in one of three eighth grade teams, each of which is comprised of about one-hundred and fifteen students and four teachers. When she arrives at school, she goes to the cafeteria to eat breakfast before going to her homeroom. She starts the day with a bowl of cereal, a biscuit and a carton of orange juice. Her first class, a pre-chemistry course, is taught by a first year teacher who has a lot of energy, and sometimes surprises the students with a mysterious demonstration. Although she doesn't like the subject of "pre-chemistry" she loves coming to this class because her teacher encourages all the students to learn and enjoy science. Her next class is math. All the students in her pre-chemistry class move in-mass to math across the hall. She hates this class. The teacher, who is also on-the-job for the first time, embarrasses the students by pointing out their mistakes, especially when they are sent to the board to "work" problems. In interrelated arts, the teacher has invited a well-known potter to come to her class to show the students some of his work, and how he makes pots. Mary is excited and looks forward to interrelated arts today. Mary's class eats at the first lunch period, which causes her to be hungry every day around 2:00 P.M. Her science teacher has asked for volunteers to form a science club. Mary is not sure whether she will go. She decides to ask two of her friends is they are going. They say they are.

Terrance. He is the oldest in a family of five children. Both of his parents work, his mother during the day, and his father at night. Terrance usually leaves home without breakfast, but stops at the "QuickMart" for a sweet roll and a soft drink. Terrance is a very quiet student and tends to keep to himself, except for two friends that he sees each day at lunch, and briefly after school while he walks to the bus station to go to work. Terrance reads at the sixth grade level, and is having a great deal of difficulty with homework assignments in English and in U.S. History. He goes to his homeroom for attendance, and then his first class, general chemistry. His teacher explained that they are using a new book this year, and the emphasis is on chemistry in the community, and how chemistry applies to everyday life. In chemistry class, the teacher is explaining the chemistry of digestion, and as he does Terrance's stomach is rumbling. When it rumbles very loudly, a student in the next seat starts to giggle, and pretty soon the back of the class is giggling. Terrance likes school okay, but he would rather be at work. He is assistant manager of the evening shift of a pizza joint, and he feels very important in this role. He often wishes he was graduated from high school, and gives a great deal of thought to dropping out. His younger brother did.

Joe. He is a fifteen year old in the seventh grade in a junior high school. He is overweight and towers over all the students. He was retained twice in the third grade, and can't wait until next year when he will be able to drop out. Joe goes to bed late each night. He lives with his mother and two older sisters in an apartment in a high rise. Joe is a member of a gang, most of whom live in his apartment building or the ones just adjacent. His gang has not been involved in any violence, but regularly meet and smoke dope. Joe knows that his teachers and especially the assistant principal keep an eye on him and his friends. Still Joe has smoked in the boys room, and come to class many times stoned. His first class is life science, and like all the remaining classes, Joe never shows up with his textbook, pencil or paper. Joe shows up to school on an average of three or four days a week, and is forever behind in his work. Joe shows some interest when the teacher does a hands-on activity, but otherwise disdains reading the text, or doing worksheet exercises. The teacher, however, rarely does a hands-on activity, because some of Joe's friends misbehave and can not be trusted with the teaching materials.

Alicia. She is a senior at a small high school in a mid-sized city in a Western state. She, like most of the students attending the school, rides the bus. She would like to have her own car, but she can't afford one, and her parents refuse to get her one. Alicia is fond of art and language, especially French, and is a member of the drama club. This year she decided to try out for one of the the lead roles in *Romeo and Juliet*. In art class, the teacher has agreed to help the drama coach build the set for Romeo and Juliet. Alicia offers to make some quick sketches so they can get an idea of how the different plans would look. Derek sits down next to Alicia and starts talking about how bad he is going to feel when they leave school in a few months. After class, they go to the student lounge and talk for a while longer. Alicia suddenly feels sad herself and is happy to share her feelings with Derek. The conversation becomes more personal. Derek tell Alicia that he has liked her for a very long time, but has been afraid to say anything because Alicia was dating another boy. The bell rings. Alicia and Derek have to go to separate classes. Alicia goes to advanced biology where the students are giving reports. Her mind wanders to the conversation with Derek. At lunch she does her best to avoid looking at Derek. Derek finds her after school, and talks to her again. He has tears in his eyes, and tells her how much he likes her. She tries to comfort him, but nothing helps. She goes home sad, angry and flattered.

These are only a few of countless scenarios of students in secondary schools. You can add to it from your memory store. As you progress in the process of becoming a science teacher, I hope these scenarios will help you appreciate that students in your class experience a life "outside of science" that will have a significant effect their learning, just as the theories and models of learning and teaching that will be presented in this book.

Minds on Science *Gazette*

Volume 1	Think Pieces	A Reconnaissance

Think pieces are opportunities for to reflect on important topics in science education. You will find several think pieces in each gazettee throughout the Minds on Science Website. In most cases you will post these on an Internet bulletin board, or in your journal. Being brief is sometimes a virtue.

1. Why is inquiry teaching not a common teaching methodology in secondary science classrooms?

2. In what ways should the teaching of science reflect the nature of science?

3. What are your reasons for wanting to be a science teacher?

4. What are the best qualities of a science teacher?

Minds on Science *Gazette*

Volume 1	CASE STUDIES	A Reconnaissance

Case Study 1. The Student Who Just Can't Relate to This 'Physics Stuff'

The Case. A high school physics teacher typically asks students an open ended evaluation question on each unit exam. On the first exam, the teacher receives this comment from one of the students: "Last year I related to biology so well. I saw things all around me. I just can't relate to this physics stuff. Pushes and pulls; how objects bounce off each other. So it does! So what?"

The Problem: Is this students' "complaint" about physics legitimate? Is relevancy to the students everyday world something the science teacher should be concerned about? If you were the physics teacher how would you handle this situation? What would you say to the student?

Case Study 2: Kids are just like Scientists

The Case. Northside High School is a technology magnet school (grades 9-12) in a large metropolitian community. The science department is comprised of fifteen teachers, three of whom are first year teachers. Each of the three first-year teachers have been assigned to teach two sections of introductory physical science, and three sections of survey biology. The veteran faculty in the science department are very committed to an inquiry approach to science teaching. Mr. Thomas, the science head, at the opening science department meeting reaffirmed this by saying that instruction should be based on the assumption that "kids are like scientists." He went on to point out that students should be taught to think like scientists, that the laboratory experiments should reinforce the way scientists do their work, thereby developing in students the same skills that scientists use. One of the first year teachers (Miss Jameson) , in a private conversation with the other two first year teachers, disagrees with this philosophy. She claims that some kids simply don't think the way the scientific community thinks, and shouldn't be penalized because of it. She says that other approaches should be considered in formulating the underlying philosophy of instruction. One of her ideas is that science instuction should be more application oriented; that science instruction should show students how science relates to their own lives. She wants to discuss these ideas with the department head. One of the other beginning teachers suggests that she bring it up at the next department meeting in a week.

At the next meeting the department head reacts negatively to Ms. Jamison's ideas, and says that the kids he teaches are quite capable of scientific thinking, and therefore he can't understand why students in her classes wouldn't be capable as well.

The Problem. You are the beginning teacher. What would you do in this situation? How do you respond to Mr. Thomas.

Minds on Science *Gazette*

Volume 1	**Research Matters: Teaching Authentic Science by Glen S. Aikenhead**	A Reconnaissance

With the pressure to teach authentic science instead of ideal science, what can a science teacher do? Investigations of students' views on the scientific enterprise have explored the following questions:

(1) What conditions are necessary for successful learning?

(2) How can a teacher evaluate student views?

It is extremely important for a teacher to acquire reliable feedback about his or her own teaching.

Seldom do students pick up authentic images about science from the subtle comments or elements within a science course. Rather, the ideas about the scientific enterprise (its characteristics) and limitations must be the center of attention. Two examples will illustrate this point.

(1) If a particular lab is intended to convey that human imagination is involved in scientific model building (e.g. the "black box" lab---see page 439), then students must be asked in the lab to address the role of human imagination, they must discuss it, and they must find it part of their evaluation in the course.

(2) If your objective is to teach the distinction between science (the process of understanding natural phenomena) and technology (the process of designing techniques and implements to respond to human needs), then projects and problems must be presented to help students distinguish between science and technology.

Students will come to class with their naive ideas [alternative frameworks] about the scientific enterprise---often the conception of ideal science or scientism. These ideals or mythical notions must be challenged before authentic images can be learned. Simulations, projects, reading assignments, field trips, forums, debates and especially discussions are all appropriate teaching strategies to help them relearn or reformulate their views.

Most importantly, the teacher must realize that it usually takes a long time and considerable evidence for students to change their ideas about the nature of science. It may take a full year for students to realize that well-known scientific laws are not truths found in nature, but are man-made generalizations. It may take three years before your students develop an accurate view of the methods of authentic science.

On the other hand, ideas which are new or relatively unfamiliar to students are quickly learned. Ideas such as recognizing that the scientific enterprise is comprised of public AND private science, each employing its own set of values, may be easily assimilated by students. Similarly, students are generally amenable to learning about the social and political contexts of science.

Teachers find that activities which focus on the nature of the scientific enterprise should be introduced early in a course, thus allowing for reinforcement of these ideas during the whole course. Reasonable time taken for such activities does not adversely affect student achievement or traditional science content.

Objectively-scored types of questions do offer objectivity of scoring from the teacher's point of view, but the questions are woefully inadequate in assessing student beliefs. The students' interpretations, however, are clearly evident in their written responses. Student paragraphs, typically two to five sentences in length, are more clearly written when:

(1) students are presented with a situation or statement; then

(2) asked whether they agree, disagree or can't tell; and then

(3) asked to explain the reasons for their choice.

This second point is important because it requires the student to take a position from which to argue. Students will often change their initial choice as they write their explanations. Somewhat surprisingly similar paragraphs will be written for opposite initial positions.

Teachers trained in science are not comfortable or confident in grading student writing. Here are some guidelines aimed at removing this obstacle. First, familiarize yourself with a range of answers by reading a few responses anticipated to be good and poor. Assign three points to answers that deal with the topic in a sophisticated way, given the nature of the instructional activity and the maturity level of your class. Two different explanations may each receive three marks, as long as they are logically constructed. Seldom is an answer considered right or wrong; but is analyzed as a better or poorer response.

Zero points are assigned to poor or uniformed responses, while one or two points are awarded to more informed responses---those that reflect some degree of realistic understanding. Three points are awarded to answers that are clear, precise and logical. It is very helpful to compose a scoring scheme for each individual question.

Students usually need practice in writing paragraphs about the scientific enterprise. Homework and quizzes are useful places for this to begin. Students who are shy about writing need individual attention and encouragement. English and social studies colleagues may have suggestions for motivating students, as well as comments about scoring schemes and efficient use of marking time.

Minds on Science *Gazette*

Volume 1	**Science is not Words** **by Richard Feynman**	**A Reconnaissance**

I would like to say a word or two about words and definitions, because it is necessary to learn the words. It is not science. That doesn't mean just because it is not science that we don't have to teach the words. We are not talking about what to teach; we are talking about what science is. It is not science to know how to change Centigrade to Fahrenheit. It's necessary, but it is not exactly science. In the same sense, if you were discussing what art is, you wouldn't say art is the knowledge of the fact that a 3-B pencil is softer than a 2-H pencil. It's a distinct difference. That doesn't mean an artist gets along very well if he doesn't know that. (Actually you can find out in a minute by trying it, but that's a scientific way that art teachers may not think of explaining.)

In order to talk to each other, we have to have words and that's all right. It's a good idea to try to see the difference, and it's a good idea to know when we are teaching the tools of science, such as words, and when are teaching science itself.

To make my point still clearer, I shall pick out a certain science book to criticize unfavorably, which is unfair, because I am sure that with little ingenuity, I can find equally unfavorable things to say about others.

There is a first-grade science book which, in the first lesson of the first grade, begins in an unfortunate manner to teach science, because it starts off on the wrong idea of what science is. There is a picture of a dog, a windable toy dog, and a hand comes to the winder, and then the dog is able to move. Under the last picture, it says "What makes it move?" Later on, there is a picture of a real dog and the question "What makes it move?" Then there is a picture of a motor bike and the question "What makes it move?" and so on.

I thought at first they were getting ready to tell what science was going to be about: physics, biology, chemistry. But that wasn't it. The answer was in the teacher edition of the book; the answer I was trying to learn is that "energy makes it move."

Now energy is a very subtle concept. It is very, very difficult to get right. What I mean by that it is not easy to understand energy well enough to use it right, so that you can deduce something correctly, using the energy idea. It is beyond the first grade. It would be equally well to say that "God makes it move," or "spirit makes it move" or "movability makes it move." (In fact one could equally well say "energy makes it stop.")

Look at it this way. That's only the definition of energy. It should be reversed. We might say when something can move that it has energy in it, but not "what makes it move is energy." This is a very subtle difference. It's the same with this inertia proposition. Perhaps I can make the difference a little clearer this way:

If you ask a child what makes the toy dog move, you should think about what an ordinary human being would answer. The answer is that you wound up the spring; it tries to unwind and pushes the gear around. What a good way to begin a science course. Take apart the toy; see how it works. See the cleverness of the gears; see the ratchets. Learn something about the toy, the way the toy is put together, the ingenuity of the people devising the ratchets, and other things. That's good. The question is fine. The answer is a little unfortunate, because what they were trying to do is teach a definition of what is energy. But nothing whatever is learned.

Suppose a student would say, "I don't think energy makes it move." Where does the discussion go from there?

I finally figured out a way to test whether you have taught an idea or you have only taught a definition. Test it this way: You say, "Without using the new word which you have just learned, try to rephrase what you have just learned in your own language." Without using the word "energy," tell me what you know now about the dog's motion." You cannot. So you learned nothing about science. That may be all right. You may not want to learn something about science right away. You have to learn definitions. But for the very first lesson is that not possibly destructive?

I think, for lesson number one, to learn a mystic formula for answering questions is very bad. The book has some others---"gravity makes it fall," "the soles of your shoes wear out because of friction." Shoe leather wears out because it rubs against the sidewalk and the little notches and bumps on the sidewalk grab pieces and pull them off. To simply say it is because of friction, is sad, because it's not science.

I went to MIT. I went to Princeton. I came home, and he (my father) said, "Now you've got a science education. I have always wanted to know something that I have never understood; and so my son, I want you to explain to me." I said yes.

He said, "I understand that they say that light is emitted from an atom when it goes from one state to another, from an excited state to a state of lower energy."

I said, "That's right."

"And light is a kind of particle, a photon, I think they call it."

"Yes."
"So if the photon comes out of the atom when it goes from the exited to the lower state, the photon must have been in the atom in the excited state."

I said, "Well, no."

He said, "Well, how do you look at it so you can think of a particle photon coming out without it having been in there in the excited state?"

I thought a few minutes, and I said, "I'm sorry, I don't know. I can't explain it to you."

He was very disappointed after all these years and years of trying to teach me something that it came out with such poor results.

What science is, I think may be something like this: There was on this planet an evolution of life in a stage that there were evolved animals, which are intelligent. I don't mean just human beings, but animals which play and which can learn something from experience (like cats). But at this stage each animal would have to learn from its own experience. They gradually develop, until some animal could learn from experience more rapidly and could even learn from another's experience by watching, or one could show the other, or he say what the other one did. So there came a possibility that all might learn it, but the transmission was inefficient and they would die, and maybe the one who learned it died too, before he could pass it on to others.

The world looks so different after learning science. For example, trees are made of air, primarily. When they are burned, they go back to air, in the the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree, and in the ash is the small remnant of the part which did not come from air, that came from the solid earth, instead.

These are beautiful things, and the content of science is wonderfully full of them. They are very inspiring, and they can be used to inspire others.

Another of the qualities of science is that it teaches the value of rational thought, as well as the importance of freedom of thought; the positive results that come from doubting that the lessons are all true. You must here distinguish---especially in teaching---the science from the forms or procedures that are sometimes used in developing science. It is easy to say, "We write, experiment, and observe, and do this or that." You can copy that form exactly. But great religions are dissipated by following form without remembering the direct content of the teaching of the great leaders. In the same way, it is possible to follow from and call it science, but that is pseudoscience. In this way, we all suffer from the kind of tyranny we have today in the many institutions that have come under the influence of pseudoscientific advisors.

When someone says, "Science teaches such and such," he is using the word incorrectly. Science doesn't teach anything; experience teaches it. If they say to you, "Science has shown such and such," you might ask, "How does science show it? How did the scientists find out? How? What? Where?" It should not be "science has shown,", but "this experiment, this effect, has shown." And you have as much right as anyone else, upon hearing about the experiments (but be patient and listen to all the evidence) to judge whether a sensible conclusion has been arrived at.

It is necessary to teach both to accept and to reject the past with a kind of balance that takes considerable skill. Science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers of the preceding generation. So carry on.

Minds on Science *Gazette*

Volume 1	Problems and Extensions	A Reconnaissance

1. What are your current conceptions about science teaching? What, in your opinion, does a person need to know in order to be a good science teacher?

2. Interview several science teachers to find out what they like most and least about teaching? What are they doing to improve or change those aspects they like least? Do teachers seem to agree on what they like most about teaching?

3. How important is imagination in science? In what ways can imagination be part of the secondary science classroom?

4. What has your experience in the science been like? Do you see science in the ways Bronowski, Feynman, Polyani, or Sagan see it? What is you notion of science?

5. Think back to your high school and college experience as a science student. Did you have any teachers that you admired, or considered to be outstanding science teachers? What characterized their teaching?

Minds on Science *Gazette*

Volume 1	Science Teachers Talk	A Reconnaissance

What do you like most about science teaching?

John Ricciardi: What I like most about science is that I can be myself, which is being part of a body of teenagers. Their spirit, ambience and energy can become the self that is mre and who I am becomes naturally part of them. For me, teaching science is becoming myself by becoming one with all that "sciencing" is in my students.

Ginny Almeder: Science is my way of questioning the universe, a pursuit we appear compelled to follow by our human nature. Teaching high school provides me with an opportunity to share my love of science with young people. Students are generally enthusiastic and open-minded about their world. It is a good time to introduce them to the joys of science. I appreciate having the opportunity to help young people realize their potential especially in the area of science. It is gratifying to observe students improving their skills, becoming more questioning, and developing a healthy self concept.

Jerry Pelletier: I am fascinated by science. It encompasses a myriad of subjects and experiences and is an every changing and developing field. Some ideas have remained unchanged for hundreds of years while others have changed many times through the centuries. I find that my excitement for the subject of science can easily be transmitted to the students. I enjoy observing students interacting while trying to understand and solve scientific concepts. Science lends itself to the inductive method of teaching. Students are constantly questioning themselves and their observations. In essence science is fun for students as well as myself.

Mary Wilde: What I like most about teaching science are the variety of ways and techniques one can use to teach a particular concept. You can prevent yourself from becoming "burned out" because there are always new demonstrations, activities and experiments to incorporate in your curriculum that can explain old concepts. It is very exciting to be part of the new discoveries, new theories, and new conceptual ideas that take place in the scientific world. What is even more "thrilling" is the sharing of these new theories and discoveries with our young people. The teaching of new scientific principles or old scientific principles in new ways, stimulates a curiosity and creative desire within the student. Thus, for me, science is a very successful tool to help the student develop creative skills, thought process skills, and problem solving skills while learning factual content and conceptual theories that explain how this world "ticks." Science is the "why" and "how," and isn't that what everyone wants to know?

These teachers believe that science can be fun for students, that they enjoy interacting with students, that it provides an opportunity to introduce students to the joys of scence. Let's begin our study of science teaching by visiting a high school classroom where science content, pedagogy, students and teachers meet---the science-teaching interface.

Minds on Science *Gazette*

Volume 1	Science Teacher Interview Questions	A Reconnaissance

These are the questions I used to interview teachers in preparation for the Science Teacher Talk sections of future *Science Teacher Gazette's*. You might want to use some or all of the questions to design and carry out a study assessing local science teacher's views on teaching.

1. If you were to describe to prospective science teachers what you like most about science teaching, what would you say?

2. How do you accommodate students with different learning styles in your classroom?

3. Do you have a philosophy and set of goals that guide your instructional actions with your students? How do you communicate these to your students?

4.Is the inquiry model of teaching important in your approach to science teaching? Why?

5. What strategy of teaching do you find to be most effective with your students?

6. Try to describe your normal teaching method by ranking the following techniques in terms of the frequency with which you use them. (i.e. 1 means, "I use this technique most frequently of all," 2 means, "I use this next most often," etc.). Leave blank those you almost never use at all. You may give several items the same number, indicating yoiu use them with equal frequency.

- Lectures that deviate widely from specific material.
- Lectures that are based closely on the text material.
- Exercises taken from the text and performed by students in class.
- Exercises taken from the text and assigned as homework.
- Exercises I make up myself (or find in nontext sources) and have the students perform in class.
- Exercises I make up myself (or find in nontext sources) and assign for homework.
- Class discussions, normally of the question and answer variety, based closely on text material.
- Open, wide-ranging calss discussions that deviate widely from the text and the normal question and answer format.
- Lab periods (for hands-on, scientific experimentation.
- Students working in small groups on research or projects that will be shared with the rest of the class.
- Students working independently on research or projects that will be shared with the rest of the class.
- Students working independly with self-directed study materials other than texts (self-graded workbooks, prepared media materials, the Internet, etc.).
- Field Trips
- Class activities and projects that will shared with an audience outside the classroom (exhibits, publications, web pages, plays, debates, etc.)
- In-class visitors from the community.
- Students working independently (or in small teams) on projects specifically designed, with student input, to link real world experiences in the community with the subject material being studied.
- Other:

7. How do you accommodate students with special needs, such as those with learning or behavior disorders? What have you found to be effective with these students?

8. Do you deal with controversial issues in your classroom? If so, which ones, and how?

9. What tips would you give beginning teachers about planning and preparing lessons?

10. How do you manage your classroom? What is the most important piece of advice you would give a prospective teacher concerning classroom management?

11. How do you evaluate the progress of your students? If you were to evaluate your colleagues, what criteria would you use to judge their teaching?

12. Do you have a favorite science lesson or activity? What is its essence? Why is it your favorite?

Chapter 2

MINDS ON *SCIENCE:*

How Students Learn Science

Placing a chapter on student learning near the beginning of this online text reflects a priority shift among secondary science teachers. Increasingly, science educators are paying closer attention to how students learn, and are encouraging practicing science teachers to implement the results in the classroom.

In this chapter you will explore some of the current theories that explain how students learn. There is no one theory that we can rely on to explain student learning. Rather, there are several theories that seem to compliment each other, and taken as a whole provide the science teacher of the 21st Century with the most recent ideas and research on how students learn science. Research on learning has moved from an emphasis on behaviorism and Gestalt views, to Piagetian conceptions, and currently to a cognitive science perspective. Cognitive theories are increasingly becoming more inclusive and holistic. Cognitive psychologists are investigating realms of learning which were the dominion of social psychologists, namely student motivation and and attitudes toward science. All of this is positive, because the science teacher deals with students who are whole.

The students who appear in your classroom have unique ways of learning. Teachers for a long time have recognized this and have devised ways to accommodate students with different learning styles. The chapter concludes with an investigation of this important dimension of learning, namely, student learning styles.

PREVIEW QUESTIONS

• What are the trends in achievement and attitudes toward science for secondary students over the past twenty years?

• How important is it to the secondary science teacher to know about learning theory?

• How do behavioral theories explain student learning in science?

• How do cognitive psychologists explain student learning?

• How do social psychologist explain student learning?

• What are and how do behavioral, cognitive and social theories of learning differ?

• What was the contribution of theorists like Skinner, Bruner, Piaget, and Ausubel to secondary science teaching?

• How do learning styles of students influence learning in the classroom?

• What is metacognition, and how can metacognition help students learn science?

2.14 Applying Learning Style Concepts to Science Teaching

There are many things you can do to help students learn in the science classroom, and certainly applying what is known about learning styles is a place to begin. There are many sources of information for specific ideas, such the ideas of Rita and Ken Dunn. In this section I will present some ideas on an approach to learning that incorporate brain research and student learning styles (The 4MAT System), specific suggestion for teaching students according to their own learning style, and introduce some tools to help students learn about their own learning (metacognition).

The 4 MAT System. 4MAT, devised by Bernice McCarthy (1987), is a learning style system that identifies four types of learners:

1. Imaginative learners
2. Analytic learners
3. Common sense learners
4. Dynamic learners

Imaginative learners (type 1) perceive information concretely and process it reflectively. They are sensory oriented as well as reflectors. They are imaginative thinkers, and like to work with other people. Their favorite question is Why?

Analytic learners (type 2) perceive information abstractly and process it reflectively. They are abstract thinkers who think about their creations, which tend to be models and theories. They value sequential thinking. Their favorite questions is What?

Common sense learners (type 3) percieve information abstractly and process it actively. They are practical thinkers; they need to know how things work. They are skilled oriented, experimenting and tinkering with things. Their favorite question is How does this work?

The dynamic learners (type 4) perceive information concretely and process it actively. These learners integrate experience and application. They learn by trail and error, and are risk-takers. Their favorite question is What if?

How did McCarthy arrive at these four types of learners? McCarthy based her model on the work of David Kolb, who had studied learners and ways in which they perceive and process information. Kolb theorized two continuums as follows:

Perceiving:

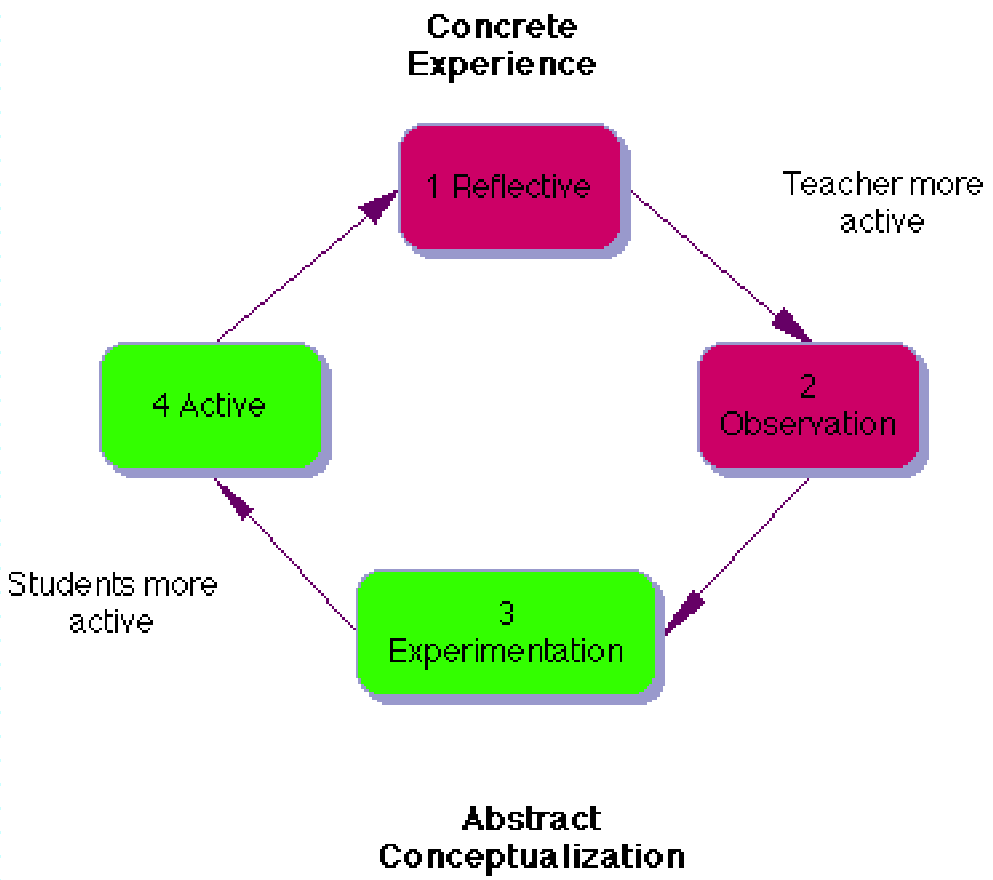
Concrete (sensing/feeling) -------------------------------- Abstract (thinking)

Processing:

Active (acting/doing) ---------------------------------------Reflective (watching)

By combining these dualities, McCarthy developed a system in which four distinct learning styles emerged, each being defined one of the quadrants in the model.

McCarthy Learning Style Model: 4MAT



McCarthy's model is a cycle of learning. If you examine the model above, imagine it as a clock. Learning begins at 12:00 with concrete experience. According to McCarthy, by moving clockwise around the circle, students then experience reflective observation; from this place they move to abstract conceptualization and finally to active experimentation. In this way, all students are taught in all four ways. Each is comfortable some of the time, while at the same time being stretched to develop other learning abilities.]

Another feature of 4MAT is that each of the four learning styles are integrated with left and right brain processing giving teachers a comprehensive teaching model. Activities for each quadrant are equally divided between left and right brain modes. For example, a teacher would begin a learning sequence in Quadrant I (Concrete/reflective) with a right brain activity to help the students explore by observing, questioning, visualizing, imagining. Students would be helped to develop a reason for studying the material. The right brain activity would be followed by a left brain activity in which the students reflect on the active/concrete experience they began with. This pattern, alternating between right and left brain modalities, is continued round the remaining 3 quadrants of the 4MAT model.

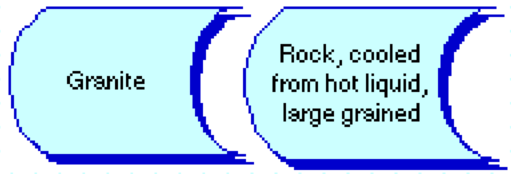
In their book 4MAT and Science, Samples, Hammond and McCarthy describe science teaching plans showing how 4MAT can be applied to the science classroom. Plans can be created for any concept or topic in science. Following are two examples, one on clouds and the other on galaxies. Juxtaposed to these plans is the generalized 4MAT model.

Teaching to Student's Individual Styles: The Multisensory Classroom. According some researchers, students who do well in school tend to be the ones that learn either by listening or by reading. The focus on these two senses, especially at the high school level tends to play havoc with the tactile and kinesthetic learners. Because so much of what happens in classrooms is focused on the auditory and visual modes, students who prefer tactile and kinesthetic modes are actually handicapped. In this section, a few suggestions are included to show how these other modalities can be included in science teaching, thereby creating a multi-sensory approach.

Keep in mind these characteristics: visual learners learn by seeing and imagining; auditory learners learn by listening and verbalizing; kinesthetic learner learns by participating, moving and talking; tactile learners learn by doing, touching and manipulating. Also remember that these modes can be combined.

• **Bring color into the science classroom**. Posters, bright bulletin boards, new paint. One technique that is effective is instead of writing on the chalkboard, write your notes and make drawings with bright marking pens on a flip chart. If you use the overhead projector, write with a variety of colored pens.

• **Make tactile learning aids**. The Dunn's describe a number of tactile aids which can be used repeatedly from class to class and year to year. One example is the task card. This multisensory resource can be used to help students review and check whether they understand material, allows students to work at their own pace, or with someone else, and frees the teacher to work with others. Suppose you want the students to review the meanings of important ideas and concepts. The teacher would prepare a set of questions with answers (or concepts with associated meanings) and prepare cards as shown below. The cards are made by cutting oaktag into strips, laminating the strips after writing the information on the cards, and then cutting each card in a unique fashion.



• **The computer as a multisensory learning aid**. Computers are powerful tools in their own right, but can be used to help the tactile and kinesthetic learner. By establishing a computer center in the classroom, and providing opportunities for individual or small groups of students to work in the center with games, tutorials, simulations, or problem solving software, the tactile and kinesthetic learner is given opportunities for personal involvement, manipulation of the keyboard and movement (to a different place in the classroom).

• **Movement**. Plan occasionally a field trip, role-playing sessions and debates, games in which the students move from one place in the classroom to another and manipulate objects. These activities favor the kinesthetic learner.

• **Hands-On**. Plan table-top learning activities in which students handle and manipulate science materials, objects, and specimens. You do not have to wait to go into the lab to favor the tactile learner. Is is possible to teach every lesson wherein there is some tactile learning happening?

• **Don't forget the auditory learner**. Showing films, video, listening to tapes, and hearing music (related to science) are activities that favor the auditory (and visual) learner. Discussion, debates and question-and-answer sessions favor the auditory learner.

There are many other ways to create a multisensory classroom. These will be presented in Chapter 3 and Chapter 6. For now it is important to remember that providing a variety of sensory modes will ensure that each student's learning style is attended to at least some of the time.