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MINDS ON *SCIENCE*

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A Web Course on the Art of Teaching Science

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Chapter 7

MINDS ON *SCIENCE:*

Models of Science Teaching

A chemistry teacher, and chair of the science department in a large school district in the Southeastern part of the United States, believes that excitement, enthusiasm and inquisitiveness should reign in science class. She uses an "inquiry-oriented" approach to teach chemistry. To drop in and visit her classroom is to observe, not only an exemplary teacher, but one who puts into practice what science educators claim should characterize high school science teaching. Students are involved in watching mini-demonstrations, and then trying to figure out what happened, testing the acidity of rain (with cabbage juice as the indicator) in the Atlanta area over a long period of time, and then drawing conclusions based on their own data, conducting micro-chemistry experiments designed to help them learn chemistry concepts inductively. Furthermore, students in her classes are linked with students in Russia by means of a computer based telecommunications system to explore cooperatively environmental chemistry issues and problems from a global perspective. In short, her method of teaching gives the students the opportunity to inquire, to question, and to explore.

The approach to teaching that this teacher uses in her classes is an inquiry approach, one of many models that science teachers employ in their classes. A model of (teaching) is a plan or pattern that organizes teaching in the classroom, and fashions the way instructional materials (books, videos, computers, science materials) are used, and curriculum is planned. We will investigate several models of teaching in this chapter that will be important to you as you begin your career.

The models that have been chosen are based on the learning theories described in Chapter 2. In addition to the inquiry model of teaching, you will explore the following models of teaching: the direct/interactive teaching model, , the learning cycle model of teaching, cooperative learning models of teaching, as well as several additional models including synectics, imagineering, person-centered learning and the integrative model of learning.

We know from research and experience that practice makes perfect. A model of teaching, to be learned, must be practiced, and practiced and practiced. Unfortunately, some teachers will try a new idea, technique or model once, not obtain very good results, and consequently abandon the notion. Some researchers report that teachers need to practice new approaches many times (perhaps as many as twenty) before the new model is integrated and part of the teacher's style of teaching. Thus, in this chapter and the next you will be introduced to two laboratory strategies that are designed to help you "practice" new ideas about teaching. Reflective teaching, which you will learn about in this chapter, will be used to help you implement the models of science teaching. By using another laboratory strategy called microteaching you will learn how to implement specific teaching strategies and skills. These laboratory strategies have been developed to help you learn about teaching through teaching.

PREVIEW QUESTIONS

- What is a model of teaching?
- When and under what conditions should different models of teaching be used?
- What is the relationship between models of teaching and theories of learning?
- What are the direct/Interactive teaching functions?
- What are some effective ways to organize content for direct/interacting teaching?
- How is inquiry teaching different than direct/interactive teaching?
- How do the models of inductive inquiry, deductive inquiry, discovery learning, and problem solving compare?
- What is the learning cycle? On what learning paradigm is the learning cycle based?
- What is conceptual-change teaching?
- What is the difference between peer tutoring, and conceptual and problem solving models of

cooperative/collaborative learning?

- What characterizes the following models of teaching: synectics, person-centered learning, integrative learning, and imagineering? How can they be used to help students understand science?

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7.1 Introduction and Goals

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7.2 Models of Teaching: How can they be of help?

Why is it important to know about models of teaching? The models that are described in this chapter are like the scaffolding for a building. Scientists use models to help them understand natural systems like rivers, atoms and cells. They are used to describe a pattern or a phenomenon. Models are also like the scaffolding of a building. It holds the building up, and gives the building its shape and integrity. A model of teaching lays the foundation for the actions and interactions between students and teachers. For example, a teacher centered model of teaching would imply a set of actions and interactions different than a student centered model of teaching. In the teacher centered model, teachers would make most of the decisions about curriculum and learning, whereas in a student centered model, students would be more involved in these decisions. What are some other differences you could name?

Models of teaching are designed to help students learn, and as you will see they are prescriptive. Each model of teaching has its set of propositions and directions enabling you to implement them in classrooms, or in tutorial situations.

Bruce Joyce and Marsha Weil (1986) describe twenty models of teaching in their book *Models of Teaching*, and they point out that the many models of teaching that are used in the schools are designed to give students the tools to grow. The models that are described in this chapter are designed to help the beginning science teacher get started in the classroom, as well as provide the tools to help secondary students learn science.

Several models of science teaching are presented, as mentioned above. There is no intention on my part to claim that one model is better than another. Rather, each model has its inherent qualities and purposes for helping students learn. Many teachers use a combination of these models, integrating them into a personal model of teaching, while other teachers focus on one of these models, and build their teaching repertoire around this favored approach.

There is a substantial body of research supporting the models of teaching selected for inclusion in this chapter. Naturally, science educators make a strong claim on the inquiry approach to teaching, and rightfully so. Inquiry certainly is an integral aspect of the nature of science, as was discussed in Chapter 1. But as science teachers, we must go beyond a singular view of teaching and incorporate a variety of models of teaching. Recent research, and trends in practice support an integrative view for formulating instructional plans. For example, most of the recent curriculum development projects at the elementary and middle school level have described models of teaching to include not only inquiry (with hands-on activities), but cooperative learning as well. A further examination of these projects also reveals that direct/interactive teaching strategies (especially teacher directed activities, and heavy reliance on teacher questioning) is an integral aspect of the approach.

What models should we explore? Using the learning theories presented in Chapter 2 as a conceptual rationale, eight models of teaching are described in this chapter (Figure 7.1), thereby presenting a kaleidoscope for the science teacher. The first model---direct/interactive teaching---is based on behavioral psychology. It is a teacher-centered model emphasizing the teaching of specific information in as a direct a manner as possible. Cognitive psychology claims several models of teaching including inquiry teaching, conceptual change teaching (the learning cycle), and synectics. Finally, two models are derived from social and humanistic psychology, namely, cooperative learning and person-centered learning.

Figure 7.1. Organization of Models of Teaching

Learning Theory Category	Model of Teaching
Behavioral Psychology	Direct/Interactive Teaching Model
Cognitive Psychology	Inquiry Teaching Model Learning Cycle Model Synectics Imagineering Integrative
Social and Humanistic Psychology	Cooperative Learning Person-centered

7.3 Direct-Interactive Teaching Model

An eight grade earth-science teacher begins a lesson by showing students several slides depicting the moon at successive one-hour intervals.. Then the teacher says, "Today we are going to discuss the sightings you made of the moon and stars in the Western sky last night for homework, and then I will do a demonstration on how to measure the altitude and compass location of a star. You will use this information to practice making measurements of fictional stars in the classroom in small groups. Finally I'll give you some problems to solve, and then you'll use what you learned today to measure changes in star motion in tonight's sky for homework.

This opening statement by a junior high science teacher conveys some of the elements of the direct/interactive teaching model. The Direct/Interactive Teaching Model (DIT) is a good place to begin because it flourishes in many classrooms, and calls on the teacher to direct students by assigning specific tasks that must be completed under direct teacher supervision. It is, however, a dynamic model in that the most effective form of direct teaching implies interaction between the teacher and the students. Thus I have combined these elements in naming this model the DIT Model.

The teaching of science information and skills can be accomplished quite effectively through the Direct/Interactive Teaching Model. In the science classroom, the material to be learned is subdivided into smaller chunks of information and is presented directly to the students. In this teacher-centered model, the teacher's role is very clear: to teach science information and skills in the most direct manner possible.

Research by a number of science educators shows that when direct instruction strategies are used a notable increase in achievement occurs. Research from a number of science education studies resulted in the following pattern. The science classroom that is based on the direct/interactive teaching model appears to be characterized by a number of factors as follows:

1. Instructional objectives are formulated and communicated to the students prior to the start of a unit of teaching.

2. Teachers gain attention at the start of each lesson by using focusing behaviors and strategies such as advanced organizers and set induction. These typically include asking questions, performing a short demonstration, or the use of an EEEP (see chapter 8).

3. Students handle, operate on, or practice with science teaching materials. This includes the full range of manipulative materials including the familiar science objects such as rocks, fossils, and plant specimens, to pictorial stimuli, as well as cardboard cutouts depicting science concepts such as crystal form, as well as the manipulation of paper products such as cards with the names and pictures of atoms, organisms, chemical equations, and the like.

4. Teachers alter instructional materials or classroom procedures to facilitate student learning. Rewriting activity or experiment procedures from a textbook,

making audio tapes of the science textbook, and giving students directions in writing are examples of how science teacher alter instructional procedures.

5. The science teacher focuses attention on the type and placement of questions asked during lessons.

6. In effective science classrooms, teachers provide immediate as well as explanatory feedback during the instructional process, rather than waiting until a quiz or major test.

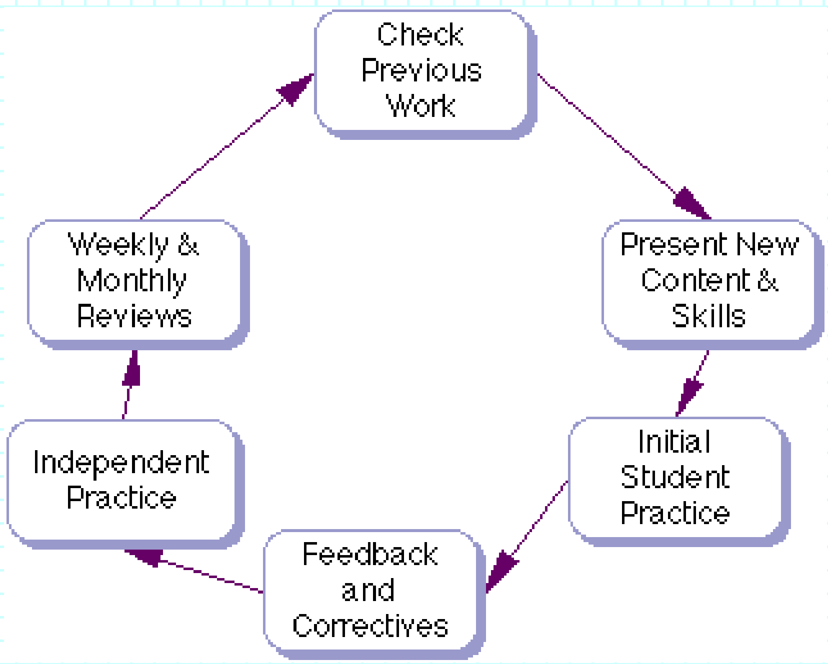
The Direct/Interactive teaching model fosters a learning environment characterized by teacher-directed learning and high levels of teacher-student interaction. Rosenshine (1983) has identified six teaching functions that taken together constitute the essential principles of direct/interactive teaching. These functions include checking previous day's homework, presenting and demonstrating new content and skills, leading the initial student practice session, providing feedback and correctives, providing independent practice, and doing weekly and monthly reviews.

Direct/Interactive Teaching Functions

Teaching Function	**Specific Behaviors**
1. Checking previous day's work and reteaching	• Check homework • Reteach areas where there are student errors
2. Presenting and/or demonstrating new content and skills	• Provide overview • Proceed in small steps, but at a rapid pace • If necessary, give detailed or redundant instructions and explanations
3. Leading initial student practice	• Provide a high frequency of questions and overt student practice • Provide prompts during initial learning • Give all students a chance to respond and receive feedback • Check for understanding by evaluating student responses • Continue practice until students are firm • Insure a success rate of 80% or higher during initial practice

4. Providing feedback and correctives (and recycling of instruction if necessary)	• Give specific feedback to students particularly when they are correct but hesitant • Student errors provide feedback to the teacher that corrections and/or reteaching is necessary • Offer corrections by simplifying question, giving clues, explaining or reviewing steps, or reteaching last steps • When necessary, reteach using smaller steps
5. Providing independent practice so that students are firm and automatic	• Seatwork and/or homework • Unitization and automaticity (practice to overlearning) • Need for procedure to insure student engagement during seatwork (i.e., teacher or aid monitoring) • Insure success rate of 95% or higher
6. Providing weekly and monthly reviews	• Reteaching, if necessary

The Direct/Interactive Teaching Model can be represented as a cycle of teaching.



As you implement this model of teaching it is important to note that four important aspects of the model stand out.

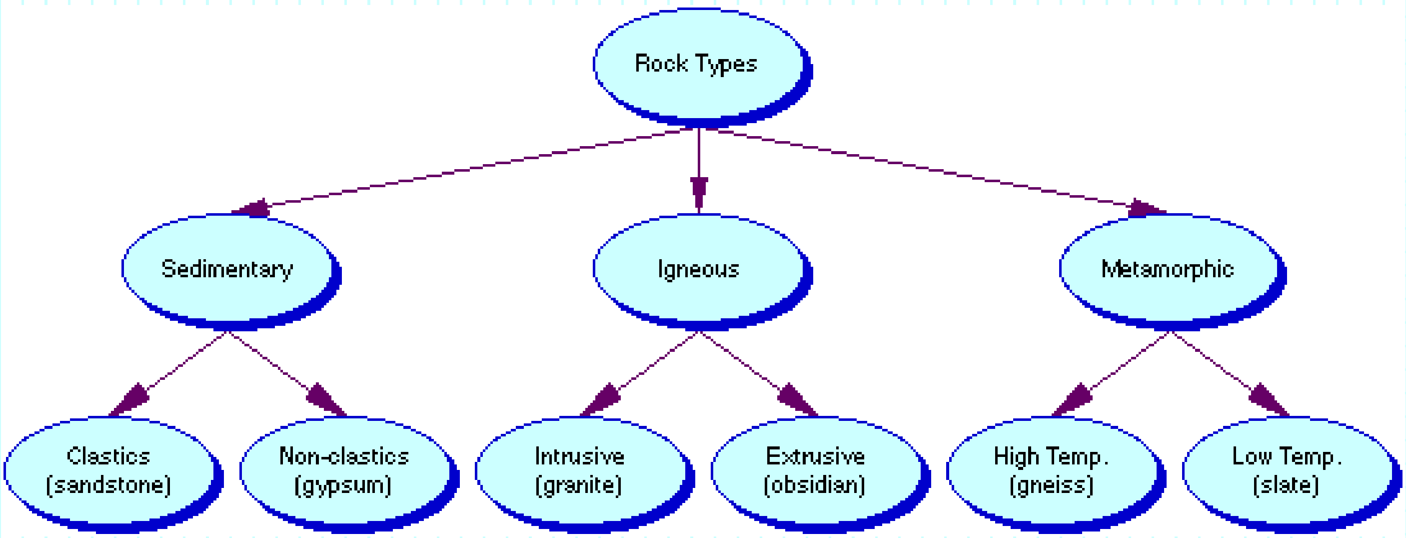
- You will need to develop and implement a variety of learning tasks.

- The learning tasks you develop should engage the learner at high levels.
- You should strive for high levels of teacher-student, and student-student interaction. You can achieve this by the use of teacher questions, use of hands-on activities and small group work).
- Your students should perform at moderate-to-high rates of success.

Structuring Content for Direct/Interactive Teaching

Another important aspect of the Direct/Interactive Teaching Model is is the presentation and structuring of science content. One of the key ingredients is to break content into manageable, teachable and learnable chunks. Borich points out that most teachers "divide" content based on the content divisions in science textbooks. As he points out, this organization is often arranged to help students read the text, and therefore may not be the best way to present content. There are a number of ways to structure new science content. Following are four suggestions that you should find helpful in dividing science content for the Direct/Interactive Teaching model. They include whole-part, sequential, combinatorial and comparative methods of content structuring.

Whole-part. Organizing content in a whole to part format is useful in introducing science content in its most general form. For instance, if you were presenting information on rock types, you might start with the question What are the types of rocks? This would lead to natural subdivisions (igneous, metamorphic and sedimentary) that can be easily learned by students.



Structuring Content: Whole to Part (Example of Rocks)

Whole-part structuring is a powerful way to organize information. Recent research using the technique of concept mapping (see chapter 2) is based on the organization of knowledge from whole to part. Whole to part thinking gives students an organizational framework from which to operate. Big ideas can be used to "hook" subconcepts and subideas, rather than as isolated bits of information.

Sequential Structuring. Sequential structuring is organizing content and skills by ordering. Typically the content or skills are presented from simplest to most complex. Sequential structuring is based on a hierarchical arrangement of science content or science skills. In a way, sequential structuring is an alternative to the Whole-part organization discussed above. Typically in the sequential structuring of science content or skills, students would be introduced to prerequisite content or skills first, and then be introduced to content or skills that was dependent on the previously learned material or skill.

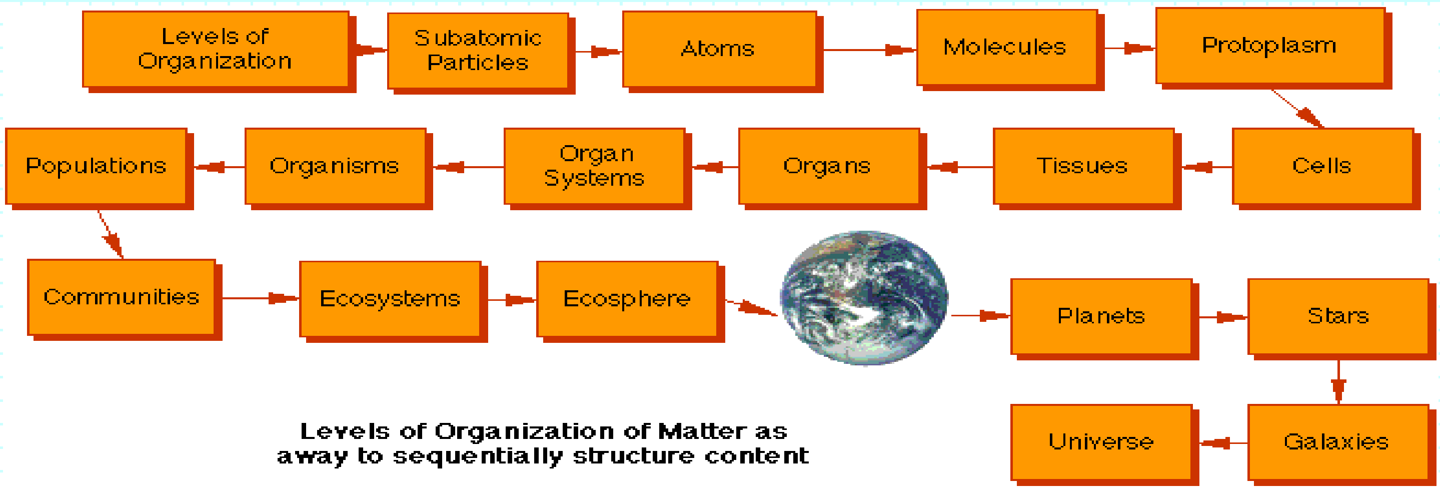
For example science skills or processes can be broken down into a number simpler skills that can be mastered in sequence. Simpler or more basic process skills would be introduced first. Examples would include:

- Observing
- Using Space/Time Relationships
- Using Numbers
- Measuring
- Classifying
- Communicating
- Predicting
- Inferring

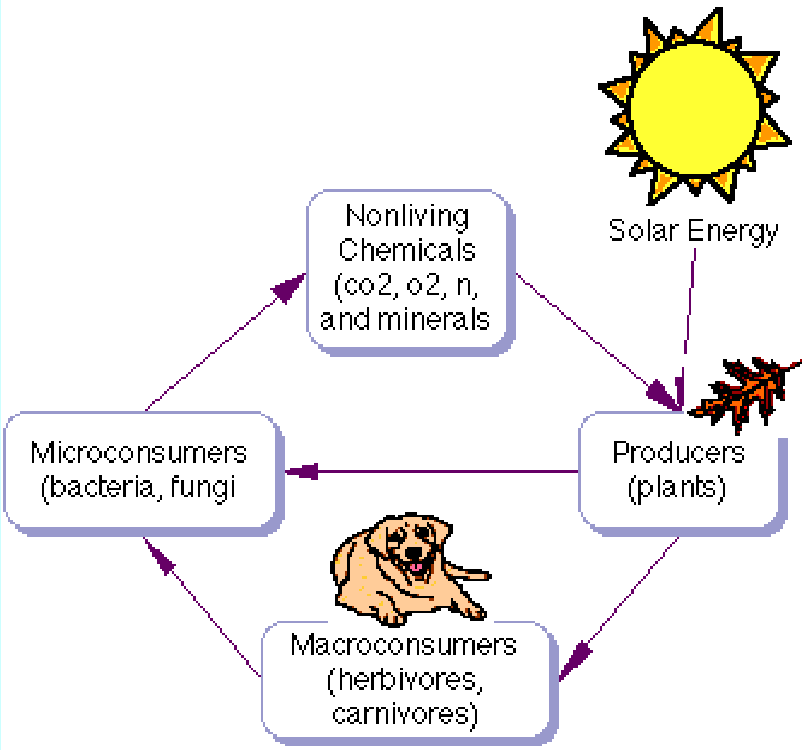
More complex science skills would be introduced later after students had mastered the more simple or basic skills. Complex science skills often involve the integration of two or more process skills, and therefore are usually refered to as integrated process skills. Some include:

- Formulating Hypotheses
- Controlling Variables
- Interpreting Data
- Defining Operationally
- Experimenting

Science content can similarly be arranged in a hierarchy. Scientists classify matter according to size and function. This classification leads to levels of organization. The levels of organization can be useful as a mechanism to sequence content. For example if we were to organize a unit of instruction on ecology, we could use the levels of organization of matter shown below as the sequence of presentation of content from the microworld, which would contain nonlife, subatomic particles, atom, atoms, protoplasm, and cells to the supermacro world consisting of stars, galaxies and the Universe.



Combinatorial Organization. Science content can be presented by highlighting connections among the various elements of content to be presented. One very effective means of doing this is to present the elements of the content in a cycle. There are many cycles in the various disciplines of science. In Earth science content could be organized, for example by means of the rock cycle or the water cycle instead of learning simply about rivers. In biology the photosynthesis, and the Krebs cycle could be organizational cycles to show relationships and combinations.



The Ecosystem Cycle can be used as a combinatorial organization to present science content

The figure above shows a summary of the major components of an ecosystem and how they are interconnected through chemical and energy cycles. Nonliving chemicals, producers, macroconsumers, and microconsumers are presented in relationship to each other. The presentation of "new content" would include the relationships as well as the specific details of the elements (e.g. macroconsumers). The cycle itself is another powerful organizing element to help the student learn and understand the material being presented.

Comparative Relationships. Another effective way to present content is comparing categories of content in order to heighten similarities and differences. The example cited (Figure 7.11) contrasts the similarities and differences among four types of drugs. The advantage of this approach is that the organization of the content into a chart is a useful learning devise for the student, and individual elements (e.g. type of drug) are learned in relationship to others. Students can graphically compare, for instance, relative dependence and effects of the drugs.

Figure 7.11 Structuring Content: Comparative Relationships---Drugs

Drug	Dependence Potential	Short-term Effects	Long-term Effects

Stimulants • Caffeine • Amphetamines • Cocaine	 Probable High High	Increased heart rate, increased blood pressure	Irregular heartbeat, high blood pressure, stomach disorders
Depressants • Barbiturates • Tranquilizers	 High High	Drowsiness, decreased coordination	Depression, emotional instability, hallucinations, death
Psychoactive drugs • Lysergic acid diethylamide (LSD) • *Cannabis sativa* (marijuana)	Probable Probable	Hallucinations Short-term memory loss, disorientation	Psychosis Lung damage, loss of motivation
Narcotics • Heroin • Codeine • Morphine	 High High High	Drowsiness, respiratory depression, nausea, constricted pupils	Convulsions, coma, death

7.4 Inquiry Models of Teaching

- A *physics* teacher asks students: "Is it a good idea to continue to develop and build new nuclear power plants?
- An *earth science* teacher asks students to interpret a set of dinosaur footprints, and generate several alternative hypotheses to explain the pattern of the prints.
- A *biology* teacher takes students on a field trip to collect leaves from different trees. Students are asked to create a classification system using the leaves.
- A *chemistry* teacher gives students an unknown substance, and asks them to use scientific tests to determine the composition of the material.

In each of the above situations, the science teacher has created a situation in the classroom in which students are asked to formulate their own ideas, state their opinion on an important issue, or to find things out for themselves. It is a radical departure from the Direct/Interactive Teaching model in which the teacher engages students to learn science information or skills. In each of the above scenarios, the student is encouraged to ask questions, analyze specimens or data, draw conclusions, make inferences, or generate hypotheses. In short the student is viewed as an inquirer---a seeker of information, and a problem solver. This is the heart of the inquiry model of teaching.

What is Inquiry?

J. Richard Suchman, the originator of an inquiry teaching program that was widely used throughout the United States once said that "inquiry is the way people learn when they're left alone." To Suchman, inquiry is a natural way that human beings learn about their environment. Think for moment about a very young child left in a play yard with objects free to explore. The child, without any coaxing will begin to explore the objects by throwing, touching, pulling, banging them, and trying to take them apart. The child learns about the objects, and how they interact by exploring them, by developing his or her own ideas about them---in short learning about them by inquiry. Many authors have discussed the nature of inquiry and have used words such as inductive

thinking, creative thinking, discovery learning, the scientific method and the like. To many, the essence of inquiry can traced to John Dewey.

Dewey proposed that inquiry is the "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends." To Dewey the grounding of "any belief" occurs through inquiry processes: reason, evidence, inference and generalization. Recently, science educations have proposed various lists of inquiry process. One such list includes: observing, measuring, predicting, inferring, using numbers, using space-time relationships, defining operationally, formulating hypotheses, interpreting data, controlling variables, experimenting and communicating.

In the context of learning, students will engage in inquiry when faced with a "forked-road situation" or a problem that is perplexing and causes some discomfort to them. In the model of inquiry presented in this chapter, the creation of forked-road situations or discomforting problems will be the essence of science inquiry activities.

What about inquiry teaching in school situations? If you recall from Chapter 1, it was shown that the predominant method of teaching in science is recitation, not inquiry. In fact, the evidence is that very little actual time is spent by students doing inquiry activities. Holdzdom and Lutz (1985) report that direct teaching strategies have greater impact than indirect ones. *However, they also report that when inquiry models of teaching were implemented, they were very effective in enhancing student performance, attitudes and skill development* . They reported that student achievement scores, attitudes, and process and analytic skills were either raised or greatly enhanced by participating in inquiry programs.

While the research supports the inclusion of inquiry models of teaching in secondary science classrooms, there appears to be a reluctance on the part of the science teachers to implement inquiry in the classroom. Several problems need to be recognized in order to overcome the reluctance to implement inquiry in the classroom.

Why is it that science teachers express the importance of inquiry yet pay little attention to it in the classroom. One reason may have to do with teacher education. It is possible that many teachers have not been exposed to inquiry teaching models in their preparation, and therefore lack the skills and strategies to implement inquiry. Some teachers report that inquiry teaching models are difficult to manage, and some report that they don't have the equipment and materials to implement inquiry teaching. Another concern expressed by teachers is that inquiry doesn't work for some students. These teachers claimed that inquiry was only effective with bright students, and it caused too many problems with lower ability students.

In spite of these problems the evidence is that inquiry models of teaching are viable approaches to teaching, and should be part of the science teachers repertoire. Science teachers have had a love affair with inquiry, and feel strongly that it should be a fundamental part of science teaching. Read about what teachers think about inquiry in theScience Teachers Talk section in the Science Teacher Gazette of this chapter. Note how the teachers interviewed link inquiry with discovery, and indicate that the reason they liked science was because of the excitement of finding out about things, probing, exploring---in short inquiring.

Inductive Inquiry

We will explore three models of inquiry teaching: inductive inquiry, discovery learning, and problem solving. We begin with inductive inquiry.

Perhaps the best example of inductive inquiry is the Inquiry Development Program developed a number of years ago by J. Richard Suchman. Suchman produced a number of inquiry programs designed to help students find out about science phenomena through inquiry. Suchman's views on inquiry are quite applicable today, and this statement by him is worth pondering:

> "Inquiry is the active pursuit of meaning involving thought processes that change experience to bits of knowledge. When we see a strange object, for example, we may be puzzled about what it is, what it is made of, what it is used for, how it came into being, and so forth. *To find answers to questions* (emphasis mine) such as these we might examine the object closely, subject it to certain tests, compare it with other, more familiar objects, or ask people about it, and for a time our searching would be aimed at finding out whether any of these theories made sense. Or we might simply cast about for information that would suggest new theories for us to test. All these activities---observing, theorizing, experimenting, theory testing---are part of inquiry. The purpose of the activity is to gather enough information to put together theories that will make new experiences less strange and more meaningful" (Suchman, 1968, p.1).

The key to the inquiry model proposed by Suchman is providing "problem-focus events." Suchman's program provided films of such events, but he also advocated demonstrations, and developed a series of idea books for the purpose of helping students organize concepts. It is the inquiry demonstrations that we use to help you develop inquiry lessons.

The Inquiry Session

As mentioned above, the inquiry demonstration is a method to present a problem to your students. The demonstration is *not* designed to illustrate a concept or principle of science. It is instead designed to present a discrepancy or a problem for the students to explore. In fact, we refer to inquiry demonstrations as discrepant events. An inquiry session is designed to engage the class in an exploration of a problem staged by means of the discrepant event. An inquiry session should begin with the presentation of a problem through a demonstration (the discrepant event), a description of an intriguing phenomena, or a problem posed by the use of prepared materials (see the inquiry box activity below). In Minds on Science, you will be introduced to an alternative approach to creating an "inquiry situation" by means of using EEEPs (see Chapter 8).

Suchman proposed six rules or procedures that teachers have found helpful in conducting inquiry sessions (Figure 7.13). According to the inquiry model, students learn that in order to obtain information they must ask questions. Questioning becomes the students initial method of gathering data. Thus the climate of the inquiry classroom must foster the axiom: 'there are no dumb questions." Students must come to believe that you will accept their questions---no holds barred. For example if you use the "Wood Sinks and Floats" (page 000), students will immediately be drawn to the discrepancy that one of the blocks of wood sinks. Once the event is presented, the teacher must be sure the students understand the real problem. Once the problem is established, the students engage in the inquiry session to construct a theory to account for the focus event. The major portion of the inquiry session is devoted to the students asking questions to gather data, which is then used to formulate one or more theories. You should refer to the "procedures for an inquiry session" before conducting an inquiry session yourself (Figure 7.13 and 7.13a).

Procedures for an Inquiry Session

Rule	**Procedure**
Rule 1: Questions	The questions by the students should be phrased in such a way that they can be answered yes or no. This shifts the burden of thinking onto the students.
Rule 2: Freedom to ask questions	A student may ask as many questions as desired once they begin. This encouraged the student to use his or her previous questions to formulate new ones to pursue a reasonable theory.
Rule 3: Teacher response to statements of theory	When students suggest a theory, the teacher should refrain from evaluating it. The teacher might simply record the theory, or ask a question about the student's theory.
Rule 4: Testing theories	Students should be allowed to test their theories at any time.
Rule 5: Cooperation	Students should be encouraged to work in teams in order to confer and discuss their theories.
Rule 6: Experimenting	The teacher should provide materials, texts, reference books so that the students can explore their ideas.

Inquiry Activities

There are numerous sources of inquiry activities (including discrepant events). I recommend the inquiry activities developed by Tik L. Liem. He has put together hundreds of discrepant events and inquiry activities that you can use in all areas of science.

Following are some examples of inquiry activities and discrepant events.

The Inquiry Box. Of all the approaches to help students learn about inquiry, the inquiry box might be considered the universal strategy. The inquiry box can be made with a shoe box, and it should be painted black. For a classroom of students, you could prepare several inquiry boxes. Students are given the box, and asked to determine what the inside of the box is like. An inquiry box contains a marble, which is the main probe that the student can use to determine the pattern that exists within the box. You can prepare different patterns by taping pieces of cardboard in interesting and perplexing patterns.

The inquiry activity consists of having teams of students explore each inquiry box that you have prepared. The student's theory consists of a diagram of the possible pattern in each box.

The Wood Sinks and Floats Discrepant Event. The teacher shows two blocks of wood, one much larger than the other. They are placed on an equal-arm balance and the results shows that the larger block is more massive than the smaller block. The blocks are then placed in container of water. The larger, more massive block floats, while the smaller and less massive ones sinks.This discrepant event leads to an inquiry into the following questions: Why did the lighter block sink and the heavier one float? Why do objects sink and float? Science principles that emerge include displacement, Archimedes' principle, and pressure.

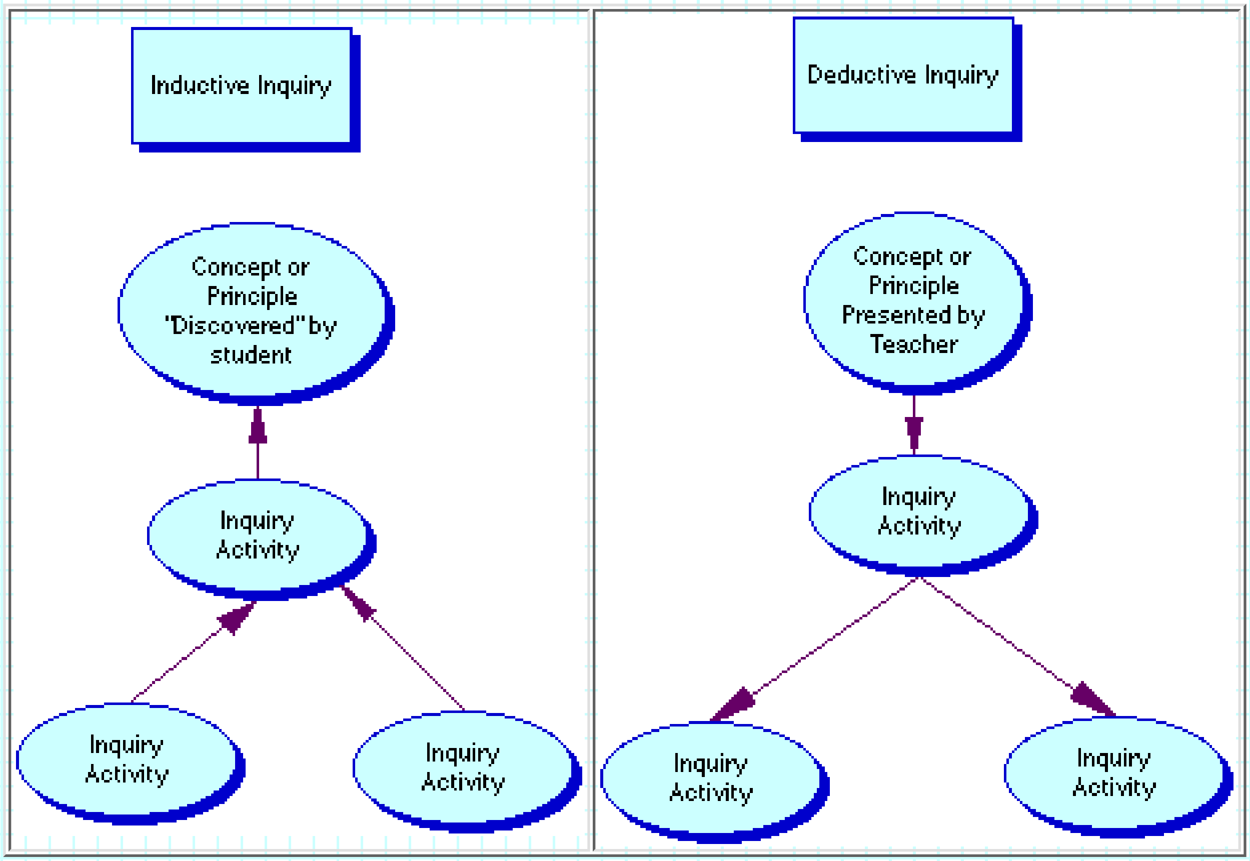
The Coin Drop and Throw. The teacher places one coin (a quarter) on the edge of a table and holds another in the air next to it. At the same instant he flicks the quarter on the table so that it flies horizontally off the table, and drops the other quarter straight down. Both coins strike the floor at the same time. An inquiry about "Why do the coins strike the floor at the same time? ensues. Hint: practice this demonstration before you perform it with a group of students. Science principles that will emerge from this inquiry include vectors, universal gravitation, and Newton's second law of motion.

The Double Pendulum. The teacher places a long rod (meter stick) across the backs of two chairs. From the rod two simple pendulums of the same length are hung. One of the pendulums is started swinging. The other is allowed to hang straight down. In a few minutes the stationary pendulum begins swinging as the arc of the swinging pendulum decreases. The inquiry focuses on: Why does the second pendulum begin to swing? Why the arc of the first pendulum decrease? The science principles in this inquiry include periodic motion and conservation of energy.

The Balloon in Water. A balloon is partially inflated, tied shut and tied to a heavy object (a rock). It is dropped into the bottom of a tall cylinder filled almost to the top with water. A rubber sheet is placed over the top of the cylinder and sealed with a rubber band. The teacher pushes on the rubber cover, and the balloon becomes slightly smaller. When the rubber cover is released, the balloon returns to its original size. The inquiry focuses on Why does the balloon become smaller and then larger again? Principles of science in this inquiry include pressure, gases, liquids and solids, and Newton's first law of motion.

Deductive Inquiry

Another form of inquiry teaching is deductive inquiry, which we can contrast with inductive inquiry. In this approach to inquiry, the teacher presents a generalization, principle or concept, and then engages students in one or more inquiry activities to help understand the concept. For example suppose the teacher's lesson plan calls for the introduction to the differences between physical and chemical weathering. The lesson begins with an explanation of physical weathering. Next the teacher discusses the attributes of chemical weathering. During the discussion of physical weathering the teacher would discuss various types of mechanical weathering including frost action, drying, and cracking. Chemical weathering processes such as carbonation, oxidation, hydration and leaching would be introduced.



Inductive and deductive inquiry contrasted in concept maps

After the development of the major concepts through presentation and questioning, the teacher then engages the students in an inquiry activity in which they explore the concepts of physical and chemical weathering. One approach that has been successful with these concepts is the following. The teacher places in individual trays, examples of earth materials that have been effected by either physical or chemical weathering (e.g. rocks with cracks, soil, mud cracks, plants growing in cracks in rocks, staining evident in the minerals of rocks). Working in teams, students study each tray and hypothesize what caused the change they observe. After all teams have investigated each tray, students write their hypotheses on a large chart on the chalkboard. The teacher leads a post-activity discussion in which the students defend their hypotheses.

Most of the science textbooks written for middle and secondary science courses contain hands-on activities that reinforce the deductive inquiry approach. If the activities are used in the context of deductive inquiry they can be extremely helpful in aiding students' understanding of the concepts in the course.

Discovery Learning

Discovery learning, a concept advocated by Jerome Bruner, is at the essence of how students learn concepts and ideas. Bruner talked about the "act of discovery" as if it were a performance on the part of the student. To Bruner, discovery, "is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to new insights. Bruner believed that discovery learning could only take place if the teacher and student worked together in a cooperative mode. He called this type of teaching "hypothetical teaching" and differentiated it from "expository teaching." In Chapter 1 referred to these forms of teaching as "engagement" versus "delivery."

Discovery learning in the science classroom engages the student in science activities designed to help then assimilate new concepts and principles. Discovery activities help guide the students to assimilate new information. In such activities students will be engaged in observing, measuring, inferring, predicting, and classifying.

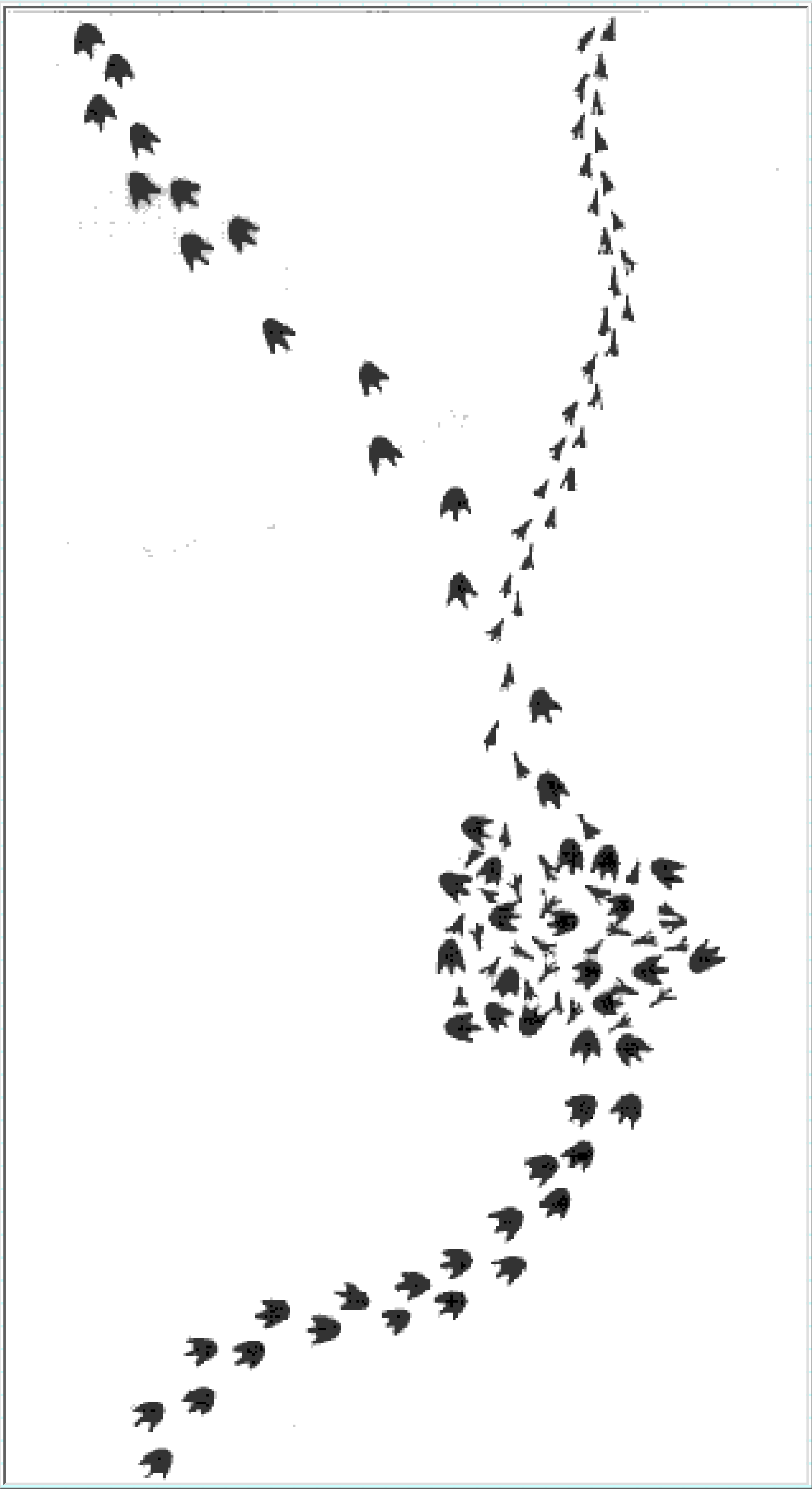
There are a number of practical suggestions that you can implement to foster discovery learning in the classroom.

1. Encourage curiosity. Since the student in discovery learning is the active agent in learning, the science teacher should foster an atmosphere of curiosity. Discrepant events and inquiry activities are excellent ways to foster curiosity. Having interesting and thought provoking bulletin boards is another way to arouse curiosity.

2. Help students understand the structure of the new information. Bruner stressed that students should understand the structure of the information to be learned. He felt that teachers needed to organize the information in a way that would be most easily grasped by the student. Bruner suggested that knowledge could be structured by a set of actions, by means of graphics, or by means of symbols or logical statements. Demonstrating the behavior of objects is a more powerful way for some students to grasp Newton's laws of motion, rather than by the three classic verbal statements.

3. Design inductive science labs or activities. The use of inductive science activities is based on the assumption that the teacher is aware of the generalization, principle or concept that the students are to discover. An inductive lab or activity is designed so that the student is actively engaged in observing, measuring, classifying, predicting and inferring. Generally speaking the teacher provides the specific cases, situations or examples that students will investigate as they are guided to make conceptual discoveries. An example of an inductive science activity is the footprint puzzle (see below) in which students are guided to make discoveries about the behavior and environment of dinosaurs that made these prints. After the students have explored the footprint puzzle, and have written at least three alternative hypotheses to explain the tracks, the teacher leads a discussion to help the students discover some concepts about the dinosaurs.

One of the points Bruner made about discovery was that it the is result of making things simpler for the student. In science, making the science concepts simpler through inductive activities is a far more powerful approach than presenting vast amounts of information about the concept.



The Dinosaur Footprint Activity

4. Encourage students to develop coding systems. Coding systems help students

make connections among objects and phenomena. Bruner felt that students could learn the method of discovery---the heuristics of discovery---if provided with many puzzling situations. For example, giving students a box of rocks and asking them to invent a classification system of their own would help them understand the principles of coding and classification. The computer is a powerful learning tool in this regard. Programs are available to enable students to practice working with puzzling situations and develop expertise in coding.

5. Design activities that are problem oriented. Students need to be engaged in problem solving on a regular basis if they are to learn about the heuristics of discovery. Bruner said "It is my hunch that it is only through the exercise of problem solving and the effort of discovery that one learns the working heuristics of discovery." In short, he said that students need practice in problem solving or inquiry in order understand discovery. Activities that are problem oriented often have a simplistic ring to them. For example, here are some problems, anyone of which, could be a learning activity for students:

- . Find a million of something and prove it.
- . Go outside and find evidence for change.

6. Foster intuitive thinking in the classroom. Intuitive thinking to Bruner implied grasping the meaning, significance, or structure of a problem without explicit analytical evidence or action. Here is where Bruner thought that playfulness in learning was important. Students in a classroom whose teacher values intuition knows that it is acceptable to play with all sorts of combinations, extrapolations, and guesses, and still be wrong. Including some science activities that encourage guessing and estimating will foster intuitive thinking. Qualitative activities in which students are not encouraged to find a specific answer to a problem will encourage intuitive thought. Skolnick, Langbort, and Day (1997), in their book How to Encourage Girls in Math & Science suggest a number of intuitive strategies including estimating, and engaging in activities with many right answers and multiple solutions.

Problem Solving

Problem solving as a method of inquiry can be used to teach problem solving skills and to engage students in the investigation of real problems. Don't be fooled by questions and problems that appear at the end of the chapters in science text books. For the most part, these "problems" are merely questions that require students to look up the answer in the text, or plug in the numbers of a formula.

Problem solving in the context of inquiry engages students in problems that real and relevant to them. The problems do not have to be ones that students generate (although this approach is probably more powerful). They can be problems that the teacher has presented to the students for investigation. Science, unfortunately, is often presented in textbooks as "problem-free." That is, the content of science is arranged in a very neat and tidy way. The truth of the matter is that science is often messy and cluttered, and full of problems.

There are many approaches to dealing with the question of problem solving as a model of inquiry teaching. Dorothy Gabel (1989)points out that some science educators prefer an approach that focuses on process skills, others concentrate on helping students solve global qualitative problems, while others focus on mathematical problem solving.

For example, Charles Ault (1989) makes these suggestions for teaching problem solving in earth science classes. These suggestions are quite applicable to physical and life science.

- Identify the conceptual models needed to reason in specific domains. For example, accounting for falling raindrops is not simple. How do droplets form in the sky? How do they get bigger? What keeps small droplets suspended? Do ice and water coexist in clouds? Do static charges make drops coalesce or not? When rain stops, why are there often still clouds in the sky? Good conceptual models have the raw materials for constructing answers to unusual questions as well as standard ones.
- Solve problems about phenomena familiar to students' experiences. Include plenty of usable content that can resolve dilemmas, such as those dealing with condensation nuclei and the vapor pressure of ice crystals versus water droplets in the preceding example.
- Use props to assist visualization and abstract reasoning. If there are distortions of scale, make them explicit.Have students construct three-dimensional, two-dimensional, and verbal representations of problems. Link the levels of representations.
- Ask for oral and written restatements of problems, emphasizing precise meanings of terms and relationships in models.
- Connect abstractions to everyday experience by analogy: For example, compare escalators and merry-go-rounds to relative motion and orbit. Be certain that important relationships are well understood in the context of the analogies.
- Use imagination and imagery to express scale: Contrast ancient toeholds in the Betatakin ruins of the Anasazi people with the even-older excavation of the canyon and cavern. Try body language to convey patterns in Earth forms or motion in celestial bodies.
- Remember that the complexity of teaching and learning Earth science vastly exceeds the ability of research to offer prescriptive advice.
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7.5 Constructivist Models

Suppose you are teaching a general science course in a middle school and the first unit of the year is *ecosystems*. Suppose further that your college professor introduced you to a method called concept mapping, and you decide to use it to identify the concepts that students might need to understand a unit on ecosystems. Figure 7.20 shows the subconcepts and their relationship to the general concept of ecosystem.

Figure 7.20

Concept Map for a Teaching Unit on Ecosystems

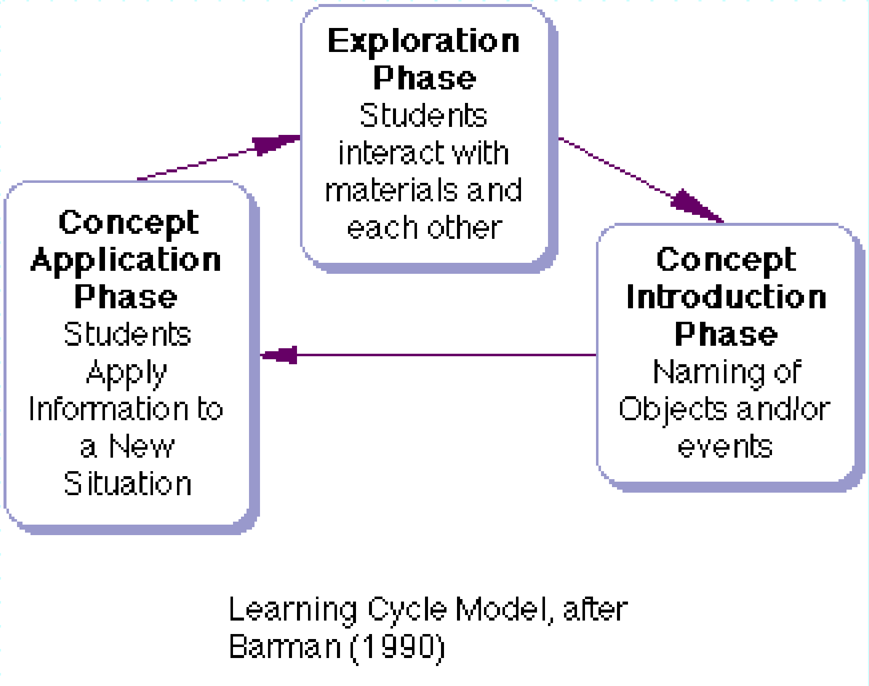
What is the best way to teach students concepts as depicted on this concept map? Recent research (see Chapter 2) has suggested that students construct their own ideas about their world---including concepts---and any attempt to teach "new" concepts to students must take this into consideration. Researchers who have supported this view have been labeled "constructivists" because of their belief that students construct their own knowledge structures---concepts, beliefs, theories. More often than not, the concept-base that students bring to your class is naive and full of misconceptions. To understand science from the constructivist view means that students will have to change their concept--hence the term conceptual-change.

The Learning Cycle Model

A number of constructivist models have emerged over the last thirty years that suggest that teachers should sequence instruction into a series of teaching/learning phases. The sequences have been described as learning cycles. For example, the earliest example of a learning cycle was suggested by Chester Lawson in which he described scientific invention as "Belief - Expectation - Test." But the first direct application of a learning cycle to science teaching was proposed by Robert Karplus, Director of the Science Curriculum Improvement Study (SCIS) in 1970. He proposed a three phase cycle consisting of *preliminary exploration, invention, and discovery*. In essence, Karplus believed that students need to first explore the concept to be learned using concrete materials. The initial introduction of the concept was called invention. In this phase the teacher assumed an active role in helping the students use their exploration experiences to invent the concept. To Karplus, the discovery phase provided the student with the opportunity to verify, apply or further extend knowledge of the "invented" concept.

Recent work by Charles R. Barman (1990), and the team of Lawson, Abraham and Renner (1989) have proposed a learning cycle based on the work of Karplus, but have changed the terminology. We shall use their terminology in this book when we refer to the learning cycle model.

The learning cycle has three phases that form the foundation for sequencing science lessons. Normally a sequence would take at least three sessions---see the sample lessons that follow. Exploration, concept introduction and concept application phases are described below.



Exploration Phase. During this phase the students explore a new concept or phenomenon with "minimal guidance." Students might make observations of and classify objects. They might be involved in "messing about" with batteries, bulbs and wires to find out how the light bulb works. Students might also perform experiments to gather data to test an hypothesis. In short, the exploration phase allows the students to examine "new ideas" and test them against their own ideas. Students are actively engaged in interacting with ideas, as well as their peers during the exploration phase. During this phase the teacher should facilitate the work of the students by establishing a reasons for exploring new ideas. The use of discrepant events, followed by interesting science activities is a way to get into the exploration phase. The teacher plays a facilitative role during this phase.

Concept Introduction Phase (Also called the Term Introduction Phase). During this phase the teacher assumes a more direct, active role and uses the students' exploratory activities as a means of introducing the scientists view of the concept or theory that was investigated in the exploratory phase. During this phase students express their ideas about the concepts and ideas, and the teacher presents in very succinct ways, the meaning of the concepts and ideas from a scientific point of view. The teacher assumes the direct/interactive mode during this phase planning lessons along the guidelines presented in the direct/interactive section. The concept introduction phase is an intermediary step, and the teacher should move quickly to the next phase.

Concept Application Phase. The concept application phase is a student centered phase in which small teams of students engage in activities designed to apply and extend their knowledge of science concepts. The teacher should design activities that challenge the students to debate and defend their ideas. Activities in the concept application phase should be problem-oriented. The teacher resumes the facilitative role in the concept application phase.

Learning Cycle Lesson Example 1:

What can be learned from skulls?

Overview: Students observe a variety of vertebrate skulls and attempt to identify the animal and what it eats. Concepts such as herbivore, omnivore, carnivore, nocturnal, diurnal and niche are introduced.

Exploration Phase. Skulls are placed at ten numbered stations. Students work in small teams and "visit" each numbered station, or the skulls are passed to each team. The teacher explains that the teams should be challenged to make inferences, like paleontologists do, about the lifestyle and habitat of vertebrates by observing their skulls. The teacher provides each group with one copy of the following questions:

• What type of food does this animal eat, and what is the evidence for your inference?

• Is this animal active during the day, night, or both? What is the evidence?

• Is the animal a predator or a prey? Why?

Concept Introduction. After the student teams have gathered data on each skull, conduct a session in which you ask different teams to describe each skull. Conduct a discussion focusing on the differences among the skulls. Students will focus on teeth. Write their words on the board they use to describe them. Use the teeth to suggest function. Introduce the terms herbivore, carnivore and omnivore. Ask the students to explain what these terms mean. You can clarify student concepts and misconceptions by explaining carefully, for example: "This animal has sharp teeth for tearing and no flat teeth for grinding. This implies that it eats only animals. An animal that eats other animals is called a carnivore."

Concept Application. Provide opportunities for students to investigate a variety of bones in addition to skulls. What inferences can they make from the structure about their function?

Learning Cycle Example 2:

What Caused the Water to Rise?

Overview. Students invert a cylinder over a candle burning in a pan of water. They notice that the flame soon goes out and water rises into the cylinder. They engage in discussions to explain their observations. They then test their explanations which leads to new explanations and understanding of combustion, air pressure and scientific inquiry.

Materials. aluminum pie tins, birthday candles, matches, modeling clay, cylinders (open at one end), jars (of various shapes and sizes), syringes, rubber tubing.

Exploration. Begin the lesson by giving each team a student hand out describing the inquiry procedure, as well as the materials listed above. Students should then be given the opportunity to explore the phenomenon by the following these procedures:

1. Pour some water into the pan. Stand a candle in the pan using the clay for support.

2. Light the candle and put a cylinder, jar or beaker over the candle so that it covers the candle and sits in the water.

3. What happened?

4. What questions are raised?

5. What possible reasons can you suggest for what happened?

6. Repeat your experiment in a variety of ways to see if you obtain similar or different results. Do your results support or contradict your ideas in #5? Explain.

After 30 minutes of experimenting stop the students for a discussion of their results. Focus the students on the questions *Why did the flame go out?* and *Why did the water rise?* The most likely explanation (misconception) to the second question is that since the oxygen was "burned up" the water rose to replace the oxygen which was lost.

Lead the students to realize that is hypothesis predicts that varying the number of burning candles will not effect the level of water rise. Four candles, for instance, would burn up the available oxygen faster and go out sooner than one candle, but they would not burn up more oxygen hence the water should rise to the same level.

Have students do the experiment. The results will show that the water level is affected by the number of candles (the more candles, the higher the water level). Their ideas has been contradicted. Explain that an "alternative explanation" is needed and ask the students to propose one.

As students propose alternative ideas do not tell them if they are correct. For example, the "correct" explanation (the heated air escaped out the bottom) should not be revealed even if students suggest it. Ask students to think of ways to test their hypotheses. If they propose the heated air hypothesis, this should lead to the prediction that bubbles should be seen escaping from the bottom of the cylinder. As alternative hypotheses are suggested, have the students test the hypotheses and look for evidence to support predictions. If students do not suggest the "correct" explanation, suggest it yourself. You might say, "What do you think about this idea? The heat from the flame heats the air and forces it out the the bottom of the cylinder." Encourage students to test your explanation rather than accepting as is.

Concept Introduction. After students have collected data testing various hypotheses, you should introduce the "correct" explanation again and introduce the term air pressure and a molecular model of gases which assumes air to be composed of moving particles that have weight and can bounce into objects (such as water) and push them out of the way.

Concept Application. Provide a number of problem solving situations in which students must apply air pressure and the molecular model of matter.

• Application Problem #1: Give students a rubber tubing, a syringe, a beaker and a pan of water. Tell them to invert the beaker of water in the pan of water. Challenge them to find a way to fill the beaker with water in that position. (The students will try forcing water in, before discovering they must extract air from the beaker.

• Application Problem #2: Challenge the students to find a way to insert a peeled, hard boiled egg into a bottle with an opening that is smaller in diameter than the egg. They can not touch the egg after it is placed on the mouth of the jar. (After a small amount of water in the bottle has been heated, it is only necessary to place the smaller end of the egg over the opening of the bottle to form a seal. The egg will be forced into the bottle by the greater air pressure outside as the air cools inside.

• Application Problem #3: Pour a small amount of very hot water into a large (2 L) plastic soda bottle. Then screw the cap on tightly to form a seal. Place the bottle on a desk so that students can view it. The plastic bottle will begin to be crushed. Challenge the students to explain the result using the molecular model of gases and air pressure.

7.6 Generative Model

generative learning model is a teaching sequence based on the view that knowledge is constructed by the learner. It is therefore, a conceptual-change model. As James Minstrell, a high school physics teacher and cognitive researcher says, "restructuring students' existing knowledge has become the principal goal of instruction." Minstrell shows how he begins a unit of teaching based on the generative model with this "preliminary phase" lesson:

Teacher: Today we are going to explain some rather ordinary events that you might see almost any day. You will find that you already have many good ideas that will help explain those events. We will find that some of our ideas are similar to those of scientists, but in other cases our ideas might be different. When we are finished with this unit, I expect that we will have a much clearer idea of how scientists explain those events, and I know that you will feel more comfortable about your explanation.

Teacher: A key idea that we are going to use is the idea of force. What doe the idea of force mean to you? (A discussion follows. My experience suggests that the teacher should allow this initial sharing of ideas to be very open)

Teacher: You've mentioned words that represent many ideas. Most of them are closely related to the scientist's idea of force, but they also have meanings different from the scientist's ideas. Of the ones mentioned, probably the one that comes closest to the meaning the physicist has is the idea of push or pull, so we'll start with that. We'll probably find out that even that has a slightly different meaning to the physicist. (the teacher should allow the class to begin with this meaning for force rather than present an elaborate operational definition)

Teacher: OK, let's begin. (dropping a rock): Here's a fairly ordinary event. We see something like this happening every day. How would you explain this event, using your present ideas about force? Instead of speaking right now, make drawings of the situation and show the major forces acting on the rock when it falls. Use arrows to represent the forces, and label each as to what exerts the force.

Students (naming the forces they have represented: Gravity by the earth. Weight of the rock. Both gravity and the weight. Air. Friction. The spin of the earth. Nuclear forces.

Teacher: Which of these is the major force, or which are the major forces acting on the rock while it is falling?

Students: Its weight. Gravity.

Teacher: Is the falling rock moving at a constant speed, or is it speeding up or slowing down? How do you know? (Teacher waits three to five seconds)

Students: The same speed. (More wait time) No wait, if two things fall, they both fall equally fast. I don't know. I think the rocks speeds up. (Students continue making suggestions. The teacher encourages as many students as possible to comment.

Teacher: During the next several days we will look more closely at the idea we call force. Many of the ideas you've suggested today will be useful, but we may also find that we will want to change some of our notions about force to make them more consistent with the phenomena.

The "preliminary phase" of the generative model of learning is designed to identify existing student ideas. In the example cited here, the teacher, performing a simple demonstration, asked students to make a drawing of the event, and then engaged the whole class in a discussion designed to identify the students existing ideas. No attempt was made by the teacher to "correct the student responses or label them wrong" or give the scientific meaning of the concepts. Student existing ideas can also be determined by giving a diagnostic test at the beginning of a course, or a short pre-instruction quiz at beginning of a unit.

Osborne and Freyberg, advocates of the generative learning model have identified three distinct phases to the the model, in addition to the preliminary phase, namely: focus, challenge, and application. The generative learning sequence is shown in Figures below.

The Generative Learning Model Teaching Sequence
Preliminary------------->Focus------------->Challenge-------------->Application

The focus phase is designed to help the teacher and student clarify the students' initial ideas. Osborne and Freyberg suggest that the focusing phase is the time to involve the students in activities that focus on phenomena related to the concepts, to get the students thinking about these phenomena in their own words. The teacher's role is a motivational one, as well, during this phase. As I mentioned earlier, motivation to learn, in the cognitive view, is related to the intrinsic nature of learning. Providing interesting activities that focus attention on getting the students involved is suggested.

The challenge phase focuses attention on challenging student ideas. The teacher, through small group discussion, or with the class as a whole, creates an environment whereby students can articulate their ideas, and hear other students' points of view. The students are challenged to compare their ideas to the scientists' view. The discussion during the challenge phase centers on the experiences students encountered during the focusing phase. During this phase, some degree of conceptual conflict will occur as students accommodate new ideas. It is in the words of the cognitive psychologists, the tension or struggle that occurs mentally to accommodate new structures, or modify existing ones.

The application phase is the instructional period in which students can practice using the new idea in differing situations. The teacher's role is one of creating problem situations for student application of the new ideas. Designing small group activities and independent investigations that challenge students to apply the new concepts to different phenomena will facilitate the accommodation of the new idea, and provide the time students need to reflect or think about their new learnings.

By now you should have noted the high degree of similarity between the generative model of learning described here and the learning cycle model. Note that the major difference is the identification of a preliminary stage in the generative model, otherwise the phases correlate.

The Generative Learning Model

Phase	Teacher Activity	Pupil Activity
Preliminary	Ascertain students' views	Complete surveys, quizzes, or activities to ascertain existing ideas
Focus	Provide motivation experiences. Asks open ended questions. Interpret student responses. Interprets and elucidates students' views.	Engage in activities in order to become familiar with phenomena related to "new concepts." Ask questions about phenomena and activities. Describes what they know about events and phenomena. Clarifies own views on concepts. Presents own view to small groups and whole class.
Challenge	Facilitate exchange of views. Creates an environment in which all views are considered. Demonstrates procedures, phenomena, if necessary. Presents evidence to support scientists ideas. Explores the tentative nature of students' reaction to new view.	Considers the view of another student, as well as all students in class. Compares the scientists' view with the class's view.
Application	Designs problems and activities which can be solved with the new idea or concept. Helps students clarify views on the new ideas. Encourages an atmosphere whereby students verbally describe solutions to problems.	Solves practical problems using the new concept as a basis. Presents solution to other students. Discusses and debates the solutions. Suggests further problems arising from the solutions presented.

7.7 Cooperative Learning Models

A number of studies, as well as numerous practical applications, have led to a mountain of evidence that supports the use of small, mixed-ability cooperative groups in science classes. We are using the term collaborative in the heading of this section to emphasize the importance of verbal communication among the students within the small teams. Students need to talk about their observations, their ideas, and their theories in order to understand science. Students need to get along with each other.

As we said in Chapter 2, cooperative learning is a model of teaching in which students work together to achieve a particular goal or complete a task. A variety of cooperative learning models have been developed, field-tested, and evaluated. Some delineate how tasks are structured and how groups are evaluated. In some models, students work together on a single task; in others, group members work independently on one aspect of a task, pooling their work when they finish. Regardless of the model, there appears to be essential components of cooperative learning that are integral to any model of cooperative learning. We'll examine these essential components first, then move on and look at several cooperative learning models.

Essential Aspects of Cooperative Learning

Cooperative learning brings students together to work on tasks---solving problems, reviewing for a quiz, doing a lab activity, completing a worksheet. In all cases its the "working together" that is important. And this has presented a challenge to teachers, as well. When cooperative learning was introdued (in the early 1970s), American schools were faced with two important social changes. One was the mainstreaming of handicapped and disabled students into the regular classroom; the other was the integration of schools in which students from different cultural background were brought together in desegregated settings. One of the solutions proposed to help students from different racial groups work together in the same school setting, and for many handicapped students who lacked many "social skills," was cooperative learning. David and Roger Johnson (1996) outlined the essential components of a teaching and learning strategy that would focus on bringing small groups of students together in teams to work "cooperatively" as opposed to individually or competitively.

The Johnsons proposed a model in which five elements were essential for cooperative learning groups to be successful. That is, the lessons that teachers taught needed to be characterized by the following elements:

Face-to-Face Interaction. The physical arrangement of students in small, heteorogeneous groups encourages students to help, share and support each other's learning.

Positive Interdependence. The teacher must structure the lesson either through a common goal, group reward, or differentiated role assignments to achieve interdependence among students in a learning team. One way to achieve this is instead of having each member of a lab team write up their own report, each team has *one* lab sheet and all students might sign off agreeing with its contents. A single grade is given based on the *team's* lab sheet. Assigning each person a role in the group is another way to achieve positive interdependence, e.g. members are assigned one of the following roles for an activity: chief scientist, researcher, observer/recorder, lab technician.

Individual Accountability. Each student in a learning team must be held accountable for learning and collaborating with other team members. Teachers can achieve individual accountability by focusing on a) individual contributions of individuals (using roles, dividing the task, using experts, giving feedback) and b) individual outcomes of individuals (using tests, quizzes, grading homework, giving group rewards for individual behavior, using random calling-on procedures).

Cooperative Social Skills. The Johnsons found that students needed to learn interpersonal skills such as active listening, staying on task, asking questions, making sure everyone contributed, using agreement, and so forth. Just as science teachers focus on scientific thinking skills (observing, inferring, hypothesizing, experimenting), and assume that students need to be taught these skills, cooperative learning experts have discovered that students need to be taught cooperative social skills.

Group Processing. The fifth essential element of cooperative learning is group processing. Students need to reflect on how well they worked together as a team to complete a task such as a laboratory activity. The teacher can structure this by simply asking the students to rate how well they did in the activity; or how well they "practiced" the social skill that was central in the activity.

The models that are presented here fall into two broad categories: tutorial methods, and problem-solving and conceptual methods. The tutorial methods tend to be structured and teacher-centered, while problem-solving methods tend to be more open-ended, and student-centered. The tutorial methods posses many of the characteristics of direct instruction, while the problem-solving methods facilitate inquiry learning. Elements of both methods will be seen to useful in learning cycle models.

Tutorial Models

In tutorial models students work in small teams to rehearse and learn science information that has been identified by the teacher. Often the material is based on the science textbook, and because of this, tutorial models are easily applied to the secondary science classroom. These methods tend to be motivational because they often involve teams competing against each other for reward structures (e.g. points, prizes, free time). Three models are presented, Student Teams Achievement Divisions, Jigsaw and Two Level Content Study Groups.

Student Teams-Achievement Divisions (STAD). STAD was originated by Robert Slavin and his colleagues at Johns Hopkins University. The STAD model underscores many of the attributes of direct instruction, and it is a very easy model to implement in the science classroom. As in all the cooperative learning models to follow, STAD operates on the principle that students work together to learn and are responsible for their teammate's learning as well as their own.

There are four phases to the STAD model (Figure 7.28): teach (class presentation), team study, Test and Team Recognition. We will illustrate how STAD works by using an example for life science---food making (photosynthesis).

Phase I: Teach (Class Presentation). The class presentation is a teacher-directed presentation of the material---concepts, skills, and processes---that the students are to learn. Carefully written and planned objectives should be stated and used to determine the nature of the class presentation, and the team study to follow. Examples from a unit on Food making would be:

• Students will identify the steps in the food-making process

• Student will compare the light and dark phases of photosynthesis

Key concepts should be identified as well. In this case the following concepts would be presented: ATP, chlorophyll, dark phase, energy, glucose, light phase, photosynthesis.

The presentation can be a lecture, lecture/demonstration, or audiovisual presentation. You also could follow the lesson plans in the your science textbook, including the laboratory activities in this phase of STAD. Several lessons would be devoted to class presentations.

Phase II: Team Study. In STAD teams are composed of four students who represent a balance in terms of academic ability, gender, and ethnicity. The team is the most important feature of STAD, and it is important for the teacher to take the lead in identifying the members of each team. Slavin recommends rank ordering your students in terms of performance. Each team would be composed of high and low ranking student and two near the average. The goal is to attempt to achieve parity among the teams in the class. Teams should also be formed with sex and ethnicity in mind. Each team should be more or less an average composite of the class.

Team study consists of one or two periods in which each team masters material that you provide. Team members work together with prepared worksheets and make sure that each member of the team can answer all questions on the worksheet. Students should move their desks so that they face each other in each small team. Give each team two worksheets and two answer sheets (not one for each student). For example in the case of the Food Making unit, the teacher would provide the diagram shown below (Figure 7.29) summarizing photosynthesis, and construct a worksheet consisting of about thirty questions related to Food Making on a worksheet (Figure 7.30).

Figure 7.29

(Photosynthesis diagram)

In the STAD model the following team rules are explained and posted on the bulletin board:

1. Students have the responsibility to make sure that their teammates have learned the material.
2. No one is finished studying until all *teammates* have mastered the subject.
3. Ask all teammates for help before asking the teacher.
4. Teammates may talk to each other *softly*.

It is important to encourage team members to work together. They work in pairs within the teams (sharing one worksheet), and then the pairs can share their work. A principle that is integral, not only to STAD, but to all cooperative learning models is that students must talk with each other in team learning sessions. It is during these small group sessions that students will teach each other, and learn from each other. One of the ways to encourage deeper understanding is for students to explain to each other their answers to the questions. One way to facilitate this process is for the teacher to circulate from group to group asking questions, and encouraging students to explain their answers

Sample Worksheet Questions (STAD)

1. The organ of the plant in which photosynthesis most often takes place is the a. stem b. root c. leaf	2. Plants need which of the following to carry on photosynthesis? a. O2, CO2, chlorophyll b. H2O, CO2, light energy, chlorophyll c. H2O, O2, light energy, sugar	3. The energy stored in plants comes form a. soil b. air c. sunlight	4. The first phase of photosynthesis is sometimes called the a. light phase b. dark phase c. chlorophyll phase
5. The oxygen released during photosynthesis comes from the a. chlorophyll b. carbon dioxide c. water	6. Photosynthesis takes place in the _________ of a plant cell. a. cell wall b. cytoplasm c. chloroplast	7. The energy from the sun is stored in a chemical compound called a. ATP b. CO2 c. H2O	8. The second stage of photosynthesis is called the a. light phase b. dark phase c. chlorophyll phase

Phase III: Test. After the team study is completed, the teacher administers a test to measure the knowledge that students have gained. Student take the individual tests and are not permitted to help each other. To encourage students to work harder, STAD uses an "individual improvement score." Each student is assessed a base score---based on his or her previous performance on similar quizzes and tests. Improvement points, which are reported for each team on a team recognition chart on the bulletin board, are determined based on the percentage of improvement from the previous base score. Generally speaking, if the student get more than 10 points below the base score, the improvement score is 0, 10 points below to 1 point below results in 10 improvement points, base score to 10 points above gives a score of 20, and more than 10 points above is worth 30 improvement points. (A perfect score, regardless of base score earns 30 improvement points.

Phase IV: Team Recognition. Team averages are reported in the weekly recognition chart. Teachers can use special words to describe the teams' performance such as *science stars, science geniuses, or Einstein's.*

Recognition of the work of each team can occur by means of a newsletter, handout, or bulletin board that reports the ranking of each team within the class. Report outstanding individual performances, too. Sensitivity is required here. It is important to realize that praising students academically from low status groups is an integral part of the effectiveness of cooperative learning. Elizabeth Cohen has found that it is important to be aware of students who you suspect have consistently low expectations for competence. When such a student performs well (not just on the quiz), give immediate, specific and public recognition for this competence.

One final note about STAD. There is another model developed by Slavin called Teams-Games-Tournaments (TGT) that is also recommended and is very similar to STAD. The same materials used in the team study are used in a series of games in a tournament style class session.

Jigsaw II.

Jigsaw II (developed by Eliot Aronson) is a cooperative learning model in which students become experts on part of the instructional material about which they are learning. By becoming an expert, and then teaching other members of their team, students become responsible for their own learning. The Jigsaw II model has the advantage of encouraging students of all abilities to be responsible to the same degree, although the depth and quality of their reports will vary.

In Jigsaw II students are grouped into teams of four members to study a chapter in a textbook. However, the content is broken into chunks, letting each team member become an expert on the one of the chunks and then responsible for teaching his or her team members that chunk. The phases of Jigsaw two are as follows (Figure 7.31).

Figure 7.31. Jigsaw II

Phase I: Text. The first step in the use of Jigsaw II is to select a chapter that contains material for two or three days. Divide the content in the chapter into chunks based on the number of team members. For example if you have four members in a team, then a in a chapter would be divided into four chunks (as shown in a chapter on electronics in aphysical science course

- Chunk 1: How do early electronic devices work?
- Chunk 2: How are electronic devices used?
- Chunk 3: How is information processed in a computer?
- Chunk 4:What are some ethical issues concerning the use of electronic devices?

Each member of the team is assigned one of the topics and must read the chapter to find information about his or her assigned "chunk." In the next phase, each team member will meet with experts from other groups in the class.

Phase II: Expert Group Discussion. Expert group should meet for about half of a class period to discuss their assigned topic. Each expert group should receive an expert sheet (See Figure below for sample worksheets for the study of rocks). The expert sheets should contain questions and activities (optional) to direct their discussion. Encourage diversity in learning methods. Groups might do hands-on activities, read from other source books, or use a computer for a game or simulation. The groups' goal is to learn about the subtopic and to prepare a brief presentation that group members will use to teach the material to members of their respective learning teams.

Expert Sheets for Jigsaw II Unit on Rocks

1. Expert Sheet for Igneous Rock Group

Provide the group with an assortment of igneous rocks

1. How were these rocks formed?

2. Under what environmental conditions are these rocks formed? Try to illustrate your theory.

3. Observe each rock and collect observations on a chart which should include: name of rock or mineral, color (light or dark), shape and color of crystals, arrangement of crystals (even or banded), effect of acid, presence of fossils, and use of the rock.

4. What are some minerals in these rocks?

5. Where would you find these rocks in (your state).

6. Would you find igneous rocks in, on or under your school grounds?

7a. What would you predict about the size of crystals in igneous rocks if magma: a) cooled slowly, b) cooled rapidly, c) cooled in water?

7b. Explain your prediction.

8. What is the difference between an intrusive and extrusive igneous rock? Give some examples.

9. If you wanted to demonstrate how an igneous rock is made, what would you do?

10. Do you think there are igneous rocks on Mars?

2. Expert Sheet for Sedimentary Group

Provide the group with an assortment of sedimentary rocks

1. How were these rocks formed?

2. Under what environmental conditions are these rocks formed? Try to illustrate your theory.

3. Observe each rock and collect observations on a chart which should include: name of rock or mineral, color (light or dark), shape and color of crystals, arrangement of crystals (even or banded), effect of acid, presence of fossils, and use of the rock.

4. What are some minerals in these rocks?

5. Where would you find these rocks in (your state).

6. Would you find sedimentary rocks in, on or under your school grounds?

7. Why might you expect to find fossils in sedimentary rocks?

8. Does shaking a jar of mixed sized sand and water and observing the results demonstrate part of the sedimentary process? Explain by using a diagram and words.

9. Do you think there are sedimentary rocks on Mars?

3. Expert Sheet for Metamorphic Group

Provide the group with an assortment of metamorphic rocks.

1. How were these rocks formed?

2. Under what environmental conditions are these rocks formed? Try to illustrate your theory.

3. Observe each rock and collect observations on a chart which should include: name of rock or mineral, color (light or dark), shape and color of crystals, arrangement of crystals (even or banded), effect of acid, presence of fossils, and use of the rock.

4. What are some minerals in these rocks?

5. Where would you find these rocks in (your state).

6. Would you find metamorphic rocks in, on or under your school grounds?

7.If you wanted to demonstrate how a metamorphic rock is made, what would you do? Illustrate and explain.

4. Home Sheet

Note: This sheet is to be used in home groups after expert groups have met. Give this study sheet to each home team in preparation for a quiz on rocks

1. Consider the following rocks: sandstone, granite and marble. a) Under what environmental conditions is each formed? b) Would they be found on Mars? and c) Where would you find these in (your state)?

2. What are the differences between igneous, sedimentary and metamorphic rocks?

3. What are some rocks that can be identified by an acid test? What does this tell you about the composition of the rocks?

4. Complete these sentences:

a. Metamorphic rocks from when...

b. The Southern part of (your state) contains rocks such as...

c. In (a county next to yours), you'll find these rocks...

d. Fossils can be found in...

Phase III: Reports and Test. In the next phase of Jigsaw II, each expert returns to his or her learning team, and teaches the topic to the other members. Encourage members to use a variety of teaching methods. They can demonstrate an idea, read a report, use the computer, or illustrate their ideas with photographs or diagrams. Encourage team members to discuss the reports and ask questions, as each team member is responsible for learning about all of the subtopics.

After the experts are finished reporting, conduct a brief class discussion or a question and answer session. The test, which covers all the subtopics should be administered immediately and should note take more than fifteen minutes. Test design should include at least two questions per subtopic.

Team recognition should follow the same procedures used in STAD.

Two Level Content Study Groups.

Jones and Steinbrink have made changes in Jigsaw II and developed a model specific to science in what they refer to as the "Two level content study groups" model of cooperative learning. Their method involves the identification of two levels of cooperative groups, namely a "home team," and an "expert group." They also have developed job descriptions to clarify roles in these two levels of groups. Another change they have made is the size of the group. Home teams are comprised of from three to five members depending upon the way the content can be divided in the text. They point out that if a chapter has three equal divisions, then each home team would be comprised of three members.

Problem Solving-Conceptual Models

The cooperative learning models presented to this point have stressed rehearsal for a quiz, or placed emphasis on having students master a body of information. In each of the models, students tutor each other and then compete against other teams either through tests, tournaments or games.

What cooperative learning models can be implemented if the science teacher's goals include problem solving and the development of higher order cognitive thinking skills? The cooperative learning models that follow emphasize a structure in which students share ideas, solve problems, discover new information, learn abstract concepts, and seek answers to their own questions.

Group Investigation

Developed by Shlomo Sharan and Yael Sharan and their colleagues, the Group Investigation method is one of the most complex forms of cooperative learning. Its philosophy is to cultivate democratic participation and an equitable distribution of speaking privileges. It also encourages students to study different topics within a group, and to share what they learn with group members and with the whole class.

This method places maximum responsibility on the students, who identify what and how to learn, gather information, analyze and interpret knowledge, and share in each other's work. It is very similar to another method of cooperative learning developed by Spencer Kagan called Co-op Co-op, and would have the greatest chance of success if students have experience with other forms of cooperative learning.

There are several phases to the Group Investigation method. Although GI places more responsibility on each group to make decisions about content and process, the teacher must stay in contact with the groups, and facilitate their flow through the phases (see the chart below). The best topics for Group Investigations are ones that require problem solving on the part of each team. Although, topics can be fairly descriptive, encouraging an investigative approach will reinforce inquiry learning in the science classroom. Group Investigation might also used in place of individual science fair projects (see Chapter 8).

Phase I: Topic and Problem Selection. Students organize into groups of five (or fewer) and choose specific topics or problems in a general subject area of science. Group Investigation lends itself to a wide range of problem solving strategies. Students can ask questions that require empirical research, survey or questionnaires, or historical reporting. Each group plans its own topic or subject of investigation, and strategy for exploration. Then individuals or pairs with the group selects subtopics or specific investigatory tasks and decide how they will carry them out.

Phase II: Cooperative Planning. You and the students in each learning team plan specific learning procedures, tasks, and goals consistent with the subtopics of the problem selected.

Phase III: Implementation. Students carry out the plans formulated in the second step. Learning should involve a wide range of activities and skills, and should lead students to different kinds of sources, both inside and outside of school. Students might work in small groups or individually to gather data and information.

Phase IV: Analysis and Synthesis. Students meet to discuss the results of their subgroup or individual work. Meetings of this nature will naturally take place more than once during the implementation of Group Investigation. The information that has been gathered on the topic or problem is analyzed, and each group members' piece is synthesized to prepare a report for the whole class.

Phase V: Class Presentation. One of the attractive features of Group Investigation is that each team makes a presentation to the whole class. Students have to cooperate to prepare a presentation. Teams should be encouraged to prepare presentations that involve the audience, such as debates, demonstrations, hands-on activities, plays, or computer simulations.

During the presentation, the presenting team is responsible for setting up the room, gathering any equipment and materials, and preparing necessary handouts. Encourage the teams to allow at least five minutes for questions and comments from the class. In some cases, you should facilitate this aspect of the presentation.

7.8 Other Models

So far we have presented three types of models based on behavioral, cognitive and social-humanistic learning theory. Several additional science teaching models are described that extend the previous models. These models include:

- Synectics
- Person-centered teaching
- Integrative Learning
- Imagineering

7.8.1 Synectics

is a process in which metaphors are used to make the strange familiar and the familiar strange. Synectics can be used to help students understand concepts and solve problems. Synectics was developed by William J.J. Gordon for use in business and industry, but it has also been used an innovative model in education.

According to Gordon, "the basic tools of learning are analogies that serve as connectors between the new and the familiar. They enable students to connect facts and feelings of their experience with the facts that they are just learning." Gordon goes on to say that "good teaching traditionally makes ingenious use of analogies and metaphors to help students visualize content. For example, the subject of electricity typically is introduced through the analogue of the flow of water in pipes." Synectics can be used in the concept introduction phase of the conceptual change teaching model.

The synectics procedure for developing students' connection-making skills goes beyond merely presenting helpful comparisons and actually evokes metaphors and analogies from the students themselves. Students learn how to learn by developing the skills to produce their own connective metaphors.

Gordon and his colleagues, know as SES Associates, have developed texts and reference materials, and provide training to help teachers implement synectics into the classroom. Here is an example of a synectics activity that you could do with students. In this example students learn to examine simple analogies and discuss how they relate to teach other.

Give students analogies and then ask them to explain how the content (the heart) and the analogue (water pump) are alike. Here are some examples:

- The heart and water pump
- Orbits of electrons and orbits of planets
- The nucleus of an atom and a billiard ball
- Location of electrons in an atom and droplets of water in a cloud
- Small blood vessels and river tributaries
- The human brain and a computer
- The human eye and a camera

After students feel skillful linking the strange with the familiar, challenge them to create analogies for concepts they are studying.

7.8.2 Person-Centered Learning Model

The person-centered model of teaching focuses on the facilitation of learning, and is based on the work of Carl Rogers and other humanistic educators and psychologists. The model is based on giving students freedom to not only choose the methods of learning, but to engage in the discussion of the content as well. In practical terms, the person-centered model can be implemented within limits. Rogers believed, as do other psychologists, that making choices is an integral aspect of being a human being, and at the heart of learning. Secondly, Rogers advocated trusting the individual to make choices, and that it was the only way to help people understand the consequences of their choices.

There are several aspects of the person-centered model that appeal to the science teacher, namely, the role of the teacher in the learning process, and the creation of an learning environment conducive to inquiry learning.

The Teacher as A Facilitator. In order to implement a person-centered approach, the teacher must take on the role of a facilitator of student learning rather than a dispenser of knowledge or information. Three elements seem to characterize the teacher who assumes the role of learning facilitator: namely realness, acceptance, and empathy. In the person-centered model, the teacher to show realness must be genuine and willing to express feelings of all sorts---from anger and sadness to joy and exhilaration. In the person-centered model, the teacher acts as counselor, guide and coach, and in order to be effective must be real with his or her students.

Rogers also advocated and stressed the importance of accepting the other person---indeed prizing the person and acknowledging that they are trustworthy and can be held responsible for their behavior.

Finally, to Rogers at least, the most important element in this triad was empathy. Empathy is a form of understanding without judgement or evaluation. Empathy in the science classroom is especially important in developing positive attitudes, and helping students who have been turned off to science to begin to move toward it.

Naturally there is more than these three elements to being a learning facilitator. Technical aspects such as setting up a classroom environment conducive to learning, providing learning materials, and structuring lessons that encourage person-centered learning are involved as well.

The Person-Centered Environment and Inquiry. In the person-centered classroom, students are encouraged to ask questions, choose content, decide upon methods and resources, explore concepts and theories, and find out things on their own and in small teams. Clearly these are elements that foster inquiry. Teachers who truly implement inquiry will find themselves fostering the attitude advocated by person-centered educators. Here is a check list of elements that signal the existence of a person-centered environment:

In the person-centered classroom, students are encouraged to ask questions, choose content, decide upon methods and resources, explore concepts and theories, and find out things on their own and in small teams. Clearly these are elements that foster inquiry. Teachers who truly implement inquiry will find themselves fostering the attitude advocated by person-centered educators. Here is a check list of elements that signal the existence of a person-centered environment:

- A climate of trust is established in the classroom, in which curiosity and the natural desire to learn can be nourished and enhanced.
- A participatory mode of decision-making is applied to all aspects of learning, and students, teachers, and administrators each have a part in it.
- Students are encouraged to prize themselves, to build their confidence and self-esteem.
- Excitement in intellectual and emotional discovery, which leads students to become life-long learners, is fostered.

7.8.3 Integrative Learning Model

Imagine for a moment a physics classroom. After the students have come in and seem ready to begin class, the teacher says that they are going to begin a new unit on mechanics. He begins the lesson by getting students (and himself) to stand in a circle and begin passing a tennis ball around. At first the teacher tells the students to pass the ball at a constant speed or velocity. Then he says, "Accelerate the ball!" After a few moments, "Now, decelerate it!" The teacher now turns the activity into a game, students may take turns calling out "constant velocity," "accelerate," and "decelerate." As simple and as unusual as this activity is, this teacher has a reputation in the school for doing such activities in his physics class.

In another school, an earth science teacher is playing classical music while she reads a story to the class about how the giant continent of Pangea broke up, and drifted apart, creating new ocean basins, pushing rocks together to form huge mountain chains, and causing earthquakes and volcanoes. After the story is read, students get into small groups to collaborate and create a metaphor of the story, e.g. a drawing, a clay model, or a diagram.

The head of the biology department is seen taking her students outside (once again). This time, the teacher explains that the students are going on a "still hunt." Once outside, the students are assigned to sit in an area of the school grounds (this school has a wooded area to which the teacher takes the class quite often). For five minutes the students sit in their assigned area watching for the presence of organisms----ants, spiders, earthworms, birds, mammals---anything that they can see. They are asked to observe and to record their observations in a *Naturalists Notebook*. The students are assembled at the edge of wood and report their findings from the still hunt. Then the teacher gives the students modeling clay, string, paper, yarn, buttons, cloth, and toothpicks, etc. and says, "Design an animal that will fit into this environment but will be difficult to be seen by other animals." When the creatures are completed students place them in "their habitat." The teacher then has the whole class walk through the area looking for the creatures to find out how well they were designed to survive unnoticed in their environment.

Each of these teachers is implementing a model of learning which some refer to as integrative learning. It is a model of learning which suggests that all students can learn with a limitless capacity, and that students can learn by interacting with their "environment freely, responding to any and all aspects of it without erecting barriers between them."

The learning cycle used in the integrative learning model consists of three phases: input, synthesis, and output. Equal emphasis is placed on all three of these phases. The origin of integrative learning can be traced to Georgi Lozanov, of the University of Sophia (Bulgaria). Lozanov had discovered a method of learning which involved the use of music to help relax the learner, the creation of an atmosphere in which the mind is not limited, presentation of new material to be learned with what is called an "active concert," followed by a period of relaxation, and ending with a series of games and activities to apply the new material that was learned.

The Lozonov method made its way to the United States and can be found in such work as superlearning, accelerated learning, whole brain learning and so forth. Peter Kline, developer of integrative learning has stressed the importance of student synthesis and output in learning. In the integrative classroom, the teacher encourages students to use their personal styles of learning (see McCarthy, Chapter 2), and thus provides auditory, kinesthetic, visual, print-oriented and interactive learning activities. Music, movement, color, mini-fieldtrip, painting, the use of clay, pair and small group discussion are an integral part of the integrated learning model.

In Chapter 12, Science for All, a more complete exploration will be made of the integrative learning model.

7.8.4 Imagineering

is model of teaching developed by Alan J. McCormack and is designed to encourage visual/spatial thinking. McCormack explains that imagineering is the result of fusing parts of the words "imagination" and "engineering." Imagineering is designed to apply existing scientific knowledge to visualizing solutions to challenging problems.

McCormack, who is well known for his presentations at local, state and national science teacher meetings, advocates the use of teacher demonstrations to set the stage for imagineering. Here is one example from his collection of imagineering demonstrations. It is called the "water-expanding machine.

This is how McCormack explains the use of this device (Figure 7.36) in an imagineering lesson:

"This device is a cardboard box with an input funnel located on its top and an output tube that extends through one of its sides. The teacher states that this great new invention can expand by three times any volume of water that is poured into the funnel to be "processed" by the device. An actual demonstration follows: 500 mL of water is poured into the machine and 1500 mL flows from the output tube. Teacher asks the key question that already puzzles everyone: "Has water actually been expanded?" Few students believe that it has, so they are challenged to draw an "imagineering blueprint" of what might be inside the machine that could account for the apparent volume expansion of the water. Later ideas are presented, compared, and criticized. Invariably, a number of good, plausible explanations have been invented. Meanwhile, youngsters have honed both visualization and creative problem-solving skills."

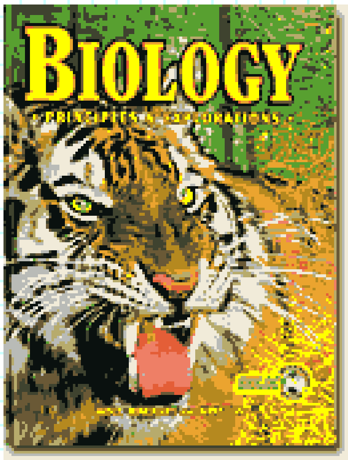
McCormack has designed an array of imagineering activities that can be used in any science curriculum. You might want to refer to his book, *Inventors Workshop* published by David Lake Publishers.

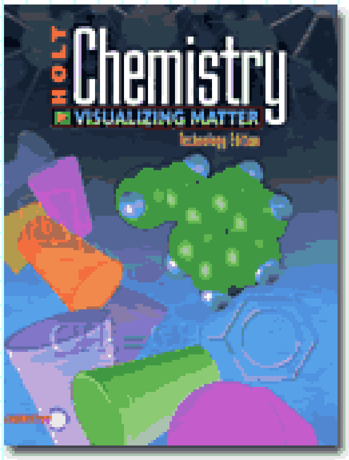
ACTIVITY 7.2: Inductive Versus Deductive Inquiry

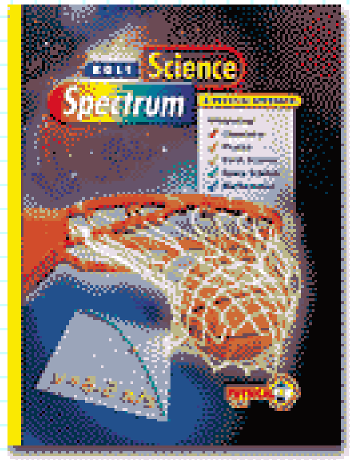
In this activity you will examine some secondary science textbooks, and make decisions about how inductive and deductive inquiry learning could be implemented.

Materials

Two or more secondary (middle or high school) science textbooks







Procedure

1. Examine the textbook and identify a chapter that interests you. Identify in the chapter the flow of concepts and how they are presented in the text.

2. Design the chapter inductively. That is, organize a series of lessons (describe them very briefly) in which the students will be introduced to the main concepts inductively.

3. Now design the chapter deductively. Organize a series of lessons in which the students will be introduced to the main concepts deductively.

Minds On Strategies

1. What did you discover about inductive versus deductive teaching?

2. In which manner was the textbook organized, inductively or deductively?

3. Which model do you think is better for student learning? Why?

Minds on Science *Gazette*

Volume 7	Think Pieces	Models of Teaching

1. Create a poster report that conveys the meaning of any one of the models of teaching presented in this chapter. Assume that you will present the poster at a local science teacher conference whose theme is: "Effective Models and Strategies of Science Teaching for the Nineties."

2. Design a graphic representation of your model of teaching. Don't be afraid to be inventive, and realize that creative thinking involves combining elements of other ideas. Present your model in class.

3. Which of the following models of teaching do you prefer.

- Direct/Interactive teaching
- Direct inquiry
- Cooperative learning
- Integrative learning
- Person-centered learning

Prepare a brief speech (three to five minutes) in which you identify the characteristics of the model and why you prefer it over other models. (And of course you can use visual aids if you are called on to give the speech!)

Minds on Science *Gazette*

Volume 7	Case Studies	Models of Teaching

Case Study 1. Descent from Innocence

The Case. Michael A. Miller, who grew up in an upper middle class community in upstate New York and graduated (cum laude) from the State University of New York at Buffalo, accepted a teaching position with the Los Angeles Unified School District. He was assigned to Orange High School, with has an enrollment of over 3000 students---approximately 1500 Hispanics, 1000 Blacks, 450 Asians, and about 300 other students.

Miller reports his experience teaching with nontraditional activities:

"It wasn't until I had been teaching for a few months that I fully understood the odd smile that appeared on the faces of other teachers when I told them of my class assignment: in addition to two periods of biology, I would be teaching three life science classes. Life science appears to be the dumping grounds for non-college bound, nonacademic, potential dropouts. Now I realize that the smile meant, "Poor, naive, innocent soul --- like a lamb to the slaughter and he doesn't even know it."

My descent from innocence was swift and brutal. I was given a temporary roll sheet, assigned a room---actually three different rooms---and with little other preparation was thrust into the world of teaching....I launched into my lessons.

One of the first units I covered was the metric system.....I assumed that this unit would be a brief review for the students. Little did I suspect that, not only did the students have no knowledge of the metric system, they were also ignorant of measuring using the standard English system.

In order to teach this unit, I planned to conduct a brief lecture on metric prefixes and then have a laboratory exercise in which the students measured various objects and converted from one measurement unit to another. I typed up lab sheets explaining in detail what should be measured and in what units I wanted the measurements. The students were then assigned to lab tables, paired off, and provided with meter sticks. What next ensued can only be described as Pandemonium.

My intention had been to visit with each group of students and answer any questions that they might have....The first group I visited with was made up of four girls. They were having a grand time chatting about local current events and had given up the lab as a futile exercise. It just wasn't possible to measure heights with a meter stick, since they were all taller than the stick. Unable to argue with such logic, I proceeded to the next lab group.

I arrived just in time to witness the finishing touches that a student was adding to his self-inspired metric project. He had beautifully carved his gang symbol into the meter stick with an eight inch knife he had been carrying. He also asked me if, perchance, I would like to buy some "ludes" from him. I declined his offer, asked him to put away the knife, complimented him on his artwork, and proceeded to the third group.

At this lab table,two young men were having a dispute over a question on the lab handout which directed them to provide the width of their little finger in both centimeters and millimeters. They couldn't decide whether this measurement should be the long or short dimension of a finger. Peter was strongly emphasizing his point of view with well-placed punches on David's arm and chest region. I managed to separate them and clarify the meaning of the lab question. As I left them to visit with group number four, I overheard David say to Peter, "This side of the stick is meters," to which Peter replied, "No it isn't. That's the inches side." Two or three dull thuds punctuated Peter's response.

At table four, one student, who had just been released from jail the day before, was sharing with his lab partners the economics lesson he learned while incarcerated. Mercifully, the bell rang. "Well," I sighed hopefully to myself, "Only four more periods to go!"

This was just one of many labs conducted during my first year of teaching that didn't go quite as planned. Although none were as disastrous as the metric lab, each was as much an experiment for myself as it was for the students. Often, I half wished that I had taken my student up on his offer and purchased a healthy supply of central nervous system depressants. As they say, even the best laid plans sometimes go awry.

Now I am in my second year of teaching...

The Problem: Do you think Michael had too-high expectations for his students in doing lab activities? If you had watched this lab activity, what specific suggestions would you make to Michael to change the lesson in order to eliminate the "Pandemonium?"

Case Study 2: Hugging a Tree.

The Case. David Brown is an undergraduate student and has been granted permission to student teach in the high school he graduated from because it is the type of school he in which he would like to teach. David's school, however was located 200 miles from the university. His college supervisor, Dr. Ahrens, associate professor of biology, was not enthused about having to drive the distance to supervise him. Ahrens was under pressure to to conduct research and publish the results, and he was having difficulty finding the time to do so. Furthermore, some of his younger colleagues were already full professors, and were receiving federal grants for their research.

David was accepted with open arms at his "old" high school, and the department head assigned Bob Smith, one of David's favorite high school teachers, as his cooperating teacher. On his first biweekly visit to supervise David, Dr. Ahrens saw performance unlike anything he had witnessed in fifteen years of supervising student teachers. The lesson topic focused on trees. David at gotten up at daybreak and gone into a wooded area to collect leaves. But what Dr. Ahrens saw was much more than a leaf collection. David had brought tree limbs---dozens of them---and the classroom looked like an aboretum.

Dr. Ahrens entered through the door at the back of the room and quietly sat down. As usual, he prepared to take notes and complete an assessment form, and he quickly became surprised by David's activities that he forgot to complete the form. David was running from one part of the room, to another, and then another, taking limbs and small trees with leaves and giving them to students to examine. First he had the students taste the sassafras leaves. Some comments about root beer were heard. Then David took a double handful of sweet-shrubs and crushed them. As he walked down each row of students letting every student smell them, the students "oohed" and "aahed." Next David gave each student a leaf from a cherry tree. He asked them to break the leaves in half and sniff them to see who could tell him the type of tree these leaves came from. Some said that they smelled like a milkshake. Others said the smell reminded them of the chocolate-covered cherry candy that they get at Christmas. After a wisecrack guess that it was a Christmas tree, someone screamed, "cherry."

Next, David had some yellow roots. He asked the student to take a small hair of the root and taste it. They were as bitter as quinine. Students gasped in exaggerated disapproval of the bitter taste; some ran to the door and spat outside. By the end of the period every student was grappling with a piece of sugar cane, twisting it and swallowing the sweet juice.

When the bell rang the students applauded and commented about the lesson. Some said that this is the way school ought to be---fun. David was pleased that the students received the lesson so well.

Dr. Ahrens realized that he had become so engaged with observing the activities and so bewildered and upset at having seen something that didn't even resemble a lesson that he failed to complete the rating instrument and was, therefore, unprepared for the assessment conference that was to follow. Nevertheless, he felt he must give David some badly needed feedback, however general. He would spare no words for this young maverick.

Dr. Ahren's first step toward resolving this perceived disaster was to meet with Mr. Bob Smith, David's cooperating teacher. After sharing a few brief pleasantries he fired the following questions at Mr. Smith.

"What do you think about this lesson?"

"The kids were really excited over it."

"Would you say that this was typical of David's lessons?"

"Yes, he always gets the students fired up."

"Do you think the lesson was well structured, well planned?"

"He obviously kept things moving at a good pace, and he didn't run out of material."

"Does David usually give you a well-prepared lesson plan when he teaches?"

"David has the type of personality that enables him to move through the lesson well without a written plan. I think lesson plans are good if you need them, but they can handicap a natural teacher. David knows that as long as his lessons work, I really don't insist on seeing a written lesson plan," Bob Smith stated.

From this brief conversation Dr. Ahrens concluded that he would get little help from this lackadaisical teacher. In fact, he assumed Mr. Smith was influencing David negatively by providing a loose, unstructured role model. Clearly, it was time to talk to David.

Dr. Ahrens began the session by asking David what he thought he was doing. He continued, "I drove two hundred miles to watch you teach, and instead you provided a circus. My job is to help you raise the achievement scores in this class. From our prestudent teaching seminar you learned that effective teachers give clear goals, hold high expectations, use direct instruction, and closely supervise all assignments. Instead of following this instructional model, you arranged for a disorganized, student-centered picnic, complete with refreshments. I am very disappointed. I will have to record these activities and place the report in your permanent records."

David was shocked. What could he do to salvage his student-teaching grade and his teaching career?

The Problem: Put your self in David's place. What would you do?

Minds on Science *Gazette*

Volume 7	**Problems and Extensions**	**Models of Teaching**

1. Present a discrepant event related to specific concepts drawn from Earth science, life science, physical science, or environmental science. Your presentation should be brief, and should be designed to engage the class in inquiry.

2. Present a five-to-ten-minute lesson based on one of the following models of teaching. Write a one page report on the strengths and weaknesses of the lesson, and how you would change the lesson if you were to teach it again.

- Direct/interactive instruction
- Inductive inquiry
- Deductive inquiry
- Discovery learning
- Problem Solving
- The Learning cycle
- Cooperative/collaborative learning

3. Create a chart in which you analyze at least five models of teaching. Your chart should provide insight into the purpose of the model, the essential characteristics of the model, and under what conditions the model should be used.

4. One criticism of inquiry and discovery methods of science teaching is that this approach takes too much time, and students can learn concepts and skills if presented more directly. Debate this criticism by first taking the side of inquiry, and then the side of the criticism. In which were you more convincing? Is there a solution to this problem?

5. Observe a video of a science teacher teaching a lesson. Make anecdotal comments on the chart below indicating examples of the various models of teaching observed during the lesson. What generalizations can you make about this teacher's approach to teaching? View a video of another teacher and compare the two teachers approaches to teaching.

Model of Science Teaching	**Anecdotal Comments** **Examples of how the model was implemented; examples of teacher and student behavior**
Direct/Interactive Teaching	

Inductive Inquiry	
Deductive Inquiry	
Discovery Learning	
Problem Solving	
Learning Cycle	
Cooperative/Collaborative Learning	
Synectics	
Person-centered Learning	
Integrative Learning	
Imagineering	

6. Is there a relationship between metaphors of teaching and the models of teaching presented in this chapter. Three metaphors for the nature of teaching are:

- Entertainer: teaching is like acting; your on a stage and you perform.
- Captain of the Ship: teaching is like directing and being in charge.
- Resource: teaching is making your self available; assisting; facilitating

Either observe two teachers in their classrooms, or observe video tapes of two teachers. Analyze their teaching in terms of these metaphors. What relationship exists between the perceived metaphor and models of science teaching?