WELCOME TO

MINDS ON *SCIENCE*

O N L I N E

INQUIRY	CONTRUCTIVISM	LEARNING

A Web Course on the Art of Teaching Science
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Chapter 7

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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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Chapter 8

Strategies Fostering Thinking in the Science Classroom

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Strategies Fostering Thinking in the Science Classroom

Would anyone believe that thinking is not as central part of the science classroom? Who would not emphasize thinking in the science classroom? Unfortunately research studies indicate that the predominant strategy used in science classes is recitation, with the teacher in control. What impact will this strategy have on student thinking? In most cases this form of teaching will reinforce memorization and rote learning. An example of this is reported by Anderson and Smith when they have noted that student can pass a chapter quiz on photosynthesis and still not understand that plants make their own food.

In this chapter we will explore teaching strategies in the context of how they influence and facilitate student thinking. The first set of strategies will be explored in terms of their impact on students' ability to think critically and creatively. We will explore strategies such as questioning, structured discussions and debates, field trips and role playing.

Thinking in science can also be facilitated by reading and writing strategies. However, many students have trouble comprehending contemporary secondary science textbooks. What strategies can be utilized to solve this problem? We'll examine language abilities and skills strategies that aid student learning in science.

We will also explore strategies that will foster independent thinking among secondary students. How can students be empowered to be thinkers in their own right? We'll examine science process skills more carefully, as well as the nature of problem solving, and make some connections to science projects and science fairs.

Finally, we'll consider how the computer can be instrumental in enhancing student thinking in the science classroom. We'll examine the computer as a medium to enhance student's scientific skills, along with its power to help students write, communicate and do research.

PREVIEW QUESTIONS

• What teaching strategies can be used to foster critical and creative thinking among students?

• How can the communications skills of reading and writing in the science classroom be improved?

• What strategies aid student independent and collaborative thinking?

• How can computer technologies be used to enhance thinking in science?

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8.2 Critical and Creative Thinking

Critical and creative thinking are counterparts of a wholistic view of student thinking. They are not opposite; they are indeed complimentary (Figure 1). Critical thinking is "reasonable, reflective thinking that is focused on deciding what to believe or do." Critical thinkers in a science class have learned how to look at phenomena aware of their own biases, and approach the situation objectively and logically. Creative thinking, on the other hand, is the ability to form new combinations of ideas to fulfill a need. Examples of creative thinking in science classes are brainstorming, creating alternative hypotheses, synthesizing information and thinking laterally.

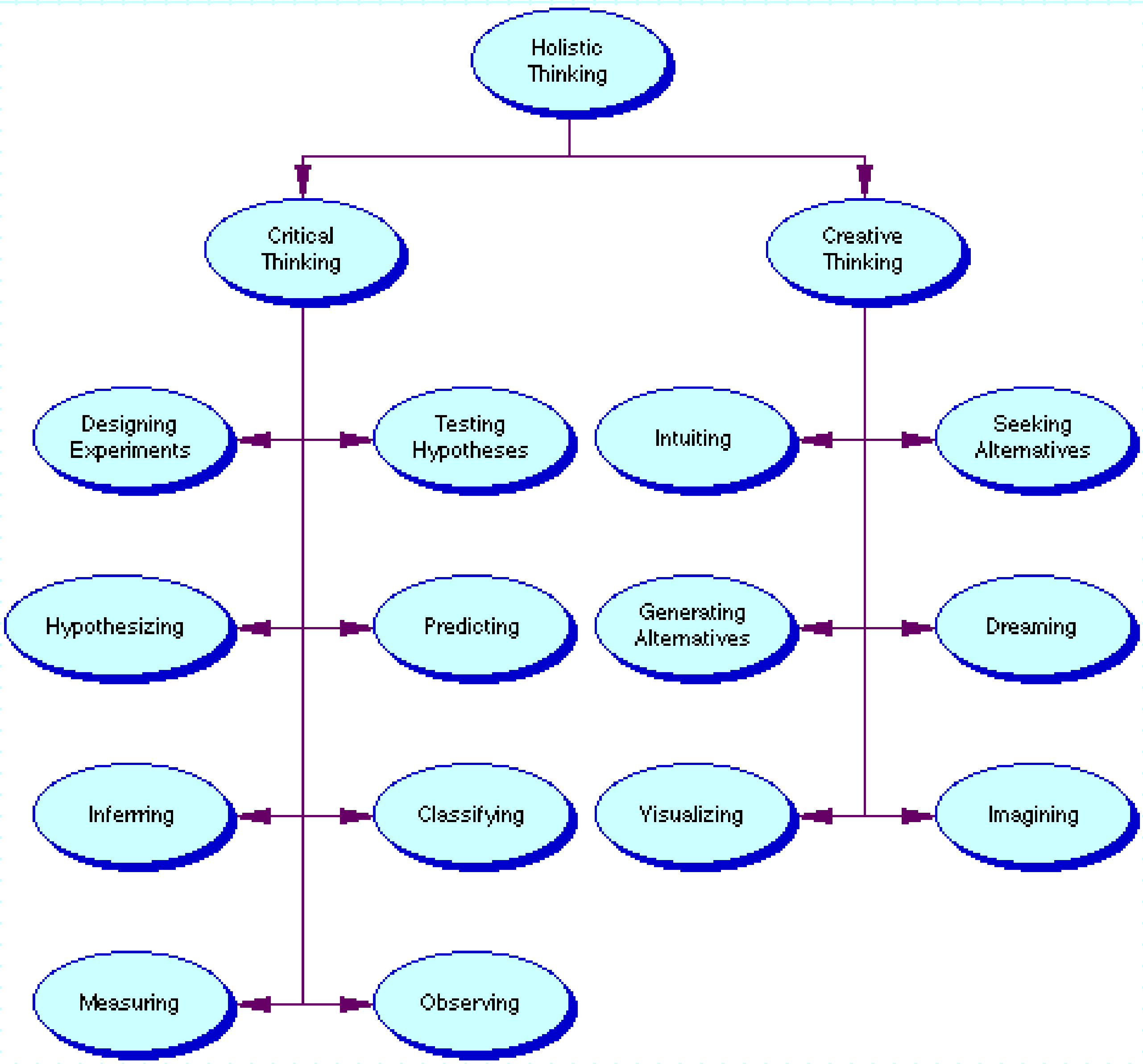


Figure 8.1. Holistic Model of Thinking

Critical thinking and creative thinking can be contrasted (Figure 1) to indicate the differences in these forms of thinking. Look over this list of science teaching tasks and decide which ones are examples of critical thinking and which are examples of creative thinking:

- Summarizing the main ideas in a chapter on forces and momentum.

- Building models of atoms using clay and toothpicks.
- Inventing a system that will measure the mass of an elephant.
- Writing review question based on specific pages in the science textbook.
- Observing an event and then writing at least three alternative explanations.
- Estimating the volume of their biology I classroom.
- Listing as many observations of a burning candle during a five minute observation session.

There are many strategies to foster creative and critical thinking in the science classroom. Three assertions will guide our approach to these strategies that foster this development. Critical and creative thinking are fostered in:

- interactive classrooms that focus on inquiry teaching
- classrooms that deal with controversies thereby encouraging discussion, debate and discourse.
- classroom that bring students in contact with real world problem solving.

8.3 Interactive Teaching Strategies

Critical and creative thinking require that students be actively engaged in learning science, as opposed to the more traditional, yet typical approach in which the student is on the receiving end of a lecture. The interactive classroom is one in which communication patterns involve students to teacher, teacher to students, and students to students. The interactive classroom is a stimulating place in which students have been motivated to learn, and are given the freedom to explore, discover and inquire. In the interactive classroom you will find teacher-centered as well as student-centered activities. Regardless of the type of activity that the teacher selects, there appears to be at least six specific strategies that teachers use to create an interactive science classroom.

Interactive teachers:

- Use advance organizers to establish interest and instructional goals
- Create a stimulating classroom environment
- Understand the art of questioning
- Use examples to help students understand concepts
- Create a positive learning environment
- Use closure and transitional skills

Lets look at each of these strategies in some detail.

8.3a Advance Organizers

Wouldn't you agree that helping students make meaningful connections between what they know and what is to be learned would facilitate learning new ideas? An advance organizer is a device that teachers use to help students make these connections. Advance organizers are frameworks for helping students understand what is to be learned.

An advance organizer is not an overview, but rather a presentation of information (either verbal or visual) that are "umbrellas" for the new material to be learned. The concept of advance organizer was proposed by the psychologist David Ausubel. To Ausubel, effective advance organizers are presented by teachers at a "higher level of abstraction, generality, and incisiveness" than the science material that is to follow.

Advance organizers can be useful devices at the start of a unit, before a discussion, before a question-answer period, before giving a homework assignment, before student reports, before a video, before students read from their science textbook, before a hands-on activity, and before a discussion of science concepts based on student's laboratory experiences.

Let's look at some examples of advance organizers, and then have you consider designing some of your own.

- A teacher shows a picture of Mendeleev in his laboratory in Leningrad and discusses his contribution to the development of the periodic table before introducing any of the details of the table of the elements.

- A teacher has students bring in pictures that show the destruction caused by the 1989 San Francisco area earthquake (or any earthquake) before introducing earthquake waves and how they are measured.

- The teacher discusses the origin of life on the Earth before introducing Darwin's theory of evolution.

- The teacher shows a poster depicting many forms of energy and asks students to discuss and identify the examples of energy before introducing the students to a new unit on heat energy.

Advance organizers help the students organize the conceptual knowledge they are to learn. The teacher can refer back to the organizer and use it to link a sequence of lessons.

For example, the science textbook can provide clues and examples of advance organizers. Look at a secondary science textbook and identify advance organizers for one of the chapters in the book. Discuss the advance organizers with a peer in your class. Do they meet the criteria of being "at a higher level of abstraction, generality and inclusiveness," than the materials in the chapter?

8.3b Creating a Stimulating Environment

Imagine walking down the hall of a school and being able to peer through the door windows enabling you to compare classroom environments of a variety of teachers. One teacher is sitting on the desk talking with the students; half hour later you pass by the classroom and the teacher is still sitting there. In an other classroom, you have to strain your head to find the teacher; the teacher is in the corner of the room pointing to the aquarium during a discussion. In a third classroom you are struck by the hand and body movements of the teacher explaining what the students are to do in lab. In the fourth class you observe the teacher walking among six groups of students who appear to be wrapped up in intense discussions.

There are a number of specific teaching skills that impinge on creating a stimulating environment in the classroom, which will have positive effects on critical and creative thinking of students. The use of movement, gestures, focusing, different interaction styles, and multiple sensory channels (Table 1) appear to impact the environment that the teacher establishes in the classroom.

Table 1. Interactive Teaching Skills

Classroom Teaching Skill	Teacher Actions
Movement	Moving into the classroom and not hovering at the front of the classroom, especially behind the demonstration desk is desirable here.
Gestures	Complimenting verbal messages with body language is an important aspect of communication. Teachers should use hand, head and body to convey meaning.
Focusing	Teachers who focus students use verbal statements (look at this chart of vertebrates), and use gestures (pointing to a fault line on a map projected on the overhead), or use a combination of both.
Interaction Styles	Stimulating environments occur where there is a variety of interaction styles among teacher and students. Whole class, small group and individual interaction styles should be utilized.
Multiple Sensory Channels	Student learning styles research suggests that creation of multiple sensory classrooms. Teachers should provide verbal, tactile, and kinesthetic experiences for students.

8.3c The Art of Questioning

Of all the skills discussed in this section, questioning, according to many science educators, is one of the most important. Teachers ask sometimes over a hundred questions in a class session to encourage student thinking. Do science teacher's questions facilitate critical and creative thinking? Are some questioning strategies more effective than others. Let's examine some aspects of the art of questioning, including: types of questions, wait time, and questioning and creativity.

Categories of Questions. Examine the following list of questions. Can you assign each question to one of two categories? Please identify the criteria you used to name the categories.

1. Are all the fruit flies alike for each feature?
2. What is weathering?
3. What do you predict will happen if a jar is put over a candle?
4. Using evidence that you choose, do you think scientists should be limited in the areas they want to research?
5. How many elements are in the periodic table?
6. Which planet is largest: Mars, Venus, or Mercury?

There are many systems that teachers use to classify questions. Upon close observation, in most systems questions are typically classified into two categories. Various terms are used to describe these two categories (Figure 1). The binary approach is useful because two categories are more manageable for a beginning teacher to learn to implement than the typical approach of using systems with six categories.

Figure 1. Categories of Questions

Category 1	Category 2
Factual	Higher cognitive
Closed	Open
Convergent	Divergent
Lower level	Higher level
Low order	High order
Low inquiry	High inquiry

What kinds of questions do teachers ask in the classroom. Gall reports that 60% of teachers' questions require students to recall facts, about 20% require students to use higher cognitive processes, and the remaining 20% are procedural.

If teachers want to foster critical and creative thinking in the classroom, then this pattern of questioning should be changed. Let's examine more closely how questioning strategies might be used to enhance critical and creative thinking.

Low Inquiry vs High Inquiry Questions. One way to classify questions is to determine whether they are low inquiry (closed or convergent) or high inquiry (open or divergent).

Low inquiry questions. Thse questions focus on previously learned knowledge in order to answer questions posed by the teacher which require the students to perform ONE of the following tasks:

1. Elicit the meaning of a term.

2. Represent something by a word or a phrase.

3. Supply an example of something.

4. Make statements of issues, steps in a procedure, rules, conclusions, ideas and beliefs that have previously been made.

5. Supply a summary or a review that was previously said or provided.

6. Provide a specific, predictable answer to a question.

High inquiry questions. These questions focus on previously learned knowledge in order to answer questions posed by the teacher which require the students to perform ONE of the following tasks:

1. Perform an abstract operation, usually of a mathematical nature, such as multiplying, substituting, or simplifying.

2. Rate some entity as to its value, dependability, importance, or sufficiency with a defense of the rating.

3. Find similarities or differences in the qualities of two or more entities utilizing criteria defined by the student.

4. Make a prediction that is the result of some stated condition, state, operation, object, or substance.

5. Make inferences to account for the occurrence of something (how or why it occurred).

Low inquiry questions tend to reinforce "correct" answers, or focus on specific acceptable answers, whereas high inquiry questions stimulate a broader range of responses, and tend to stimulate high levels of thinking. There is evidence to support the use of using both types of questions. Low inquiry questions will help sharpen students ability to recall experiences and events of science teaching. Low inquiry questions are useful if you are interested in having students focus on the details of the content of a chapter in their textbook, or a laboratory experiment.

High inquiry questions encourage a range of responses from students and tend to stimulate divergent thinking. Figure 2 summarizes the differences between low and high inquiry questions.

Figure 2. Differences Between Low and High Inquiry Questions

Type of Question	Student responses	Type of response	Examples

Low inquiry (convergent)	• Recall, memorize •Describe in own words • Summarize • Classify on basis of known criteria • Give an example of something	Closed	How many... Define... In your own words...state similarities and differences... What is the evidence...? What is an example...?
High inquiry (divergent)	• Create unique or original design, report, inference, prediction • Judge scientific credibility • Give an opinion or state an attitude • Make value judgements about issues	Open	Design an experiment... What do you predict...? What do you think about...? Design a plan that would solve...? What evidence can you cite to support...?

Wait Time. Knowledge of the types of questions, and their predicted effect on student thinking is important to know. However, researchers have found that there are other factors associated with questioning that can enhance critical and creative thinking. One of the purposes of questioning is to enhance and increase verbal behavior of students in the science classroom. Mary Budd Rowe has discovered that the following factors effect student verbal behavior:

1. Increasing the period of time that a teacher waits for students to construct a response to a question.

2. Increasing the amount of time that a teacher waits before replying to a student response.

3. Decreasing the pattern of reward and punishment delivered to students.

She has found that if teachers increase the time they wait after asking a question to five seconds or longer, then the length of response increases. In the science classroom, where the teacher is trying to encourage inquiry thinking, wait time becomes an important skill, as well as a symbol of the teacher's attitude toward student thinking. Teachers who are willing to wait recognize the that inquiry thinking requires thoughtful consideration on the part of the students. Rowe points out that teachers who extend their wait times to five seconds or longer increase "speculative" thinking. The use of silence in the classroom can become a powerful tool to enhance critical and creative thinking.

Rowe also believes that teacher sanctions (positive and negative rewards), if used indiscriminately, can reduce student inquiry. At first glance, this doesn't make sense. However, Rowe has found that when rewards are high, students tend to stop experimenting sooner than if rewards are low. When students begin attending to rewards rather than the task, the spirit of inquiry tends to decrease.

Another factor related to questioning is the attitude of the teacher. Have you ever been in a class situation in which you wanted to ask a question but feared the teacher's reaction to your question---it might be a dumb question. One classroom rule that we think is important is "there are no dumb questions." A corollary to this rule is "there are no dumb answers." Students need to believe that their responses will be accepted by the teacher; anything short of this will tend to reduce the probability of student participation.

8.3d Using Examples to Help Students Understand Concepts

The word "example" comes from the word "sample" which means a portion of the whole which shows the quality and character of the whole. The use of examples is fundamental to helping students understand science concepts. The teacher that identifies examples of concepts, or asks students to cite examples of concepts is acknowledging that learning must be tied to students prior knowledge. Using examples is a way to tie science teaching to the students world.

Examples should be exciting, and should be recognizable as everyday phenomena. We use the acronym EEEP to mean "Exciting Examples of Everyday Phenomena." EEEPs should be used to help students understand science concepts. EEEPs can exist in the form of an object (a rubber door wedge to represent an inclined plane), an artifact (a piece of pottery to help students understand soil), a machine, photograph, a piece of technology, or a toy.

One way to help you think about examples is to examine a list of categories and use the list a stimulus for connecting these categories with science concepts. What kinds of examples can you generate from the following list?

- detergents
- household chemicals
- fertilizer
- nails
- muddy water
- vegetables
- flowers
- building materials (bricks, mortar, wood)
- paper products
- beach stones
- playground rocks
- food items
- slinkies
- dishware
- eye glasses and lenses
- recycled newspaper
- biodegradable plastic bags
- balloons
- oil and other viscous fluids
- toy cars

Examples can be used deductively or inductively in helping students understand concepts. However, it is important to keep in mind what we have discussed about the learning cycle and the generative model of learning. As you recall, cognitive psychologists theorize that students construct their knowledge (of concepts) and must do so through their interaction with ideas, phenomena and people.

In the deductive approach of using examples, learning begins with the idea, principle or concept, and is then followed by an exploration of examples and phenomena. The process culminates in relating the concept to the examples (Figure 1)

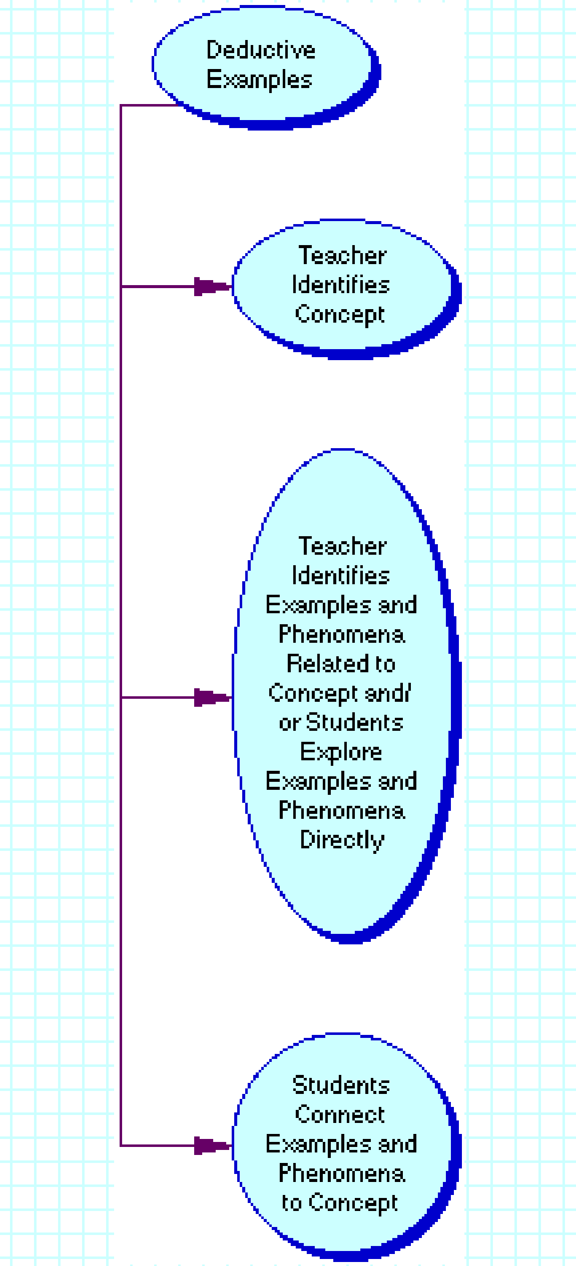


Figure 1. Deductive Use of Examples

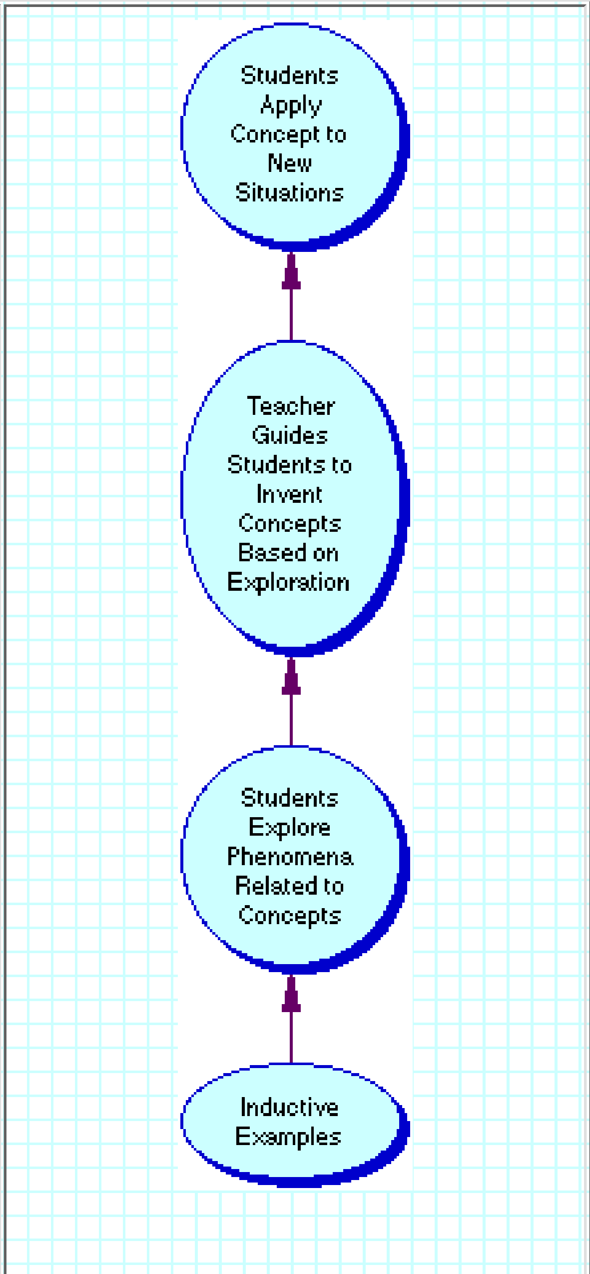


Figure 2. Inductive Use of Examples

In the inductive approach, which is closer to the constructivist notion of how students learn concepts, students begin with an exploration of ideas and phenomena, followed by a teacher directed activity to facilitate the "invention" of the science concepts. (Figure 2)

In either approach it is important to start with the simplest examples, and ones that are relevant to your student's experience and knowledge. Examples can be thought of as metaphors and analogies of the science concepts in the curriculum. The more familiar the examples are to the students experience, the greater the probability of hooking the student's understanding of the concept.

Research by Treagust et.al. has shown that examples, especially those in the form of analogies are rarely used to help students understand science concepts. Typically, the teacher introduces the new science concept by defining it, or using an example that is not too familiar to the students.

An interesting finding by Treagust and his colleagues was that teachers who were not familiar with the content being taught typically use definitions to explain concepts; teachers well versed in the content used definitions the least.

8.3e Positive Learning Environment

The psychologist Carl Rogers has shown that student attitudes (toward themselves, their peers, their teachers and subject) are an integral aspect of student learning. He has suggested that a climate of inquiry, which is essential for critical and creative thinking, is fostered when students perceive the learning environment in terms of realness or genuiness, acceptance, and empathy. Throughout this book we have emphasized the importance of inquiry learning, and have substantiated the claims of cognitive psychologists that students must explore, invent and apply their knowledge in real situations in order to develop and construct science concepts. The science teacher must foster a classroom climate that projects and supports this cognitive perspective. Such an environment is characterized as follows:

- The teacher projects an image to the students which tells them: I am here to help you build your character and your intellect.

- The teacher conveys the notion that each and every student is unique and is interested in them as a unique person.

- The teacher conveys the idea that all students can accomplish work, can learn and is competent.

- The teacher expects high standards of values, competence and problem solving ability.

- Teachers convey, through their own behavior, a character of authenticity.

- The teacher conveys high ethical standards by establishing a high degree of private or semi-private communication with students.

Rogers claims that the most important aspect of the teacher/facilitator role is that of empathy. In the context of science education, this makes perfectly good sense. The student who has "science anxiety" can only be helped in an environment in which the teacher empathizes with this state. Too often, the student who was interested in science in the early grades, gets turned off to science in the middle grades. Perhaps one of the reasons for this low interest in science is the lack of an empathic classroom climate.

8.3f Closure and Making Transitions

Closure is the complement of advance organizers. Closure acts as a cognitive link between past knowledge and the new knowledge (experiences). Closure can also function to help give the students a feeling of accomplishment or achievement.

Closure is not limited to the end of a lesson. There are many instances in a lesson in which you will help the students make a transition, for example from a pre-lab session to the laboratory activity itself. Closure in this instance functions as a transition from one activity to another.

There are a number of ways to integrate closure and transitions into your lesson plans. Three are identified below.

1. Drawing attention to the completion of a lesson or a part of the lesson.

The teacher can provide a consolidation of concepts and elements which were covered before moving to a subsequent activity. It is extremely helpful to relate the lesson back to the original organizing principle (advance organizer). Some teachers review (preferably the student) the main ideas of the lesson by means of an outline or a concept map. Another closure technique is to stop throughout a teacher directed lesson and ask student pairs to explain the ideas that were developed.

2. Making connections between previously knowledge and the new science concepts.

Teachers find it helpful to review the sequence which has followed in moving from previous knowledge to the new ideas. The learning cycle or generative model emphasizes this general sequence. Using examples (EEEPs) can facilitate student transition from a misconception state to one of understanding the concept.

3. Allowing students the opportunity to demonstrate what they have learned.

It is a much more powerful technique if students can suggest ways that demonstrate closure. One technique that researchers and teachers have found effective is concept mapping. A concept map drawn after a lesson, chapter or unit of study is a visual mechanism in which students describe their understanding.

8.4 Controversies in the Science Classroom--Real World Problem Solving

A strategy that appears to encourage critical and creative thinking is to involve students in the exploration of science controversies---a kind of academic conflict that arises when one student's opinions and ideas are incompatible with those of another student. Johnson and Johnson have experimented and field tested a series of environmental issues structured for controversies in the science classroom. The recent emphasis on STS (Chapter 6) provides the science teacher with a wide range of topics for a structured controversy strategy. You should also refer to Robert Barkman's book, Coaching Science Stars: Pep Talk and Play Book for Real-World Problem Solving. Some potential topics include:

- Global Warming: Is the Earth really heating up?
- A hungry Earth: Can the Earth feed its human population?
- Crisis in the Ocean: How polluted is the Ocean?
- The garbage problem: What is the best way to manage waste?
- Chemicals on the highways: How can hazardous waste be managed?
- Extinction: How endangered is life on the planet?

The strategy of structured controversies consists of four procedures: selecting a topic, preparation of learning materials, structuring the controversy, and conducting the controversy in the classroom.

Selecting a topic

Teacher and student interest are critical in the selection of a topic. It is important that two positions on the issue can be identified, and that the students are able to deal with the content of the topic. The teacher can either present the class with the topic or have the students choose from a list of topics.

Preparing Teaching Materials

According to the developers of this strategy, the following materials are needed for each position on the issue:

- a description of the group's task
- a description of the phases of the process (see conducting the controversy below)
- a definition of the position to be advocated
- resource materials including a bibliography, pamphlets, magazines, newspaper article

Structuring the Controversy

The controversy should be investigated in a cooperative learning context. Students should be grouped into teams of four heterogeneously; pairs of students will work together on one side of the issue. (Refer to section on cooperative learning models in Chapter 7).

Conducting the Controversy in the Classroom

To manage the process in the classroom, students should be lead through a series of phases as follows:

- Learning position: Each partner team should become thoroughly familiar with their position on the issue by reading the materials, and preparing a persuasive presentation. Additional reading may be required in order to master the position.

• Presenting positions: Each partner team presents their position to the other team in their group. It is important to listen carefully as well as ask questions in order to clarify points on the issue.

• Discussing the issue: During this phase each team should argue their position forcefully by presenting facts to support points on the issue. Students should be encouraged to ask their opposing teammates to support their arguments with information and facts.

• Reversing positions: In this phase each pair presents the opposing pair's position in as a sincere and forceful manner as possible.

• Reaching a decision: In this final phase each team must prepare a report on the issue that summarizes and synthesizes the best arguments for both points of view. However, as a team, they must reach consensus on a position that is supported by the evidence. Each team should prepare a single report, and be prepared to engage in a large group discussion.

Throughout the process, students should be held accountable by acknowledging a set of discussion rules:

1. I am critical of ideas, not people.
2. I focus on making the best decision possible, not on "winning."
3. I encourage everyone to participate and master all the relevant information.
4. I listen to everyone's ideas, even if I do not agree.
5. I restate (paraphrase) what someone has said if it is not clear.
6. I first bring out *all* the ideas and facts supporting both sides and then try to put them together in a way that makes sense.
7. I try to understand both sides of the issue.
8. I change my mind when the evidence clearly indicates that I should do so.

Throughout the process, critical thinking emerges as students analyze points of view, and search for evidence to support their arguments. Facts and information are analyzed in terms of a position or argument. Creative thinking manifests itself in a number of ways. Students have to reverse positions on the issue requiring them to move from one side of the issue to the other. This encourage flexibility in thinking, an important component of creative thinking.

8.5 Reading Strategies for the Science Classroom

Picture this: The bell is ringing and the teacher shouts, "For tonight's homework, read Chapter 8 and do problems 1-11 on page 243!" Secretly the teacher knows that very few of the students will "read" the chapter, and maybe half of them will turn in the answers to the questions.

In another classroom, the teacher is explaining an assignment in which the students are to identify the main ideas in the first half of a chapter in their text, and then write supporting details that explain, prove, or tell something about the main idea.

Still, in a third classroom, a teacher has prepared on large sheets of paper the main terms in the current biology unit. The words are written in English and Spanish, and the teacher has pictures pasted next to each word. The teacher is reviewing the words the with the class.

To a growing number of science educators, the teaching of language abilities and skills should be an integral aspect of science teaching. The three examples cited here are only the tip of the iceberg with regard to the actual language arts teaching that occurs in the science classroom. To some, the teaching of language or study skills is seen as remedial action necessary for students with low reading scores or abilities. For these students, this is beneficial if they do indeed have teachers that provide "special" instruction to help them comprehend their science textbook, or give them pointers for writing reports.

However, there is more powerful argument to support the integration of language skills in the science classroom. Three of the four goal clusters recommended by Project Synthesis involve personal, societal and career awareness objectives. These goals take the purpose of science teaching beyond the laboratory or the the academic context, and into everyday life: newspapers, magazines, television, and the local as well as global community. Students need to develop the skills (in the science classroom) so as to evaluate and find information, make decisions about issues, and communicate this information effectively. Language skills are at the heart of this goal. In this section, we will explore strategies that will aid students in the science classroom to improve their ability to read science information, and to communicate their ideas in writing.

First, lets start off with the notion that reading is as much of a scientific activity as observing, classifying, measuring and hypothesizing. If we want science to be more accessible to our students, then we must recognize reading as a new science process skill. Leslie Bulman in *Teaching Language and Study Skills in Secondary Science*, writes:

> "If pupils can read about science it makes it potentially more accessible both in terms of present understanding and, even more important, of future interest. Most learning after the exposition of school and lecture hall is over, is via books...Reading is more important as a scientific technique than many practical skills. It is clear from the aims of science education...that they cannot be achieved with advanced reading skills."

The most recent edition of *Modern Biology*, the most widely used science textbook in the United States has over 800 pages of text, and lists over 1100 entries in the glossary. Quite a formidable task for a fourteen year old student to undertake! Regardless of the students intellectual development, student success in science courses could be enhanced if they were taught in a manner that we might call: learning how to learn. Recent research in metacognition supports efforts in which students are taught strategies of learning that will enable them to learn science, but also understand their own thinking processes. With this in mind, we shall explore several thinking strategies that will enhance student's reading abilities.

8.5a Listening

Teacher's talk about 2/3 of the time in an average classroom; therefore listening is an important survival skill that students need to develop. A good listener is an active listener in that they concentrate and participate in the process of communication. Listening is one half of the act of communication; however in the classroom, students do not always have the opportunity to respond and interact directly with the speaker. The listener must develop skills to "communicate" alone, and the teacher must implement strategies that provide students (in pairs or small groups) the opportunity to interact.

Listening Skill Activity #1

In this activity students practice being an active listener by concentrating and participating. Tell the students that you are going to read a passage to them, and they should participate in the following ways:

1. When you listen, ask yourself questions about what you are hearing; answer the questions if you can.

2. Try to connect what you hear with what you already know.

3. Try to "picture" in your mind what is being said, and draw a picture if it is appropriate.

4. When the passage has been read write the main idea in your notebook.

Passage to be read: In this science class you will be doing a number of activities in the laboratory and it is important to use the right tools and instruments. You wouldn't use a thermometer to measure the height of a building. You wouldn't use a microscope to observe the moon. You wouldn't collect rocks in a glass beaker. You would choose the equipment that best fits the task you are doing. In this course, you will be measuring and observing objects, living things and phenomena and you will learn what tools and instruments you should use.

Listening Skill Activity #2:

Another active listening device is taking notes. In this activity we will focus on notetaking during the listening process; more strategies for notetaking are found ahead in the section on mapping. In this activity, students listen to a passage and actively participate in the process by taking notes. However they are instructed as follows:

1. Do not write down everything. Instead, listen for words that seem key or important. Listen for speakers clues such as emphasis, or repetition.

2. As you listen, jot down all the key words or phrases.

3. When the speaker is finished, go back and write a phrase or sentence for each key word.

4. Describe the main idea by writing a sentence or two.

5. Share your main idea with a partner, listening to your partner's as well. Compare the results, and make any modifications.

Passage to read: *Evolution---the theory that species change over time---is the unifying theme of biology. The theory of evolution helps explain how all the kinds of organisms came into existence. It helps us understand why organisms look the way they do and how organisms of the past are related to organisms alive today. It also helps explain relationships among various groups of living organisms. Scientists suggest that evolution occurs by a process called natural selection. According to the theory of evolution by natural selection, organisms that have certain inheritable traits are better able to survive in specific environments than organisms that lack those traits. Such favorable traits are called adaptations.*

Listening Skill Activity #3:

This activity is a modification of the "Think-Pair-Share" strategy in which students are presented with some information, a problem, or a question, and are asked to think about their response or comprehension, and then share their idea with a partner. In the science classroom this technique is very powerful, especially if it is repeated over the course of the year.

Present information to students in the form of a mini-lecture. At a convenient point in the presentation stop, and either ask a question, or ask the students to identify the main ideas or concepts presented. Give the students a minute to think about their response, then have them share their thinking with their partner. The process enables all students in the class to become active listeners, and participants in small group interaction.

8.5b Coming to Terms: The Vocabulary Problem

Thelen suggests that science teachers not preteach new vocabulary words. If indeed the words are new, then students should be engaged in learning activities to construct knowledge about these new words, most of which are science concepts. Instead, she suggests that science teachers reduce the number of vocabulary words that students need to learn, and use vocabulary reinforcement activities to help enhance vocabulary development.

One technique that science teachers can use to reduce vocabulary is to use a structured overview---a sort of visual overview showing the relationship among science concepts. In this approach the teacher would identify the vocabulary of the learning activity, chapter or unit, and arrange the words in a scheme that depicts the relationships among the concepts. The structured overview (much like a concept map) is then presented to the students, and used to find out what they already know about the concepts and terms. The structured overview or organizer can be used as students explore the topic (Figure 1).

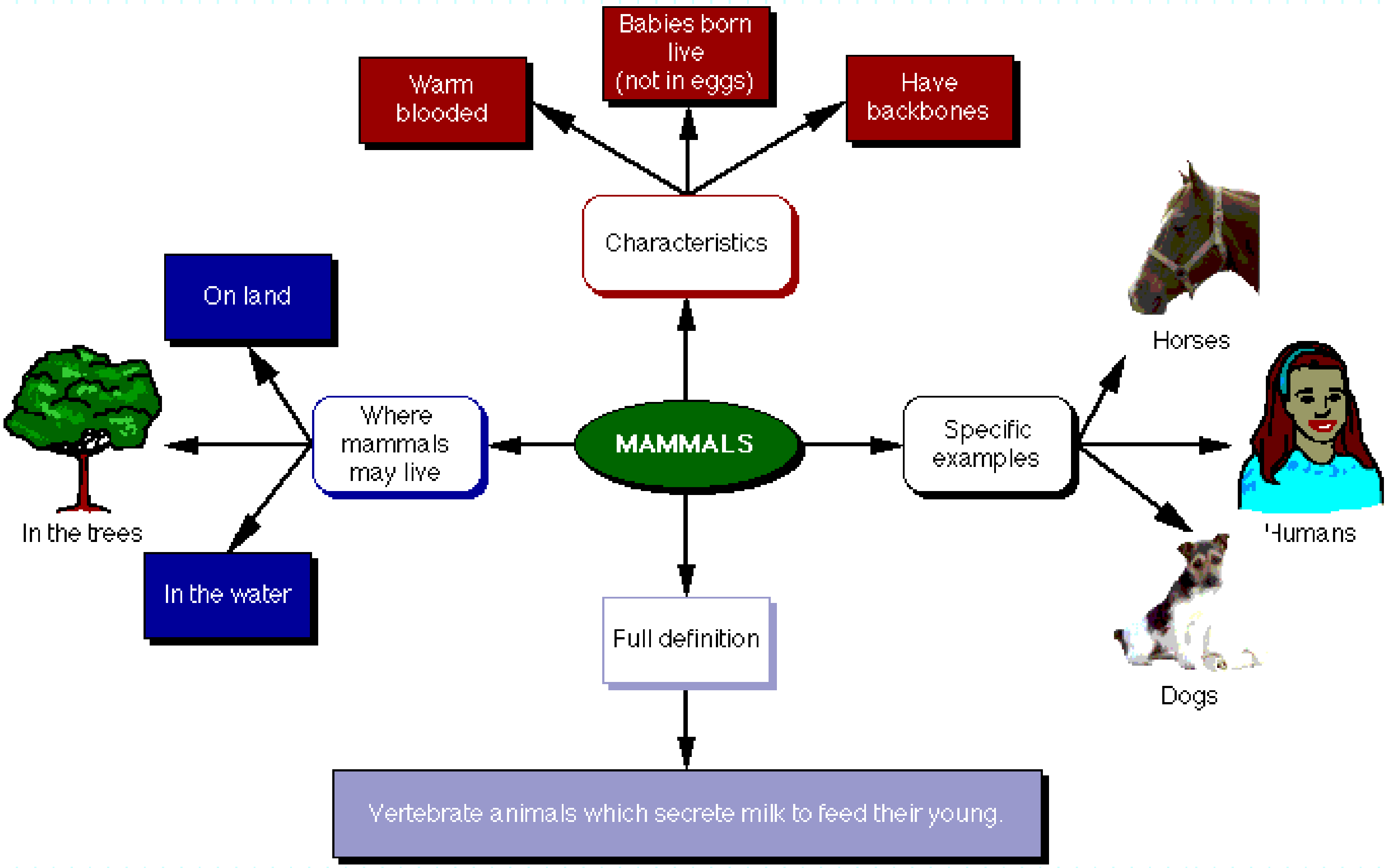


Figure 1 Structured Overview of Mammals

Most science textbooks identify by means of bold print, underline, or italics the key vocabulary words in a chapter. Students need to learn how to interpret meanings by reading about the concepts by focusing on context clues. Context clues are the sentences and phrases in the text surrounding the vocabulary word. Reading guides might suggest an activity after the student has read a passage in a text, or might ask the student to read a passage and then write the meaning of several vocabulary words.

For example, you might have the students read a passage such as the one shown below, and then write the meaning of the words shown beneath the passage. The meaning of the words will be based on the student's prior knowledge as well as the contextual clues in the passage.

All organisms are composed of and develop from cells. Some organisms are composed of only one cell. These organisms are called unicellular organisms. Most of the living things you see around you are composed of more than one cell. Such organisms are called multicellular organisms. Multicellular organisms usually arise from a zygote. The process by which a zygote becomes a mature individual is called development.

unicellular ____

multicellular ____

development ____

Figure 2 shows how a reading guide can be useful in helping students make use of some of the context aids in the text to enhance vocabulary and concept development. In this case the teacher is selecting and identifying what is important and telling the student to focus on these aspects of the chapter in order to develop conceptually.

Figure 2 Science Text Reading Guide (From Thelan, 1984, p.33)

Paragraph 10 (Yes, that's right, Paragraph 10.) Read paragraph 10 and keep it in mind as you follow the exercises on this sheet. Now proceed to:

Paragraph 1.

Draw a picture of a light spectrum.

a. Does it look like a rainbow?

b. Why do they call it a rainbow pattern?

c. If you take the orange out what color will replace it---black or white?

Paragraph 3

a. Read sentence 1

b. Look at Fig. 5.8 and read sentence 1.

c. 1. Does it look like a rainbow?

d. List 3 things that are the same or different between 5.8

and a rainbow.

1.

2.

3.

A number of types of vocabulary activities can be used to reinforce and extend students' vocabulary development. These include categorizing, word puzzles, matching, magic squares, crossword puzzles, and various writing forms (see ahead in the section on science writing). Here are some examples.

Word categories

There are five words in each section below. Cross out the two words in each you feel are not related to the others. Explain the relationship by titling each group.

1.______________________

amino acids waste

energy storage

water food

enzyme pocket

protein contractile

2.______________________

waste

storage

food

pocket

contractile

Word puzzles

Using the clues on the next page, complete the spelling of each word.

1.-----S-

2. -----O----

3. ---U-----

4. -R--------

5. ----C-------

6. --------E------------

7. -----S---

Clues:

1. Source of chemical energy in all animal cells.

2. Plant energy source.

3. Reaction involving gain of electrons.

4. Conversion of organic acid.

5. One place where reaction for liberation of energy takes place.

6. Key substance which occurs in every living organism and cell.

7. ADP

8.5c Reading for Meaning and Understanding

How can textbooks be used so that students will read them for meaning and understanding? A partial answer to this question lies in how we think students learn. Let's accept the cognitive psychologist's assertion that human learning is dependent on the individual's active interaction with the environment, and that new learning must be tied to what the student already knows. If the textbook is to be one of the "environments" which the learner will interact, then we must find a way that involves the student actively with the textbook. Simply saying, read pages 20-30 for homework will not work. Critics of textbooks charge that:

> ...the textbook is weak in that it offers little opportunity for any mental activity except remembering. If there is an inference to be drawn, the author draws it, and if there is a significant relationship to be noted, the author points it out. There are no loose ends or incomplete analyses.

Although textbooks have become more visual, there is still the problem that "few users of textbooks, instructors and students alike, are literate enough to derive full value from the textbook's illustrations."

In order for students to read for meaning and understanding, a teaching strategy must be employed that actively engages them comparing what they already know to the new material, as well as involving them in processes such as predicting, inferring, hypothesizing, summarizing, drawing conclusions, and discussing.

Two strategies will be presented here that have been used in science classrooms, and have been shown to be effective. The first is called the K-W-L procedure, and the second we shall refer to as the Survey-Read-Map-Check procedure.

K-W-L

According to Donna Ogle, the originator of K-W-L, prior knowledge is an integral aspect of how we interpret what is read, and what students will learn from reading. Unfortunately, most science teachers fail to make use of what their students bring to a topic. The K-W-L procedure supports the main assertion of cognitive psychology that the student preconceptions of science need to be determined prior to learning new concepts.

The procedure is comprised of three cognitive steps: assessing what I **K**now, determining what I **W**ant to learn, and recalling what I did **L**earn. Ogle has developed a K-W-L strategy sheet (Figure 1) which students can use as they "read" a section of the science textbook.

Figure 1. K-W-L strategy sheet

1. K-What we know	W-What we want to find out	L-What we learned and still need to learn

2. Categories of information we expect to use

A.

B.

C.

D.

E.

Briefly, here are the essential characteristics of each step in the K-W-L procedure and an example of a lesson plan on "earthquakes" (Figure 2).

Step K---What I know. This is a brainstorming session in which students express what they know about the topic. What the students know can be written on the chalkboard, on chart paper, on written by students working in small groups. The focus at this stage should be specific. If the students are going to read a section in their text on earthquakes, ask "what do you know about earthquakes," not what do you know about natural disasters, or have you ever been to San Francisco? Focusing on the content will help bring out the cognitive structures of the student's prior knowledge.

A second part of the K-step is to have the students categorize the information they have generated during the brainstorming session. For example, in the lesson plan below on earthquakes, the teacher might suggest that students group their information in the following categories: causes of earthquakes, how earthquakes are measured, and damages caused by earthquakes.

Step W-What do I want to learn? This step helps the students anticipate the reading that is to come, and helps the students focus on what they want to learn from the reading. This step should be done as a group activity. The teacher should ask the students to write down on the K-W-L worksheet questions that they are most interested in having answered as a result of the prior discussion and brainstorming session. Once the questions are written, the teacher might have the students share their questions in small groups prior to actually reading.

Step L-What I learned. Students can write down what they learned on the K-W-L strategy sheet. They can also check to see if their questions were answered, and if some of their prior knowledge was confirmed. Students should work in small groups and discuss their questions to determine if their questions were answered.

Figure 2 K-W-L Lesson Plan:Earthquakes

Objectives:

1. to describe how earthquakes are caused

2. to predict the effects of an earthquake

Reading: Students will read Chapter 19. Earthquakes in Focus on Earth Science (Merrill Publishing Company, 1989): 411 - 428.

Procedure

K: What do students already know about (earthquakes)?

1. Pairs of students brainstorm and record what they know about earthquakes.

2. Pairs of pairs (groups of 4) share lists and prepare a composite list.

3. Groups of four share with the whole class by taping lists on the walls of the classroom. Teacher focuses on the lists, and asks groups of four to categorize the information: topics include at least---causes of earthquakes, damage caused by earthquakes, earthquake waves, and how earthquakes are measured.

4. Teacher asks students how they got their information about earthquakes. This last procedures personalizes student knowledge, and acknowledges the sources of students' prior knowledge.

W: What do students want to know about the topic?

1. Each group of four develops four questions about the topic.

2. Teacher records these questions on the board. The teacher can elaborate on the questions, perhaps selecting two or more that seem interesting to the students.

L: What did students learn about the topic?

1. Group circles information on the master list that the text confirmed.

2. Information is crossed off that text refuted.

3. Students contribute to new list: What we learned!

4. Teacher goes around the class and asks each student to indicate by (thumbs up/thumbs down) if their question(s) were answered.

5. Teacher asks each group to make a map or a web of the main ideas and supporting secondary categories of what they learned from the reading.

Survey-Read-Map-Check

Another procedure which is designed to help students read for meaning involves four steps: surveying, reading, mapping and checking. The process is very similar to the K-W-L, and after studying both procedures, you might want to combine elements from both to personalize your approach to helping students read science textbooks. Let's examine the four steps in this reading procedure.

Step 1 Surveying: Surveying involves skimming the text passage and specifically students do the following: (1) look at the title; (2) look at the headings and subheadings throughout the reading, (3) read the introduction and conclusion or summary, or the first and last paragraph of the reading, and: (4) after surveying, write three things they expect to learn from the reading. Surveying should be done in small groups, and the results shared with the whole class.

Figure 3. Exercise: Surveying

Directions: Take two to three minutes to survey the chapter on "weather and climate" (or any other chapter) using the steps listed above. After you have surveyed the chapter, write three things you expect to learn from the chapter.

I expect to learn: (following are samples of what students might write)

1. What causes the weather.

2. The different kinds of clouds.

3. Tornadoes, hurricanes and other severe storms.

Step 2 Reading: During this step the students not only read the assigned materials, but search for the main ideas and supporting details. Thus it is important to break reading assignments down in to manageable chunks. Students need to informed that the main idea is the most important idea of a section and the rest of the paragraph of the section is built around the main idea. Supporting details explain and amplify the main idea.

Exercise: Reading for meaning

Directions: Find the main idea and supporting details in this paragraph:

"**Hurricanes** are tropical cyclones that form over oceans. They usually form in latitudes between 5 and 20, and move toward higher latitudes. Air over tropical oceans is very warm and humid. Sometimes centers of very low pressure develop with a rapid inflow of air, forming a nearly circular storm. Air near the center is forced aloft and flows outward at upper levels. Wind speed increases as the storm develops. When wind speeds reach 120 km/h the storm is a hurricane. An eye forms at the center as air sinks and is warmed by compression."

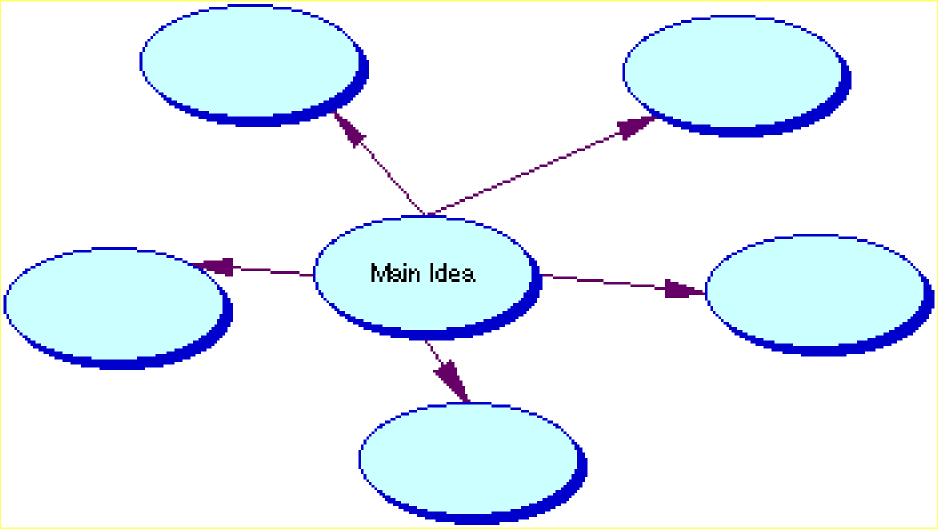
Main idea: Hurricanes are storms that form in the tropics.

Supporting details: they form between 5 and 20 latitude; must have winds greater than 120 km/h; an eye forms

Step 3 Mapping: Taking notes the third step in this reading process. Mapping is an extension of the previous step, however in this procedure the students make a map of the information they are reading. The student writes the main idea or concept in the center of a sheet of paper and circles it. Supporting details and ideas are written and connected to the main idea.

Exercise: Mapping

Directions: Find the main idea in the section you are reading. Write it down and draw a circle around it. Write supporting details on lines connected to the main idea.



Step 4 Checking. The final step in this reading process is to check what the students have learned. Checking is a process to help students identify and recall the most important points in the reading. In this step the students ask themselves: What is the most important idea in that I learned in this section?

Exercise: Checking

Directions: Review with your partner the section you read and identify the most important idea in the section. Be prepared to defend your selection.

Helping students read for meaning and understanding can be the result of creative lesson planning, and acknowledging that there is *process* for comprehending the information in science textbooks. K-W-L and Survey-Read-Map-Check are two processes that have been shown to be effective.

8.5d Semantic Mapping

Although mapping was used in both of the reading process procedures described above, the concept of mapping deserves additional discussion. Semantic mapping is the structuring of information in graphic form. It is not a new process, and has been known as concept mapping, webbing, networking and plot maps._Semantic mapping is a tool that teachers can use to help students connect prior knowledge with new science concepts to be learned in terms of a schemata or a wholistic conceptual system. In many cases, new science words are often introduced and defined in isolation from a more general system of idea.

As Heimlich and Pittelman point out, semantic maps are diagrams that help students see how words or concepts are related to one another. In most cases semantic mapping begins with a brainstorming session in which students are encouraged to make associations to the main topic or concept presented. Students are actively engaged in using their prior knowledge, as well new science concepts and experiences that the teacher has provided to develop a semantic map. Semantic maps can be accomplished individually, or in small cooperative groups, or with the whole class.

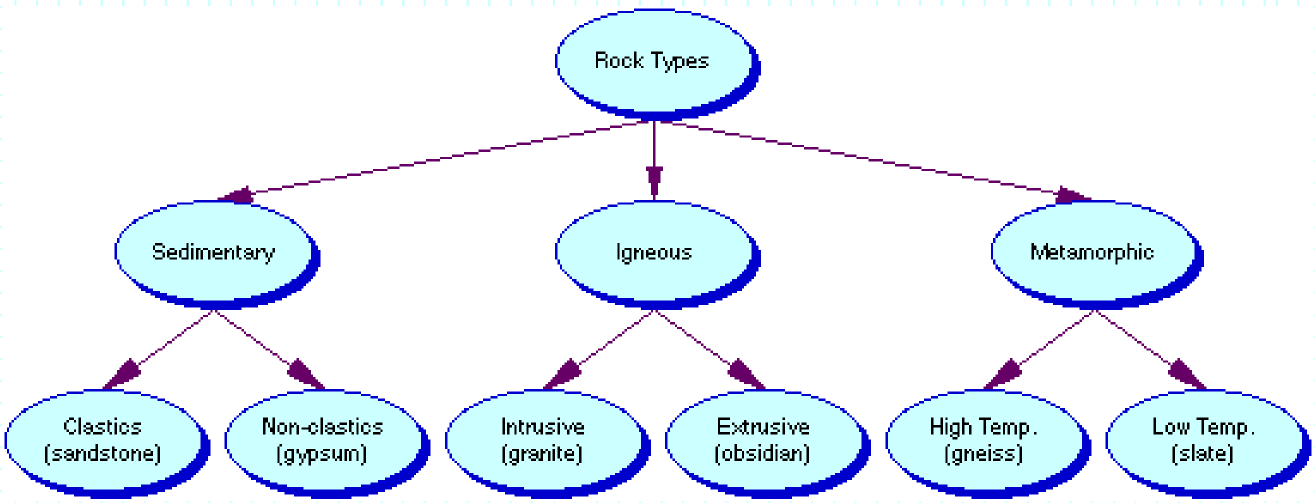
Semantic maps (Figure 1) can be used in many different contexts in the science classroom including:

1. As a science vocabulary (concept) building strategy

2. As a pre and postreading strategy

3. As a science study skill strategy

Figure 1. Semantic Map for Rock Types



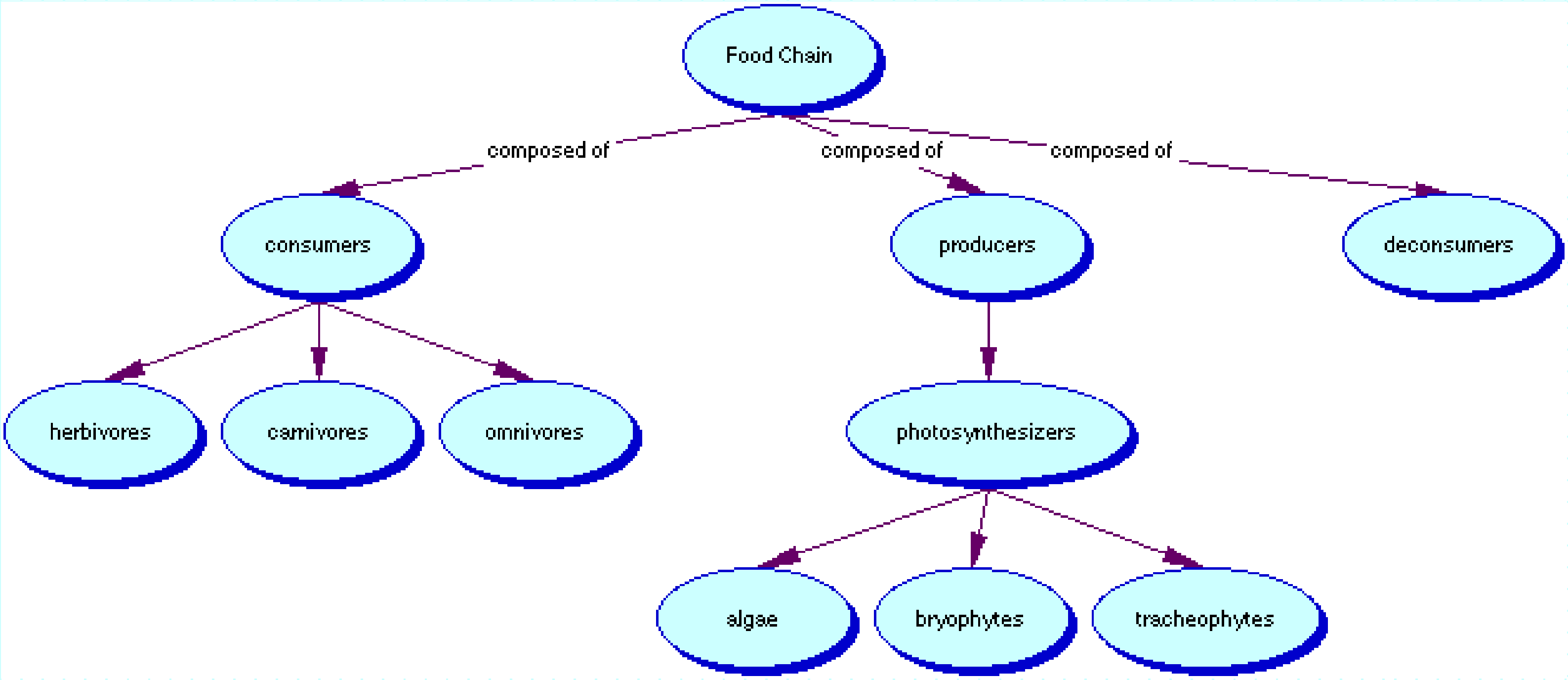
Heimlich and Pittelman have developed a basic strategy for developing semantic maps; this strategy can be used in any of the three purposes listed above. The following is an adaptation of their strategy:

1. Choose a science concept related to the chapter or unit students are studying.

2. List the concept on large chart paper or on the chalkboard.

3. Encourage the students to think of as many words or concepts as they can that are related to the main concept (see the example on *sharks* in Figure 8.27) and to list them in categories on the paper. This step of the process can be done individually, in a small team or with whole class. Encouraging interaction among the students is an important part of the process, and therefore most teachers choose to do this as a small group or whole class activity.

Figure 2. Semantic Map on the Food Chain



4. Students can share their results with each other.

5. Students should discuss by comparing and contrasting their semantic maps in order to develop deeper understanding of science concepts.

8.6 Writing Strategies for the Science Classroom

Writing activities in the science classroom have great potential. Consider this science writing lesson in a middle school earth science course.

Title: Crusty (rock) writing

Objectives:

- Collect data on rocks using observational skills
- Record notes about a natural object, a rock
- Reconstruct notes in poetry form

Description:

As part of a science unit on local geology, students select a rock that they observe carefully, using all five senses. They then write words and phrases based on their observations. After reading and thinking about their notes, they write an ode to their individual rock, beginning, "Oh, rock..."

Procedures:

Have students gather rocks as part of field trip, or bring in enough rocks from the local scene so that each student will have one to observe.

1. Stimulus

All students have a rock on their desk. Discuss what the students can observe about a rock based on each of the senses. Have a student recorder write key words on the board or on chart paper, such as:

- Sight---size, shape, color
- Hearing---rattle, scraping
- Taste---mineral content, dirt
- Touch---shape, roughness, smoothness, unevenness, bumps
- Smell---sweet fragrance, earthiness

Have students fold a sheet of composition paper in thirds, labeling one section for each sense, and the sixth one entitled Other Ideas. Ask students to observe their rocks and to jot down notes about what they observe.

2. Activity:

After have had time to observe and write notes, tell them that they can use their observation to write an ode to their rocks. Tell them that an ode is a song that begins, "Oh_" and that is usually praises a person. The can begin their poem with "Oh rock...." and speak to their rock as a person, using personification.

3. Follow-up:

After students have written for a while, have them read their poems to a partner. Partners can assist each other in adding ideas or revising the poem, as needed. Their poems might be something like this:

Ode to a Rock

Oh, wonderful little gray rock,

Bumpety, lumpety, and tough.

You have tumbled down from the high mountain,

You have survived the trampling of many rough feet,

The crush of an automobile's wheels.

I will give you an easier life now

Perched on my bedroom windowsill.

4. Evaluation:

Circulate around the room to observe student participation as they observe, write, and share. Have students determine criteria (scientific and poetic) for an especially good poem after they have shared, answering the question: What made some poems stand out as especially effective? Students can revise their poems based on the established criteria. Have students display the rock writing with rocks laid on a table or shelf.

This lesson, which enables students to make connections between science process skills and writing is not the typical way in which students write in science classrooms. Unfortunately, creative writing, which can help students become successful science learners, is low on the priority list of "science writing assignments." Bulman reports that students spend between 11% - 20% of their time in science classrooms involved in writing activities. However, Bulman also reports that over half of the writing time is devoted to copying or taking dictated notes (Figure 2).

Figure 2 Types of Writing in High School Science Classes

Types of Writing	% time spent 1st year in high school	% time spent 4th year
1. Copying: copying or dictated note-taking	46	56
2. Reference: making notes from printed material.	0	19
3. Personal: essay writing, writing in own way, diary, some project work, reports of experiments.	29	8
4. Answering: Answering worksheets, exercises, answering test and exam questions.	25	17

What is the purpose of writing in the science curriculum? To improve the writing abilities of students in all subjects, many schools districts have implemented a concept known as "writing across the curriculum" in which subject matter teachers are given training and teaching materials to integrate writing into their subject. Any approach to integrate writing into the science classroom must take into consideration the goals of student writing in science. Bulman has suggested four goals:

1. to help the growth of understanding of science concepts
2. to provide a record of concepts and activities that can be used for revision later
3. to provide feedback to the teacher on the growth of the students
4. to develop students' ability to communicate

How can these goals be achieved? What are some strategies that might help achieve these goals? In general, writing should be viewed as an integral part of the learning cycle that was presented in Chapter 7. Students need the opportunity to reflect on their thinking, and writing about their observations, inferences, hypotheses and conclusions is a powerful strategy. The strategies suggested below are designed to help students clarify and extend their thinking by having them write in a variety of forms. Five strategies are suggested:

Science logs

Letter writing

Science newspapers

Storywriting

Poetry and Science

8.6a Science Logs--Visual and Verbal Journals of Students' Ideas

Writing is a way of expressing ideas and concepts that are within us. These concepts and ideas are based on prior experiences, imagination, and the willingness to let these ideas emerge. We have already shown that reading and writing are integrated processes. In real life experiences of reading and writing, this is known to be true. For example, if you ask a writer what is essential to writing, the answer invariably is read, read, read. Writing and reading are inseparable processes, and in the science classroom the teacher can help students by providing integrated experiences language experiences.

The science log is one such experience. It can become a place---a creative space---in which students organize their ideas from their reading of the science text, from science experiments and activities, and the day-to-day activities that are part of your teaching process. Here are some specific suggestions for using the science log.

1. *As a note-taking device.* Students should follow the K-W-L or the Survey-Read-Map-Check procedures and use the log as the place to write their results.

2. *As a record of experiments and activities.* Visual and verbal thinking should be encouraged as students record the results of experiments and hands-on activities. Figure 1 shows a form that is used to encourage students to use record the results of a science inquiry activity. Note that the students are involved in making predictions, collecting data, drawing a diagram or picture of the experience, and writing an explanation for the event or phenomenon they observed.

3. *To prepare a daily log*. Some teachers have students use their logs as a post-lesson review of the lesson. However, students are asked to make a map of the lesson by writing the main idea in the center of a page in the log, and then identifying the supporting ideas and concepts by connecting them to the main idea.

4. *As a learning tool.* Iris McClellan Tiedt suggests that the science log be conceptualized as a learning log. As a learning log, students express their findings or their questions, and it can be used to clarify concepts, ask questions of the teacher, or set goals for learning. Logs can be kept in spiral bound notebooks, loose leaf notebooks, in a folder, on on the computer. As we have outlined above, logs should help students summarize and clarify what they learned in a class session, a laboratory exercise, a class discussion, or a reading. Teachers should read logs to evaluate the effectiveness of lessons, as well as a way to identify students who need specific help. Here are two sample lessons to give you an idea of how to make the science log a learning tool.

Figure 3. Science Log Lessons

Lesson 1. Using the Learning Log with the Science Textbook

Objectives:

1. to record thoughts while reading the science textbook

2. to understand how writing and reading can clarify science concepts

Description

This is a general lesson showing how the science log can be used to help students take notes while reading the science textbook. Note that the lesson focuses on finding key words---not writing everything in the text. It helps students synthesize what is read.

Procedure:

1. Stimulus: Assign students a section of the science textbook or a magazine. Tell them to use their science log to take notes.

2. Activity: Read aloud (yes, you, not a student) a section from the text that has a heading. After reading, put the main words of the heading on the board or on chart paper, for example: "Circulation." Under the main subject have the students first list the key words related to the topic (e.g. arteries, veins). Do this with the class as they read. Next, ask the students to add a phrase of clarification after the key words. (Note: you can also use the four steps of the Survey-Read-Map-Check procedure instead of this process).

3. Follow-up: Give the students a few more pages to read in class or for homework. Have them follow the same procedure for *each section*. Emphasize that they are picking out key words and reading for a definite purpose.

4. Evaluation: The next day, have the students share their notes with a partner. They should compare their choice of main ideas and come to some conclusion.

Lesson 2: Using the Learning Log with a Hands-on Activity

Objectives:

1. to write in order to clarify what they observed in a hands-on activity

2. to ask questions immediately after the hands-on activity

3. to write in science class

Description:

This lesson shows you how the science log can and should be used immediately following a hands-on activity. It provides an opportunity for you to have the students express what they have learned from the activity.

Procedures:

1. Stimulus: Have students observe an EEEP or inquiry demonstration. Students should be involved in the activity, not simply passive observers of the event.

2. Activity: Following the EEEP activity, the students record their findings in their science logs. Encourage the students to connect new learning with

old, express discoveries, ask questions of the teacher, and express any frustration related to the activity.

3. Follow-up: Have students exchange logs with their partner, or read the logs yourself.

4. Evaluation: Have the partner respond to the log in writing to the individual. A brief comment is all that is needed. Peers can answer questions, and commenton the log.

In each of these lessons the log is used in an active way. Students not only write in their own logs, but exchange their logs with other students in the class, and have an opportunity to write in their classmates logs. Logs are also viewed as feedback mechanisms for the teacher. Logs can be an integral part of the science curriculum, and can foster critical and creative thinking.

Now lets examine some other types of writing formats appropriate for the science classroom.

8.6b Letter Writing

There are at least two aspects of the letter writing format that have been shown to be effective: writing to others for information, and writing "letters to the editor." Letters can be the beginnings of potential research, especially of the survey type. For instance, students might want to write to various organizations related to a topic they are studying, e.g. the Sierra Club, Audubon Society, National Aeronautics and Space Administration, National Transportation Board, Environmental Protection Agency, the United Nations. Each of these organizations is a source of good information. Letters to the editor are especially significant if students are working on an STS project, or debating an issue that has personal and societal implications.

Students can be given a format to follow to write letters of inquiry, and letters to the editor, and use the computer to prepare the documents.

8.6c Science Newspapers

Students in your class might be interested in applying desktop publishing to produce a science newspaper which could be distributed to other students in the school, as well as to citizens in the community. There are number of software packages available that will allow students to design newspapers in a quality that compares with commercially produced newspapers. The newspaper is especially useful in that it provides a creative mode for students to write about famous scientists, discoveries made by scientists, ecological and environmental concerns, as well as science and society issues.

8.6d Storywriting: Science Fiction

Imagination is as important to science as it is to art forms such as pottery, painting and writing novels. Reading as well as writing science fiction can be a powerful medium for many students in your science class. Books by Robert Heinlein, Carl Sagan, Isaac Asimov, and Ray Bradbury can provide the stimulus needed for students to write their own science fiction. I recommend that you read passages from your favorite authors and use it as a vehicle for brainstorming about imagination and science.

An excellent resource for the science classroom in this regard is *Fantastic Reading* by Isaac Asimov, Martin Greenberg and David Clark Yeager published by ScottForesman. It is an activity book providing high-interest science fiction and fantasy stories along with vocabulary, writing, reading comprehension and study skill activities.

Writing science fiction brings students into the world of invention and creativity. Students can explore the limits of their own creativity by writing imaginative stories about the future, or the past by attempting to integrate science concepts into the story line. What kind of thinking might be activated if students were to write stories that involved:

- Black holes
- The Big Bang
- Anti-matter
- Speeds approach that of light
- Life on Io, and other moons of Jupiter

Two other resources that are helpful in the science fiction and creative writing area include:

- Alan McCormack, *Inventors Workshop*, David S. Lake Publishers, 1981.
- Joe Abruscato and Jack Hassard, *The Whole Cosmos Catalog of Science Activities*, Second Edition, Scott Foresman, 1991.

8.6e Poetry and Science

Poetic forms offer a rich variety of writing styles for the science classroom. Many science teachers have integrated language arts into science teaching by engaging students in the writing of poetry. Here is a collection of poetic forms pulled together by Molly McClauskey, a student at the University of Vermont.

Science Writing: Poetic Forms

Poetic Form	Example
Cinquian The cinquain is an extension of the haiku and has this form: • a word (think of a topic) • 2 adjectives (describe the topic) • 3 action words (what the topic does) • a statement or 4 more adjectives • a synonym or one more adjectives for the first word	Quarks tiny and fundamental up, down, up building blocks of nuclear matter energy
Limerick Limericks are rhythmic poems, usually written about a character and her/his habits or traits. Form: • 8 syllables • 8 syllables rhyme • 5 syllables rhyme • 5 syllables • 8 syllables	There was an old man with a beard Who said, "it is just as I feared, Two owls and a hen, Four larks and a wren, Have all built their nests in my beard!"

<table>
<tr>
<td>
<u>Diamante</u>

Try writing a diamante about your favorite scientist, or science theory. It has 7 lines:

1 noun
2 adjectives
3 "ing" words
4 nouns
3 "ing" words
2 adjectives
1 noun opposite of first noun

</td>
<td>Try: Galileo, Copernicus, Stephen Hawkins; plate tectonics theory, atomic theory, the "Big Bang" theory.</td>
</tr>
<tr>
<td>
<u>Haiku</u>

A haiku is a form of Japanese poetry. Try writing one; they have this form:

first line: five syllables
second line: seven syllables
last line: five syllables

</td>
<td>Pine tree silhouette

painted by the harvest moon

on a shining night</td>
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8.7 Strategies That Foster Independent Thinking

School science needs to help students become independent thinkers. In *Project 2061: Science for All Americans*, the authors pointed out that science teaching related to scientific literacy needs to be consistent with the spirit and character of scientific inquiry and with scientific values. Students must be engaged actively "in the use of hypotheses, the collection and use of evidence, and the design of investigations and processes, and placing a premium on the students' curiosity and creativity." The authors of the report refer to this kind of thinking as the "scientific habit of mind," and view its implementation as an important goal. They put it this way:

> "Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty; without the ability to think critically and independently, citizens are easy prey to dogmatists, flimflam artists, and purveyors of simple solutions to complex problems."

The habit of mind that is being suggested here is problem solving, and as Stanley L. Helgeson points out, "problem solving has been a concern of science education for at least three quarters of a century." Helgeson goes on to point out whether we use terms such as scientific method, scientific thinking, critical thinking, inquiry skills, and science processes, these are in essence expressions of a more general concept: problem solving.

Thus, in this section, we will explore problem solving, and pay particular attention to strategies that secondary science teachers can use to emphasize problem solving in their curriculum. We will first begin with the notion of problem solving, and then show the value of emphasizing the "processes of science" in secondary science lessons. Finally, we will conclude this section by relating problem solving and science processes to school science fair projects and research investigations.

8.7a Problem Solving

One of the problems with problem solving is defining it. There is a variety of definitions of problem solving. Some define problem solving in terms of the skills needed to solve problems, e.g. testing hypotheses, analyzing data. Others define problem solving as a series of steps that people use to find a solution or answer to a question.

Helgeson reports that in the literature of science education there is a strong linkage between problem solving and science process skills. That is, many science teachers teach students science process skills in the context of a subject---earth science, biology, chemistry, physics---because they accept the notion that these process skills are indeed the elements of problem solving. There are two aspects of this that should be pointed out. First, what are the generally accepted steps in problem solving, and secondly what are the science processes associated with problem solving.

Problem Solving Schema. No doubt you have come across the steps usually associated with problem solving; Are these familiar?

- Problem orientation
- Problem identification
- Problem solution
- Data analysis
- Problem verification

A more elaborate form of the problem solving strategy is one described in a typical middle school/junior high science text. Four general step are presented: Question, Test, Conclude, and Analyze. Students are shown that there are four steps involved in the scientific method to generate information and questions.

Another way to look at problem solving is from the vantage point of the scientist. Paul Brandwein depicts the scientists' approach to problem solving as the "scientists methods of intelligence." Typically the scientist's way begins with a discrepancy---a situation that does not fit the scientists present "concept." Although this theoretical model is often not applied directly to the classroom, there are a number of elements that are applicable.

Note that the model involves a number of processes---observing, hypothesizing, designing an investigation. These are examples of science thinking skills which have become one the organizing structures for teaching problem solving. Let's take a closer look at these scientific thinking skills.

Scientific Thinking Skills and Problem Solving. The curriculum projects of the 1960s and 1970s placed emphasis on problem solving, and developed as part of the organization of the curriculum a series of problem solving skills which became known as the processes of science. They are sometimes called the skills of science. Today, these skills are referred to as scientific thinking skills. It is important to note that problem solving as perceived in science classrooms is intimately related to these thinking skills.

The thinking skills of science are conceptualized as belonging to two distinct groups, basic thinking skills, and integrated thinking skills (shown in the table below). As you examine different science curriculum project materials, you will find some variation in the "lists" of skills, but in general:

- Basic thinking skills such as observing emphasize the foundations of science learning. The basic thinking skills are seen as a prerequisite for the integrated thinking skills.
- Integrated thinking skills are related more directly to problem solving, and are seen as the higher-order intellectual skills that problem solvers use.

Scientific Thinking Skills

Basic Science Thinking Skills	Integrated Science Thinking Skills
Observing Using the senses to gather information about an object or an event. Example: Describing a mineral as red.	**Controlling Variables** Being able to identify variables that can affect an experimental outcome, keeping most constant while manipulating only the independent variable. Example: Controlling the type of soil or sand and the angle of incline when testing to find out what affect the amount of flow (water) has on the depositional rate of a model river in a stream table.
Inferring Making an "educated guess" about an object or event based on previously gathered data or information. Example: Saying that a landform was once underwater because of the presence of Brachiopod and trilobite fossils in the rocks.	**Defining Operationally** Stating how to measure a variable in an experiment. Example: Stating that depositional rate will be measured in grams of sand deposited in the stream table's "ocean."
Measuring Using both standard and nonstandard measures or estimates to describe the dimensions of an object or event. Example: Using an equal-arm balance to measure the mass of an object.	**Formulating Hypotheses** Stating the expected outcome of an experiment. Example: The greater the amount of flow in a river the greater the depositional rate.
Communicating Using words or graphic symbols to describe an action, object or event. Example: Describing the change in temperature over a month in writing or through a bar graph.	**Interpreting Data** Organizing data and drawing conclusions from it. Example: Recording information about weather changes in a data table and forming a conclusion which relates trends in the data to variables (such as temperature, pressure, cloud cover, precipitation)

Classifying	Experimenting
Grouping or ordering objects or events into categories based on properties or criteria. Example: Placing all minerals having a certain hardness into one group.	Being able to conduct an experiment, including asking an appropriate question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment, and interpreting the results of the experiment. Example: Describing and carrying out a process to find out the effect of stream flow on depositional rates in rivers.
Predicting	**Formulating models**
Stating the outcome of a future event based on a pattern of evidence. Example: Predicting the position of the moon in the sky based on a graph of its position during the previous two hours.	Creating a mental or physical model of a process or event. Example: The model of how the processes of erosion, deposition, metamorphism, and igneous activity interrelate in the rock cycle.

8.7b Scientific Thinking Skills

Focusing on science thinking skills in the science curriculum is clearly one way of helping students become independent thinkers and problem solvers. How should secondary science teachers plan science courses to achieve this goal? Three approaches seem apparent. The first is a behavioral approach. In this approach the thinking skills of science are taught as separate skills or behaviors, e.g. observing, classifying, inferring, hypothesizing. A second approach---a cognitive or constructivist approach---and one that is favored by most science educators, is to integrate the thinking skills of science with the content or concepts of science. In this plan, science thinking skills would be taught in the context of learning biology, chemistry, Earth science and physics concepts. A third approach is called the research or science project approach. In this plan, students would engage in a science research project using the thinking skills of science to inquire about natural phenomena.

The Behavioral Approach: Teaching the Thinking Skills of Science

Teaching the thinking skills of science as a set of skills emerged as a consequence of Science - A Process Approach (SAPA), a curriculum project developed during the 1960s for elementary and middle schools. In this approach the complex set of skills a scientist uses was broken down into a number of skills which were to be mastered by the learner to develop a sound knowledge of science and its methods. In this approach, the major goal of the curriculum is to teach the processes or thinking skills of science. Science concepts and facts were introduced in the overall framework of the curriculum, but played a secondary role in the program. SAPA had a profound affect of other curriculum approaches, and a good deal of its impact remains today in science programs at the elementary as well as secondary level.

Most secondary science programs are not organized around a thinking skills approach, that is texts and courses are organized around units or chapters of content. However, on closer inspection, one discovers that middle school/junior and high school science programs include a series of "skill" activities spread throughout the textbook. In this approach, a skills approach becomes a strand in the science course. For example, in one science textbook the following skills are taught in separate lessons throughout the text:

Skills Taught in a Middle School Science Program

- Observations and inferences
- Determining variables and controls
- Constructing models
- Determining length, area and volume
- Performing investigations
- Constructing graphs
- Making a map
- Using laboratory equipment
- Using a globe
- Compare and contrast
- Making scale drawings
- Using star charts
- Reading a weather map
- Limiting the number of variables
- Forming hypotheses

- Interpreting a glacial map
- Classifying minerals
- Classifying rocks
- Using tables and charts
- Graphing data
- Interpreting data
- Sequencing events
- Designing an experiment
- Predicting outcomes

These 24 lessons constitute a behavioral approach to teaching the skills of science in the context of an (Earth) science course. Students, from time-to-time engage in a hands-on lesson specifically designed to teach a specific process of science.

Another approach that is used to teach the process of science is to include a separate chapter at the beginning of the course on science process skills. Usually the chapter is titled "problem solving in science," "the nature of science," or "how scientists think." Lessons that focus on the processes or skills of science are evident by the stated objectives, or question that is asked.

Cognitive/Constructivists Approach: Integrating Process and Content.

A second approach to dealing with the scientific skills of thinking is the cognitve or constructivist approach. In this method, science thinking skills are integrated with the learning of concepts. Joseph Novak, a leading proponent of this idea, points out that:

> It should be evident...that there should no longer be a debate about the extent of emphasis on teaching the content of science vs. teaching the processes of science. If a constructivist perspective guides our work, and especially if we use compatible metacognitive tools, there is no reasonable way to teach the processes of science without simultaneously teaching its concepts and principles...

In this approach scientific thinking skills are *learning strategies* that enable students to interact with the environment. If students are learn about theories of rock formation, they should observe and make inferences about rocks. If they are to learn about the structure of the atom, they might construct models, and test hypotheses with regard to different theories.

In this view the processes of science are an integral part of the learning cycle proposed by cognitive science educators. That is when the teacher engages students in the "exploration" stage of the learning cycle to encounter a new science concept, the intent of the teacher is to have the students utilize the processes of science in order to explore objects, phenomena and events. Thus students would be involved in making observations and measurements, collecting and interpreting data, and making conclusions for the purpose of investigating a scientific object, event or phenomena. In other cases, students might design experiments to test the efficacy of a particular scientific theory.

The processes of science become tools for the students in order to *understand* the concepts of science. In the cognitive perspective, science processes are the learning strategies for students to learn science concepts. Lets examine an example of a lesson that illustrates the convergence of science processes and science concepts.

8.7c Science Projects and Fairs

Critical and creative thinking can be fostered by involving students in activities that involve the solving of problems in the context of science projects, research investigations and science fairs. Although activities of this sort have in the past been carried out by individual students, many more students will benefit from these problem solving activities if teachers would organize them as group projects. Bringing into the mainstream of the science curriculum emphasis on science projects and research investigations expands students concept of science, and enables them to be immersed in problem solving. Let's take a closer look at how to implement science projects, and science fairs in the school setting.

Science Projects.

A ninth grade physical science teacher during the first semester of a two semester course organizes the students into four member teams to investigate a problem, question or topic. The teams have several weeks to complete their research and prepare for a class and a school presentation. Typical questions or topics that students investigate in this introductory physical science course include:

- Which metals conduct heat best?
- Do magnetic fields affect the growth of beans?
- Do plants grow better with tap water or distilled water?
- How are earthquakes predicted?
- Which toothpaste is most abrasive?
- What is the acidity of rain and how has it affected the environment in selected sites in North America? How does this compare to other continents?
- How can the global warming trend be changed?

An effective strategy for carrying out science projects is described by Sharan and Sharan. In their strategy, called Group Investigation (GI), students are organized into groups of four or five students, typically on the basis of heterogeneity. GI lends itself to the implementation of science projects at all levels and in all subjects of the science curriculum. It is a form of cooperative learning, and its philosophy cultivates democratic participation and encourages the development of an classroom atmosphere conducive to inquiry and student exploration.

Each group is responsible for investigating a topic or question which:

- Is assigned by the teacher,
- Identified by the group, or
- Selected from a list generated by teacher and/or the whole class.

The Group Investigation strategy is organized into six phases, with the teacher assuming the role of facilitator of learning. The teacher's role as facilitator is crucial in GI. Students need to be free to explore various questions, seek alternative methods and solutions, collaborate with their peers, as well as with "experts" in the school and the community. As you will discover in the next section, students will be able to access databases and students in other schools and cultures by means of computer telecommunications.

Implementing science projects using the Group Investigation strategy can be facilitated by following these phases:

The Group Investigation Process for Science Projects

1. Topic Selection

Students need to assume ownership for their science project, so it is best if some element of *choice* is built into the topic selection process. If the teacher has specific "projects" or "questions" that are integral to the goals and objectives of the course or unit of study, choice can still be provided by letting the groups choose from a pre-assigned list of topics.

For example a physics teacher included in the course syllabus a list of topics that student team would choose from during the fifth week of the course, and then would work on for three weeks. The teacher listed the following topics for team topic selection:

- How do the laws of reflection apply to driving an automobile?
- What was the "Hubble Trouble," and how can the problem be corrected?
- What are optical illusions, and are they really?
- How can mirrors be used as communication devices?
- How are the laws of reflection applied in everyday life?

After presenting these questions as the foci for science projects, the teacher conducted a brainstorming session in which additional topics and question were generated. From the combined lists, students in each group were asked to identify their first and second choice. Through a process of elimination, each group was involved in making a decision about the topic to investigate, although not necessarily its first choice.

Science projects, which might be a two-day to two week affair, to a full-blown science fair project that might involve some students for the major part of a semester are tools that science teachers have used to enhance student problem solving abilities.

2. Cooperative Planning

The students need time to analyze the topic they have chosen so that it can be broken into sub-topics or questions. Some teachers conduct formal sessions in which each group meets and constructs a concept map of the topic or question in order to identify sub-questions and sub-topics. Each member of the group will eventually be assigned (by the group membership) to investigate one part (a subquestion) of the project which will be shared with the small group.

3. Implementation of Research/Data Gathering

Students carry out the plans formulated in phase 2. They can investigate their sub-topic by gathering library information, doing a computer search, interviewing people, collecting materials, and even doing experiments. During this phase of the science project, students are engaged problem solving and utilize the processes of science---observing, classifying, measuring, formulating hypotheses, interpreting data.

During this phase it is important for the teacher to keep in touch with each group. Teachers meet with each group, and listen to reports on the groups' progress on its science project research.

4. Analysis and Synthesis

The teacher arranges during class time for special sessions in which each group meets to analyze and synthesize the information and research data gathered during phase 3, and plan how it can be summarized in an interesting manner for a class presentation.

5. Presentation of the Science Project

Groups give an interesting presentation of the topics studied. There is an attempt to get students involved in each other's work and to expand the perspective on the topic. In my own experience, student creativity can be facilitated if you encourage a variety of presentations and suggest that the least effective presentation is the lecture. Encourage groups to prepare presentations that involve the audience. Debates, demonstrations, hands-on learning activities, plays, video tape presentations, and computer simulations are effective ideas.

Science projects can also be designed so that the results are displayed for others not only in the class, but the school at large to observe. Using the display backboards described in the section on science fairs is one way of showing the science projects.

6. Evaluation

You and the students should evaluate each group's presentation or display. An effective evaluation technique is to have the class evaluate each group presentation. A simple form similar to the one shown in Figure 1 can be used to improve future science projects.

Figure 1. Science Project Feedback Form

Directions: Evaluate the group's presentation/display by checking a number for each of the questions below.

1. How effective was the presentation 1 2 3 4 5 6 7 8 9 10

2. How interesting was the presentation? 1 2 3 4 5 6 7 8 9 10

3. How much did you learn from the

presentation? 1 2 3 4 5 6 7 8 9 10

4. What was the quality of the materials

and demonstrations used in the presentation? 1 2 3 4 5 6 7 8 9 10

What did you like about the presentation?

What would you suggest the group change in the presentation?

Science Fairs.

Teachers who involve students in science fair projects commit themselves to many months of planning for an event that typically takes place during two or three days during the Spring of each year. Yet, the rewards of science fairs for teachers and students far exceed the effort that was put into the event. You might want to explore the page before you continue.

Science fairs can be the stimulus that is needed to motivate some students who otherwise might be turned off to science. Science fairs not only encourage critical and creative thinking, but they encourage students with a wide range of learning styles to become involved in a science fair project. Science fair projects also involve the community and the parents in science education. Parental involvement, which sometimes is seen as intrusive, can actually be a positive aspect of the science fair. School science must extend beyond the walls of the school; the science fair is the perfect event to bring science to the community.

Some school districts arrange with one of the shopping malls to use its space to display and conduct the judging of the science fair. Other school districts, such as the Atlanta Public Schools, conduct their science fair (The Atlanta Science Congress) in one of the schools, but involves hundreds of community agencies, universities and businesses by soliciting prizes for various categories, and asking professional to participate as judges.

Teachers can integrate the science fair concept into the ongoing science curriculum by encouraging science projects, and by helping the students learn how to carry out research studies. Too often, students are not given enough guidance, and lack experience in conducting a research study, or in preparing for one of a variety of science fair projects.

Three useful sources that you can use to guide you through the science fair process are:

> Robert C. Barkman, *Coaching Science Stars: Pep Talk and Play Book for Real-World Problem Solving,* Tucson, Arizona: Zephyr Press, 1991;
>
> Connie Wolfe, *SEARCH: A Research Guide for Science Fairs and Independent Study*, Tucson, Arizona: Zephyr Press, 1987; and
>
> Barry A. Van Deman and Ed McDonald, *Nuts and Bolts: A Matter of Fact Guide to Science Fair Projects,* Chicago: The Science Man Press, 1980.

Science Fair Time Line

Check off when procedure is completed

Week 1 _________ 1. Identify project/question/research focus

Week 1 _________ 2. Complete science fair entry form and turn it in for teacher approval.

Week 2 ________ 3. Initiate work on the science fair project.

Weeks 2-4 ________ A. Organize and write out a procedure or plan for your work.

______ B. Identify hypotheses (if you are doing a research study.

______ C. Conduct your study

______ D. Analyze your data

______ E. Write your report

Week 4 ______ 4. Begin work on your display. Present the information you collected in easy-to-read graphs or tables. If you did an experiment reserve special areas of your display for your Problem, Hypotheses, Procedure, Results, and Conclusions.

Week 5 ______ 5. Prepare a 2-3 minute oral report.

Week 5 ______ 6. Prepare all written materials to be included with your display.

Week 6 ______ 7. Bring your project to school.

Criteria to judge science fairs should be shared with the students at the beginning of the process. Typically the criteria include:

1. Scientific thought, approach, thoroughness (30)
2. Originality/Ingenuity (30)
3. Dramatic value/Display (20)
4. Interview/Oral Presentation (20)

When evaluating scientific thought, judges typically look at the clarity of the problem statement, sufficiency of background work, appropriateness and thoroughness of the procedures used, the validity and reliability of the data, and the justification for the conclusions.

Originality refers to the uniqueness of the project, given the age and experience of the student(s). Originality can refer to the questions being asked, the procedures used, and how the data were analyzed and conclusions made.

Judging also takes into consideration the quality and aesthetic appeal of the student's display and presentation. Was the project presented clearly, and was the method or procedure clearly shown?

The interaction that students have with judges is important. Can the students explain the project and demonstrate their knowledge of the topic and the related concepts?

Science fairs have the potential of encouraging the habit of mind that the authors of Project 2061 so aptly put forward in their report, Science for All Americans. As they point out, students can end up with richer insights and deeper understandings (by participating in an indepth study) than they could hope to gain from a superficial exposure to more topics than they can assimilate.

8.8 The Computer and Science Learning

The science classroom can be a special place. It can be one in which students work together in learning teams to answer questions, to inquire, to pose questions, and to learn new ideas about the world. It can be a place in which critical and creative thinking are fostered. In this book we have emphasized the importance---based especially on the work of Piaget and resulting theory of conceptual change teaching---that should be attached to the notion that student knowledge about the world develops as a result of their interaction with physical objects, events and phenomena, and people. We have emphasized the importance of involving students in the process of learning as described by the learning cycle.

The Microcomputer: A Medium for Science Learning

In the last 20 years, the computer has made its way into the educational scene. Can the microcomputer support and enhance the goal of involving students in the learning process, of encouraging inquiry and problem solving, and fostering critical and creative thinking. Or is the computer simply another educational innovation that will have little effect on classroom learning?

On the one hand some reports indicate that computers have not met the expectations that were raised when computers began appearing in classrooms. A report from the National Center for Technology in Education, a federally funded research center at Bank Street College indicates that computers are not an integral part of *subject-matter instruction*. Although students have more access to computers---125 students for each computer in 1984 vs. 11 students for each computer in 2000---they are not used in ways that are productive (programming, word processing, telecommunications, problem solving). There is evidence that more middle class students have access to computers than poor students, and quite often when these students do have access, the instruction tends to be drill-and-practice software programs.

On the other hand, there is evidence that some schools are using computers in ways that are productive, and enhance high level thinking in students. In some schools students use computers:

- to write their own programs to solve problems

- to conduct microcomputer-based science labs
- to search data bases for information on a wide-range of science related topics
- to interact via telecommunications networks with students in other schools within and outside their own country in order to collaborate on science investigations and topics

These and other applications of the computer represent new ways of thinking about how computers can be used in schools. Instead of using computers to "teach" what is currently in the science curriculum, these applications suggest rethinking what can be taught in the science curriculum.

Seymour Papert, in his book *Mindtorms: Children, Computers, and Powerful Ideas* presents a vision in which students use computers to develop powerful ideas not only about the world, but about their own thinking processes. To Papert, the kind of computer activities that are presented to students will effect profoundly the computer's impact of student learning and thinking. He makes the point that a computer can make a student's experience more like that of people in the real world. For example, if we consider the computer as a writing instrument---which all professionals today who write do---then using the computer as a writing instrument in the science classroom helps students act and behave like real writers.

The computer can also be used as a tool to help "concretize the formal." One of the problems in science education is that students continue to have difficulty understanding science concepts. One difficulty that has perplexed teachers is how to provide students with experiences---activities--which will help students make conceptual changes. Researchers at Harvard's Educational Technology Center have been working for a number of years to develop teaching modules which combine effective hands-on activities with computer-based activities. One approach they have taken is to design activities in which students invent models of phenomena and then use the computer to examine computer-based models. They have found this approach to useful in that it allows students to "see" their ideas and the conceptual relationships.

Papert puts these ideas this way:

> "Stated most simply, my conjecture is that the computer can concretize (and personalize) the formal. Seen in this light, it is not just another powerful educational tool. It is unique in providing us with the means for addressing what Piaget and many others see as the obstacle which is overcome in the passage from child to adult thinking. I believe that it can allow us to shift the boundary separating concrete and formal. Knowledge that was accessible only through formal processes can now be approached concretely. And the real magic comes from the fact that this knowledge includes those elements one needs to become a formal thinker."

Another aspect of science education that the computer should be tailored to is inquiry learning. We have shown that inquiry teaching provides the environment in which students can explore new ideas and as well as testing their own ideas. The computer can be used as a vehicle---especially through the use of simulation software---for students to ask questions, to manipulate variables, to examine materials, objects and events in multiple situations. The computer used in this way enables students to utilize the processes of science in the context of computer problem solving.

The possibility of having networked computers in each science classroom is a reality at the present time; the important notion is how computers will be used, and what activities will be provided to augment the role of the student as an active inquirer and learner.

In this section we shall explore how the computer can be used in the science classroom to enhance critical and creative thinking, and support the current consensus on how students learn---through an active involvement in the learning environment.

8.8a Computer Literacy

A lot of confusion exists around the issue of how computers should be used in science education. We should start with the notion of computer literacy, and then use this concept as we think about goals for computer-based science teaching.

Computer use in the science classroom should be based on how computers are used in the real word of science and society. For example I am writing these words on a Macintosh computer using a word processing program in conjuction with a web editor. Using the computer as a word processor or for publishing pages on the Web should be as common as using a telephone, yet in our schools students rarely use the computer as a writing or publishing tool in the context of science education. Computers are used by scientists to study natural environments and phenomena. How much opportunity do students have to use the computer to explore models of atoms, clouds, weather patterns, and concepts as specific as density?

Computer literacy must be linked to the use of the computer in the real world. Thus we might define computer literacy "as the skills and knowledge that will allow a person to function successfully in an information-based society." As Upchurch and Lockhead point out, the computer's use has evolved from simple computing functions to the computer as an "knowledge manipulator." They point out that the computer as a knowledge manipulator allows students to use the computer as a tool to solve day-to-day problems.

Joseph Abruscato, in his book *Children, Computers, and Science Teaching: Butterflies and Bytes* suggests that computers can be used to foster an atmosphere of curiosity and learning, and sees the computer as a knowledge manipulator as well.

In reviewing the use of computers in science classrooms he has suggests four goal areas as follows:

1. *An object that the learners study as they would a butterfly or a light bulb*. Topics studied might include such questions as

a. What are the parts of a computer?

b. How do computers affect people's lives?

2. *A medium of instruction that the science teacher uses with other teaching strategies.* For example, the teacher might provide learners with "teaching programs" that help students learn.

a. The names of the planets in the solar system and their relative positions from the sun.

b. The concept of a food chain.

c. The reasonableness of various hypotheses about dinosaur extinction.

3. *A homework and research tool that enables learners to more effectively carry out science activities, record observations, and produce charts or graphs of information gathered.* For example, a learner could use the computer to

a. Keep a list of her observations about the number of chirps per minute made by a cricket at room temperature.

b. Make a chart of data about cricket chirps.

c. Write a sample program that predicts how many times the cricket will chirp in one minute at 0 degrees centigrade.

d. Use a simple word processor to summarize conclusions about the effect of temperature on cricket chirps.

4. *A science teacher's aide*. The computer can help teachers manage student records. Examples include:

a. Keeping a list of students' names, and the quality of various science activities completed by each.

b. Using the computer as a word processor, and to write notes to learners about the quality of their work.

c. Creating individual progress graphs for each learner, showing the results of reports or quizzes that have been completed during the year.

d. Using a computer program that reminds the teacher of the science materials that need to be provided to students prior to each science activity.

The computer can be an effective medium of learning in the science classroom. It is important to keep in mind that computer as a medium for learning. Below are four different approaches or uses for the microcomputer in the context of science education. In each of these uses, computer software is an important aspect of the microcomputer. Thus as you review software you might want to examine the software in light of the National Science Teachers Association computer software evaluation form (Inquiry Activity 8-2).

We'll examine the use of the computer in the classroom in light of the following mediums: data base, tutor, communication link, science laboratory, and science writing tool.

8.8b The Computer as a Database

Suppose students are working on one the following topics:

a. Migrating birds in North America

b. Characteristics of mammals in the Southwestern U.S.

c. Properties of the ten most common elements

d. Habitats of animals in North America

e. Environmental facts and problems in Third World Countries

One use of the computer as a data base is to utilize the burgeoning number of database software packages such as Scholastic's *Curriculum Data Bases in Life Science and Physical Science* or *EARTHQUEST* ® (an environmental education database. A database is a collection of related information stored in an organized systematic manner. Databases such as these provide the raw information students need in to order to answer questions about topics such as those cited above. Students can find data to help them answer their questions and easily access the information.

A more powerful use is the dial-up system in which the modem enables the computer to become part of a telecommunications network. Databases can be accessed from a number of commercial companies.

But a more powerful application of the concept of data bases is for students to create their own data bases. Software such as Appleworks, Filemaker Pro, or the even more powerful (because it has graphics capabilities) Hypercard® enable students to design their own databases, and learn a methodology of organizing information. Some potential databases that students could create in the science classroom would include:

- biographical information about members of the class
- the elements
- commonly abused drugs
- diseases
- natural disasters
- weather and climate data
- mammals in your state

In each of these cases students will have to research the topic, determine how to organize the information and then enter it into the computer using a database program. Databases help student appreciate the complexity of information, but enable them to learn to use the computer to manage large amounts of information. Databases are nothing more than organizations of information. File cabinets, phone books, a file of index cards of recipes are common examples of data bases. Introducing the students to computer data bases simply extends what they have already experienced.s

8.8c The Computer as a Communications Link

Imagine a science classroom in which a computer is connected to the telephone line by means of a modem and the students in the classroom are communicating on a day-to-day basis with students in another city or country. Computer-based telecommunications networks enable individuals and groups to "go on line" to send and retrieve messages, send files of information, exchange graphics, and video technologies.

One of the first programs of this nature in science education is the National Geographic Kids Network. Although designed for students in grades 4-6, it paved the way showing how the computer could be used in the area of telecommunications. In the Kids Network students conduct original research, share data, exchange letters and maps in a series of units including Hello (introduction to telecommunications), Acid Rain, and Weather in Action.

Another program is the Global Thinking Project (GTP), a cross-cultural and interdisciplinary problem solving curriculum and telecommunications system. The GTP uses the Internet to enable students around the word to explore global problems and concerns, learn strategies of inquiry to solve local problems, as well as the knowledge and technological means to deal with them globally. The GTP uses the computer to link classrooms in different countries to study a flexibly-based global-ecological curriculum consisting of a series of problem solving projects.

Collaborative projects, such as the GTP provide a powerful means to engaging students in scientific inquiry and cross-cultural learning. The chart that follows describes four collaborative projects.

Collaborative Science Project	Focus of the Project
EnviroNet: earth.simmons.edu	A network of environmental educators who support a series of collaborative projects including acid rain, batnet, birdwatch, coyote howl, insectworld, plants, roadkill, salt tract, vernal pools, water shed, and whale net.
GLOBE: www.globe.gov	A k-12 project linking students, teachers and scientists around the world to learn about the environment.
Global Thinking Project: www.gtp.org	An environmental science project linking students and teachers around the world to investigate a series of projects, including the green classroom, Project Clean Air, Project Water Watch, Project Solid Waste, Project Soil and Project EarthMonth.
Hands On Universe: hou.lbl.gov	An educational program that enables students to investigate the Universe while applying tools and concepts from science, math and technology.

Designing Project Using CLEO

CLEO enables you to design your own colloboritive project online. The tools and procedures are available from the CLEO website.

http://cleo.terc.edu/cleo/cleo-home.cfm

Additional Collaborative Science Projects

- Desert and Desertification Project
- Feeder Watch
- Green: Global Rivers Environmental Education Network
- High School Human Genome Project
- I*EARN: International Educational Resources Network
- Journey North
- Kids as Global Scienctists
- Monarch Watch
- NASA" Online Interactive Projects
- Project Pigeon Watch
- SPAN: Sun Photomoter Atmosperhic Networks

Clearing Houses of Collaborative Projects

- Global School Net Clearninghouse
- Telecollaborative Learning Around the World

8.8d The Computer as a Science Laboratory

The educational software that is now available will enable you to turn the computer in a science laboratory and activity center. The computer can be used to simulate nature quickly without the usual mess, and the with addition of a simple interface box and probes, it can be used to do sophisticated science experiments with ease.

It is helpful to organized the workspace in the computer area of the classroom so that teams of students can perform investigations. Students should be encouraged to think in terms of "What if..." and be provided with the materials and knowledge that will enable them to set up experiments that test their questions.

Simulations allow one or more variables in an experiment to be controlled. High-quality software is available in the areas weather forecasting, space flight, flight simulations, ecology, volcanology, chemistry, physics, genetics, and many other topics. An earth-science simulation, for example, called *Volcanoes* from Earthware Computer Service allows students to predict eruptions of mythical volcanoes. *The Galactic Prospector* from Walt Disney Personal Computer Software gives students access to data gathered from satellites and core drillings as they search for oil, gas and various minerals.

Although simulations are no substitute for hands-on science activities, they do help students develop concepts and the ability to solve problems using logical methods. As you examine science teaching software, you should begin to think in terms of integrating it with the ongoing science curriculum. How can a particular software simulation be used in coordination with hands-on science instruction?

The computer can be a tool to promote conceptual change among students. At the Harvard Educational Technology Center a series of science units have been developed in which a hands-on approach and computer-based modeling and experimentation have been integrated to help students develop an understanding of science concepts. The unit entitled *Weight and Density* uses a conceptual change curriculum design (learning cycle) in which students explore concepts of weight and density qualitatively using hands-on experiences as well computer-based simulations. The second phase of the unit introduces the students to a quantitative understanding of weight and density, again using hands-on experiences and the computer. In the third phase of the unit students investigate thermal expansion. Researchers reported that a teaching approach integrating hands-on science with computer-based modeling was effective in bringing about conceptual change---students were able to differentiate between weight and density. However, it was also reported that the method was not effective with all students. One of the recommendations made was to design ways of making students more aware of their misconceptions, and how to exploit the work of the computer and small group activities to promote more active dialogue among the students.

8.8e The Computer as a Science Writing Tool

Science students are responsible for communicating what they are learning, for writing reports, and keeping track of their progress. Recent research on the use of the computer as a writing tool has shown that it can be used to stimulate written communication. Students ages 9 to 13 can improve their writing if they are given good reasons to write and if they are given appropriate tools. One valuable publication, *Writing and Computers* by Collette Daiute (Addison-Wesley, 1985) has excellent discussions on how to use the computer as a tool to help very young writers, early adolescent writers, adolescents, and college students.

Word processing and desk-top publishing programs are easy for students to use, and there are many to choose from. *Bank Street Writer Plus*, *Appleworks*, *Microsoft Word,* and *Word Perfect* are each powerful word processing systems that are applicable for the science teacher and student. Each of these programs is relatively easy to use, and has options including a spelling checker and a Thesaurus, two tools that are invaluable for the science writer/editor.

Writing in the science classroom, as we have discussed can take on many forms, and should be linked to the development of concepts, science projects and research investigations. However, students' writing can be enhanced if they are given specific writing formats---newsletters, articles, stories, book reports, for example. Once they learn a format they can apply it to different topics. Students should have an opportunity to engage in a variety of science writing on different topics using different formats. Writing a newspaper article, a science report, an advertisement, a fictional story, or a book report can be used to explore such topics as "Dinosaurs found in the Galapagos Islands," "A visit to Mars," "The eruption of a volcano," "Problems with Hazardous Waste."

ACTIVITY 8.1: Microteaching

In this section we have discussed several teaching behaviors that are related to the establishment of an interactive classroom. In this inquiry activity you will prepare a brief lesson, teach it to a group of peers, view a video of the lesson during a reflective teaching conference, and then reteach the lesson incorporating changes suggested by your reflective teaching coach.

Materials

- VCR
- Camera
- Video tape

Procedures

1. Prepare a five minute science lesson on a science topic of your choice. Prepare the lesson in such a way that you focus on the teaching skills listed in Figure 1. Please note that in five minutes you will not be able to teach a "complete" lesson.

2. Meet with your observer-coach (a peer) prior to the lesson to explain your objectives and the skills you plan to focus on.

3. Teach the lesson to four to six peers. The lesson should be video taped.

4. The observer-coach should use the Microteaching Evaluation Form (Figure 2) and use the results in a reflective teaching conference.

5. The observer-coach should conduct a reflective teaching conference immediately following the five minute lesson during which the video should be viewed, and suggestions on how the lesson might be changed for the reteaching session.

6. Reteach the lesson to another group of peers. Following the lesson, view the video with your coach and evaluate the effectiveness of the changes that you tried to incorporate into the second lesson.

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1. How successful were you in integrating the skills into the five minute lessons?

2. Use the microteaching format to practice other critical and creative thinking teaching strategies. Your five minute lessons can focus on the following:

• Using advance organizers in science teaching.

• Using low and high inquiry questions in science lessons.

• Using examples to help students understand science concepts.

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• Make a list of strategies you think will enhance critical thinking in science classrooms. Then make a separate list of strategies you think will enhance creative thinking. What criteria did you use to generate each list? How do the criteria compare?

• Construct an essay (no more than two pages) on the efficacy of using structured controversies in the science classroom to enhance critical and creative thinking.

• Find an article in the literature on the K-L-M reading strategy and write a brief report

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Case Study 1. Computers: Boon or Bust?

The Case. Will computers produce the changes that many educators claimed they would accomplish, or will they simply be seen as another educational fad? Two educators present evidence to support their side of the issue. Lyn Chan is Site Coordinator of the State Model Technology School, Project TOPS, South San Francisco Unified School District. Stanley Pogrow, as associate professor of education at the University of Arizona and developer of HOTS thinking skills program, specializes in instructional and administrative uses of technology.

Lyn Chan.

Definitely a boon. In scenarios played over and over again, we see how computers have improved instruction and student achievement. For example, we see a student who has been self-concious about his speech explaining the Logo Writer to his peers and teachers. Or consider a group of students I saw use a multi-media approach to create presentations on black Americans. They used the computer to search and gather images from a laser disc, accessed distant databanks through telecommunications, and used the word processor to write the script.

With the discovery of the capabilities and applications of computers, more and more teachers are empowered to be innovative and creative in their teaching. Teachers continue to search for resources and ideas outside the four walls of the classroom to increase their productivity and to better manage instruction, thereby widening the range of students' experiences. As a result, students are becoming actively involved in their own learning.

Like corporate America, which values the support of computers in everyday management and performance, teachers are determined to use computers in their profession. Of course, barriers like limited time to explore the world of computers and limited money for hardware and inservice training need to be addressed. And some administrators need to be convinced to support use of computers in the classroom. However, computers are here to stay.

Stanley Pogrow.

A bust. Computers have not worked. Research summaries have never shown much effect beyond 3rd grade. Yes, kids do like computers and are motivated by them. However, given education's tremendous problems, that is not enough.

Why the poor results? The recommendations of the technology movement have been wrong, contradictory, and without basis in demonstrated learning effects. The technology "experts" haven't the vaguest idea how to increase the learning of educationally disadvantaged students. Technology can *help* produce powerful forms of learning in these students, if (a) intensive use of technology is provided by good teachers working with students at key developmental points, and (b) use of technology is accompanied by sophisticated forms of conversation between teacher and students.

However, the technology movement believes the best way to get everyone using computers is to argue that computers can produce learning gains by themselves. As a result, the movement is not interested in models that combine technology with other techniques.

Instead of providing more training and programs, the many responsible educators interested in technology must start ignoring the recommendations of the "experts." We need to spend

> the next five years learning rather than disseminating. In particular, we need to learn how to design better ways of interacting with students. If we do, we will have something important to offer education in the future.

The Problem. Can electronic learning enhance creativity and critical thinking in the science classroom? In what ways to these two educators support or reject *your* point of view? What other evidence can you cite to support your position?

Case Study 2. Questioning: Inquiry or the Inquisition?

The Case. Joe Ellis, a high school biology teacher was conducting a review session one-day before the midterm examination. During the first four weeks of the course, he had covered the first three units in the text on biological principles, cells and genetics. Joe was in in fourth year of teaching, and had a reputation among the students which they termed, "fair but tough." During the review period, Mr. Ellis asked questions based on the material in the text, and what was covered during the labs, as well. One of the questions he asked was "What is cell theory?" He waited about a second and then called on Jack McKenna, a student who was struggling in the course, and was not doing well in his math and history courses as well. Jack started to say something, but Mr. Ellis interrupted and said,"If you can't answer this question, then there isn't much hope for you on the test." He moved quickly to another student who answered the question easily. On two other occasions Jack McKenna tried to answer questions but was ignored by Mr. Ellis.

The Problem. Should students who don't know the answer be called on in class? If a student doesn't know the answer, how should the teacher respond? What feedback would you give Mr. Ellis?

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"What strategy of instruction do you find to be the most effective with your students?

Jerry Pelletier. The technique I employ is a combination of "hands on" experiences with inductive reasoning. Students are put in situations in which they must question what they observe, analyze data and draw what they feel are logical conclusions. They are constantly questioned and encouraged to question.

John Ricciardi. Be honorable. Be equitable. Be open. When I can adhere to it, this basic strategy works well for me. Honoring your students is respecting their diversity and wholeness...their individuality and integrity. Honor their being always...whatever particular mental phase they may be in. Be equitable with your students. Rules must be fair and equal for all. No favoritism, belittlement, or force. Free choice should be the bed rock upon which all activities are constructed. Be open...and real to your limitations and weaknesses. If you do, your students will be open too, and grow with you. Be open to trust by believing in them. Be open...and aware of a learning that may be taking place in them that you don't fully perceive.

Mary Wilde. I have always had positive results with small group learning, however, I have really been able to enhance this teaching strategy by incorporating the cooperative learning format. There are many different cooperative learning models, however, the one I find most successful is where each student within a group learns different material. Then each student is required to teach the others in the group what has been learned. The group is responsible for each other, for I often give individual tests and average them together to receive a group grade. I also like to organize small groups by assigning each member of a team a different task in order to achieve a single goal. For example, when we studied shoreline erosion, each group was responsible for building a paper-mache model, painting and labeling depositional and erosional shoreline features, reading an article entitled, "America is Washing Away," and writing an abstract or review on the article. Tasks were divided among the students and each had a responsibility to the group. One group grade was given for the entire project.

I really feel that small group work helps develop responsibility and commitment. Also, more can be accomplished and learned in small groups where a variety of skills and abilities are pulled together. The learner becomes active, not passive, and greater achievement results can be obtained.

Ginny Almeder. My teaching strategy is fairly traditional and linear. I begin with an assigned reading from the text or related literature. I believe that comprehension of the material is essential provided it does not inhibit the curiosity necessary for problem solving. The reading is followed up with small group and class discussions and a hands-on activity which usually involves a lab or a post-lab discussion. Occasionally, an audiovisual or student presentation is included. Where appropriate, I will reverse the plan and begin the unit with a lab activity. This sequence allows us to proceed from the process level to the information level and shows students more clearly that it is the act of doing science that produces the body of scientific knowledge. Classwork also includes presentation and discussion of projects that students are working on independently.

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Volume 8	Research Matters	Strategies Fostering Thinking

Using Questions in Science Classrooms by Patricia E. Blosser

One objective of science teaching is the development of higher order thinking processes in students. To achieve this objective, teachers need to facilitate communication with and among students. One of the methods for encouraging students to communicate is to ask them questions. Teacher questions can serve a variety of purposes:

- to manage the classroom ("Have you finished the titration?" How many have completed problem 17?")
- to reinforce a fact or concept ("The food making process in green plants is called photosynthesis, right?")
- to stimulate thinking ("What would happen if...?")
- to arouse interest
- to help students develop a mind-set.

Any teacher can create his/her own list of additional functions questions can serve.

Science teachers are concerned about helping students to become critical thinkers, problem solvers, and scientifically literate citizens. If we want students to function as independent thinkers, we need to provide opportunities in our science classes that allow for greater student involvement and initiative and less teacher domination of the learning process. This means a shift in teacher role from that of information-giver to that of a facilitator and guide of the learning process.

Central to this shift in teacher role are the types of questions that teachers ask. Questions that require students to recall data or facts have a different impact on pupils than questions which encourage pupils to process and interpret data in a variety of ways.

The differential effects of various types of teacher questions seem obvious, but what goes on in classrooms? In one review of observational studies of teacher questioning, spanning 1893-1963, it was reported that the central focus of all teacher questioning activity appeared to be the textbook. Teachers appeared to consider their job to be to see that students have studied the text. Similar findings have been reported from observational studies of teachers' questioning styles in science classrooms. Science teachers appear to function primarily at the "recall" level in the questions they ask, whether the science lessons are being taught to elementary students or secondary school pupils.

Why doesn't questioning behavior match educational objectives? One hypothesis is that teachers are not aware of their customary questioning patterns. One way to test this hypothesis is to use a question analysis system. One commonly-used system is that of Bloom's taxonomy of educational objectives, ranging from knowledge to evaluation. Other systems categorize questions as higher-order or lower-order. Lower-order questions are those of cognitive-memory thinking and higher-order questions involve convergent thinking, divergent thinking, or evaluative thinking.

Blosser developed a category system for questions used in science lessons. In this system, questions are initially classified as:

- Closed...limited number of acceptable responses
- Open...greater number of acceptable responses
- Managerial....facilitate classroom operations

- Rhetorical...re-emphasize, reinforce a point

Questions which are classified as being either Open or Closed can be further classified relative to the type of thinking stimulated: cognitive-memory or convergent for Closed Questions and divergent or evaluation thinking for Open questions. This system has been used successfully with both pre-service and in-service science teachers to help them analyze their questioning behavior.

Investigations have been conducted to see if pre-service teachers could improve their questioning behavior through question analysis. From these studies, it has been concluded that the use of models (audio, video) is helpful, that skill in the use of science processes appears to be related to the complexity of questions asked, that the use of a question category system can be learned, and that the number of divergent and evaluative questions asked in lessons can be increased.

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Volume 8	**On Problem Solving** **by Donald Robert Woods**	**Strategies Fostering Thinking**

Many equate the teaching of problem solving with blackboard demonstrations and the assignment of homework problems. But research has shown this approach to be one of the least effective methods of developing problem-solving skills, which are among our most advanced mental skills, corresponding to the higher levels in B.S. Bloom's cognitive taxonomy. We teachers can do much more for our students than simply say, "Try solving these problems," or "Watch me while I write out this well-polished script of the highlights of the problem-solving process." What research has shown is that we can define problem solving and identify its cognitive and attitudinal components.

Students come to us with many misconceptions about problem solving, however, and with bad habits that students persist in using to approach problems. Students have been doing *exercises* for years and are generally quite good at it; along with their teachers, they have been calling this *problem solving*. Similarly, we teachers have been "working examples" on the board for years, and we think we're good at explaining and modeling the problem-solving process. In reality, it is only when we get stuck and feel panic at not knowing how to solve a problem that we really start to employ the skills this book addresses. When we use these important skills intuitively, we tend to dismiss them as "just experience."

The most challenging task in problem solving is to create a representation of the problem situation. Some call this "exploring the situation"; others describe it as making connections between the problem situation and the subject's background experience. Whatever it is called, each person approaches it uniquely. Knowledge and problem solving are intimately connected: How we learn affects how we retrieve ideas and how we create representations.

Knowledge about the principles and laws of biology, chemistry, physics and the Earth sciences is not sufficient. Each discipline also has specific tacit information from experience. This kind of information is difficulty to extract from our experience, let alone communicate to our students. Yet students need it for effective problem solving.

To develop problem solving skills, a teacher needs to assume the role of facilitator and coach, rather than lecturer and provider of information.

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Volume 8	On Computers and Science Teaching by Joseph Abruscato	Strategies Fostering Thinking

The bright, smiling students who bring "gifts" to you as you prepare the classroom for traditional science curriculum experiences are part of the first human generation to enter a world in which *work* has nothing to do with *perspiration*. They are to be twenty-first century adults, and their world will be as different from yours as sunrise is from sunset.

Your students will be the first citizens of post-industrial America. What you select as appropriate science concepts, processes, and attitudes for their attention must respond to what *their* world is becoming...not yours. All teachers, including science teachers, must develop curricula that are tempered by our best guesses about what challenges and opportunities lie ahead.

You can acquire some clues about appropriate content for the science curriculum by simply observing modern society. Ask yourself, "What changes will affect today's students, and how can the science classroom help them prepare for adulthood?" The most important societal phenomenon of our time (aside from the potential for total nuclear destruction fifteen minutes from now) is that heavily industrialized societies such as ours are divesting themselves of the responsibility for manufacturing products that require an abundance of human labor. We are quickly learning that it is cheaper to purchase manufactured items from countries that have low labor costs---typically, the Far East and South America---than to continue to be involved in labor-intensive industries. The careers that your students will eventually have will probably be related to the production, management, and transfer of *information* and the provision of *services*.

What is bringing about this change from a "goods-oriented society" to an "information-and-service-based society"? There is one simple answer---the computer.

One of my favorite sources of absurd humor is a group of performers collectively known as Monty Python. A phrase that recurs in their television skits is: "Now for something completely different." The best example of something "completely different" that I can think of is the computer. Its appearance in the midst of industrial society marks the end of the Industrial Revolution and the end of our now old-fashioned views of what the students in our classrooms can and will become.

Perhaps Herbert A. Simon said it best:

> Nobody really needs convincing these days that the computer is an innovation of more than ordinary magnitude, a one-in-several-century innovation and not a one-in-a-century innovation, or one of these instant revolutions that are announced everyday in the papers or on television. It really is an event of major magnitude.

The computer is changing more than industry. It is changing the very character of everyday life and our most fundamental ideas about what should be included in a quality education.

Teachers and books traditionally have been thought of as the ultimate repositories of information. This is now less true, since technology now gives individuals power to get information without having to go to a book or a teacher. We are becoming a nation in which each individual has access to information about himself or herself, others, and events that is a source of potential power, opportunity, and challenge. If you wish to , you can use a computer and a telephone to acquire information on the amount of money in your checking account, the behavior of female mosquitoes in Southwest Africa, or the price of tin in Tokyo.

Those individuals who know how to use computers are likely to have twenty-first century lives that are both full and productive. A science teacher who has access to a computer, but is reluctant to provide students with opportunities to use, is contributing to the development of a handicapped adult. A young person who is computer illiterate in post-industrial society will have a handicap that will be difficult, if not impossible, to overcome. All teachers, including science teachers, must develop their computer literacy so that they can, in turn, help today's children and youth survive and flourish in our postindustrial society.

Shouldn't the study of computers take place just in the mathematics classroom or special computer laboratories? The answer is, unequivocally, "NO." The computer must be viewed as a tool that is both understood and used in every portion of the elementary, intermediate, and secondary school curriculum---including science. We must provide learning environments in which children and youth become the masters of the tool, not its servant.

Successful, happy, confident twenty-first-century adults will be those who know how to use computers to acquire information, sharpen reasoning skills, and most important, help solve human problems. There is no better place to learn these skills than in a science classroom.

Minds on Science *Gazette*

Volume 8	On Creative Thinking by Roger von Oech	Strategies Fostering Thinking

I once asked Carl Ally (founder of Ally & Gargano, one of the more innovative advertising agencies on Madison Avenue) what "makes the creative person tick." Ally responded, "The creative person wants to be a know-it-all. He wants to know about all kinds of things: ancient history, nineteenth century mathematics, current manufacturing techniques, flower arranging, and hog futures. Because he never knows when these ideas might come together to form a new idea. It may happen six minutes later or six months or six years down the road. But he has faith that it will happen.

I agree whole-heartedly. Knowledge is the stuff from which new ideas are made. Nonetheless, knowledge alone won't make a person creative. I think that we've all known people who knew lots of stuff and nothing creative happened. Their knowledge just sat in their crania because they didn't think about what they knew in any new ways. Thus, the real key to being creative lies in what you do with your knowledge. Creative thinking requires an attitude or outlook which allows you to search for ideas and manipulate your knowledge and experience. With this outlook, you try various approaches, first one, then another, often not getting anywhere. You use crazy, foolish, and impractical ideas as stepping stones to practical new ideas. You break the rules occasionally, and hunt for ideas in unusual outside places. In short, by adopting a creative outlook you open yourself up to both new possibilities and to change.

A good example of a person who did this is Johann Gutenberg. What Gutenberg did was to combine two previously unconnected ideas, the wine press and the coin punch, to create a new idea. The purpose of the coin punch was to leave an image on a small area such as gold coin. The function of a wine press was, and still is, to apply a force over a large area in order to squeeze the juice out of the grapes. One day Gutenburg, perhaps after he'd drunk a glass of wine or two, playfully asked himself, "What if I took a bunch of these coin punches and put them under the force of the wine press so that they left their images on paper?" The resulting combination was the printing press and movable type.

Another example is Nolan Bushnell. In 1971, Bushnell looked at his television and thought, "I'm not satisfied with just *watching* my TV set. I want to play with it and have it respond to me." Soon after, he created, "Pong," the interactive table tennis game which started the video game revolution.

Still another example of a person who did this is Picasso. One day, Picasso went outside his house and found an old bicycle. He looked at it for a little bit, and then took off the seat and the handle bars. He then welded them together to create the head of a bull.

Each of these examples illustrates the power the creative mind has to transform one thing into another. By changing perspective and playing with our knowledge and experience, we can made the ordinary extraordinary and the unusual commonplace. In this way, wine presses squeeze out information, TV sets turn into game machines, and bicycle seats become bull's heads. The Nobel Prize winning physician Albert Szent-Gyorgyi put it well when he said:

> "**Discovery consist of looking at the same thing as everyone else and thinking something different.**"

Thus, if you'd like to be more creative, just look at the same thing as everyone else and "think something different."

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Volume 8	Problems and Extensions	Strategies Fostering Thinking

• Present a demonstration, teaching tool, simple lab activity, creative homework assignment, or some strategy or technique related to one of the following areas of science teaching: Earth science, life science, physical science, or science-technology-society.

• Create an EEEP (Exciting Example, Everyday Phenomena) for at least one concept from the fields of science identified in the previous problem and extension. Remember that an EEEP should help make the unfamiliar familiar. Prepare your EEEP and present it to the class, or video tape your EEEP describing how you would use the EEEP in a science lesson. Present the video to the class.

• Prepare a microteaching lesson that focuses on one of the following teaching strategies and present it to your peers or a small group of secondary students. Video tape the lesson, review it, and write a brief report outlining the success you had in presenting the teaching strategy, and how you might change the lesson for a future presentation. Select from these teaching strategies:

- Using advance organizers
- Elements of a stimulating classroom environment
- Questioning
- Using examples
- Closure
- Creating a positive learning environment

• Select a chapter from a secondary science textbook and analyze the questions posed in the chapter. You can use the system presented in the chapter (low inquiry vs. high inquiry), or some other system that you prefer. What is the ratio of low to high inquiry questions? To what extent is high level thinking encouraged in the chapter?

• View video tapes of science teaching and analyze the lessons in terms of the teachers' use of questions. Use the coding system shown below.

Question Category	**Lesson:** **Subject** **Grade**	**Lesson:** **Subject** **Grade**	**Lesson:** **Subject** **Grade**
Closed Questions (Low Inquiry)			
Open Questions (High Inquiry)			
Summary			

• Using the process outlined in the chapter on the use of structured controversies, prepare the necessary teaching materials to conduct a structured controversy either in your method's course, or in a secondary science classroom. Evaluate the results of the strategy by administering a student feedback form. You might use the form on page 000.

• Choose either the K-W-L or the Survey-Read-Map-Check reading strategies, and design a series of lesson plans to help students comprehend the ideas in a chapter from a secondary science textbook or one of the chapters in this book. Have your plans checked by a peer in your class. Test out your secondary science plans by field testing the lessons with your peers or a group of secondary students; if you choose this book, try them out on your peers and then send the results to me!

• Choose a partner in your class. Select a chapter from a secondary science textbook and draw a semantic map of the chapter. You and your partner should do this separately at first. Share maps with each other, and then create a cooperative semantic map. How do the individual and cooperative maps compare?

• Review the hm Science Study Skills Program materials. What language skills are developed, and what overall strategy do the authors use to help students develop language skills for the science classroom?

• Select one of the writing strategies presented in the chapter as the basis of a science lesson. Plan the lesson, then present it to a group of peers or students. How effective was the lesson in enhancing the student's writing skills?

• Prepare a lesson on the processes of science from either the behaviorist or constructivist approach. Write a short rationale, objectives, procedures and evaluation for your lesson. Meet with peers in your class and compare your lesson plans, paying particular attention to the rationale and objectives. How are they different?

• Draw a map of a classroom showing how you would set it up to include a computer center. How would you enable students to gain access to the computer, when you have twenty-eight students in each of your five classes?

Minds on Science *Gazette*

Volume 8	Resources	Strategies Fostering Thinking

Abruscato, Joseph. Children, Computers, and Science Teaching: Butterflies and Bytes. Englewood Cliffs, NJ: Prentice Hall, 1986.

> This practical book shows science teachers how they can integrate computers into the regular science classroom.

Brandt, Ronald S. Teaching Thinking. Alexandria, VA: Association for Supervision and Curriculum Development, 1989.

> This is a collection of articles that appeared in the journal Educational Leadership. The articles convey ideas about critical thinking, how to teach thinking skills in the curriculum, and the evaluation of the thinking skills approach.

Bulman, Lesley. Teaching Language and Study Skills in Secondary Science. London: Heinemann, 1985.

> This book gives practical advice to science teachers, based on the latest research into students' difficulties with scientific language. The book shows teachers how to help students develop the language and study skills necessary to be successful in science.

Gabel, Dorothy (Ed). What Research Says to the Science Teacher, Volume Five, Problem Solving. Washington, DC: National Science Teachers Association, 1989.

> This volume is intended to translate research on problem solving into practice. Several authors show how problem solving can be applied to the teaching of elementary science, middle level science, Earth science, physics, biology, and chemistry.

Heimlich, Joan E. and Susan D. Pittelman. Semantic Mapping: Classroom Applications.Newark, DE: International Reading Association, 1986.

> Semantic (or concept) mapping is a strategy to help students taps their prior knowledge. Through teaching---from planning lessons to helping students learn concepts---semantic mapping can be a useful tool. This book provides step-by-step instructions and ways of applying it to the classroom.

Marzano, Robert J. and Daisy E. Arredondo. Tactics for Thinking, Teacher's Manual. Aurora, CO: Mid-continent Regional Educational Laboratory, 1986.

> This is the training manual which accompanies Tactics for Thinking a program designed for K-12 integration. Tactics is based on dividing thinking skills into three general areas: learning-to-learn skills, content thinking skills, and reasoning skills.

Marzano, Robert J. and Diane E. Paynter. Tactics for Thinking. Aurora, CO: Mid-continent Regional Educational Laboratory, 1989.

> This large three-ring binder contains activities and blackline masters for the three categories of thinking skills for middle and secondary students.

Marzano, Robert et.al. Dimensions of Thinking: A Framework for Curriculum and Instruction. Alexandria, VA: Association for Supervision and Curriculum Development, 1988.

> This volume deals with thinking as a foundation for schooling and includes discussions on topics such as metacognition, critical and creative thinking, and the general thinking processes.

Oech, Roger von. A Whack on the Side of the Head: How to Unlock Your Mind for Innovation. New York: Warner Books, 1983.

This book will not only give you the permission to be creative, but will show you how.

Rowe, Mary Budd (Ed). What Research Says to the Science Teacher, Volume Six: The Process of Knowing. Washington, DC: National Science Teachers Association, 1990.

This volume uses cognitive science research to help science teachers understand the process of knowing.

Thelen, Judith N. Improving Reading in Science. Newark, DE: International Reading Association, 1984.

This useful book shows science teachers how to diagnose reading problems in science, what prereading strategies science should use to help learners read science texts, and how to help students with text and vocabulary.

Tiedt, Iris McClellan et.al. Reading/Thinking/Writing: A Holistic Language and Literacy Progam for the K-8 Classroom. Needham Heights, MA: Allyn and Bacon, 1989.

This book is a useful reference for the science teacher who needs relevant information about to integrate language skills into the science classroom.

Wilson, Carol and Gary Krasnow. hm Science Study Skills Program: People, Energy and Appropriate Technology. Washington, DC: National Science Teachers Association, 1983.

This is a hands-on approach designed to help secondary students develop specific study skills appropriate for science courses. Skills include listening, building vocabulary, reading for meaning, taking effective notes, graphing, solving problems and test taking.