Chapter 4

Developing Inquiry Skills
• How can an “active” approach to science make it more meaningful?
• What are the components of the learning cycle?
• What are the scientific skills?
• What are some examples of scientific attitudes?

**Focus on Inquiry**

Scientific Skill Development

*Dr. George E. O’Brien, Miami, Florida International University
Angela M. Alexander, Pine Villa Montessori School, Dade County (Florida) Public Schools*

*Picture a small community school just 30 miles from downtown Miami but in a rural, farm region of south Florida. This particular day, Ms. Alexander has arranged her students into cooperative learning groups, and they are excited, curious, and anxious about what is going to happen in the science lesson.*

Each group receives plastic gloves, dissecting needles, hand lenses, and an oval-shaped object wrapped in aluminum foil. Can the students predict and/or infer what the objects are? They unwrap the foil from the objects carefully and inspect the objects. An initial reaction from many students is, “Wow, I don’t know if I really want to touch this.” These reactions fade fast. The students use dissecting needles to separate parts that make up the oval-shaped objects and then to record observations and make inferences concerning what the objects or their contents might be and why they think so. Quickly, some students discover or infer that they are working with bones. Some say they are working with wishbones, and one student says these are hog bones (because hogs have a lot of bones). Some students think they can make out a bird’s head, and one student thinks she can see parts of a hamster. Some students guess that they are working with dinosaur teeth, human teeth, or some kind of fossil.

The students from each group sort the bones. The task of sorting and organizing the bones into recognizable entities is a problem-solving challenge. The challenge of discovering the mystery objects piques the students’ curiosity. Although on this day no one infers the objects to be owl pellets, the pieces of bones lead to more discoveries about the animals that are consumed by barn owls.

*At the University*

Back in Miami, Dr. O’Brien, a professor of elementary science methods at the university, sets up the activity in the same way as Ms. Alexander. He leads his students through the same challenge of identifying the contents of owl pellets. As bones are uncovered and carefully
removed and placed to the side on sheets of plain white paper, university students use dichotomous keys (classification) to identify skulls removed from the barn owl pellets. There is much debate and negotiation (communication) in the cooperating groups concerning the identity of the skulls. As skulls of small mammals, including moles and shrews (Order Insectivora), and rats, voles, and mice (Order Rodentia) are identified, the students take pride in their individual and group accomplishments. As a follow-up activity, the students are to diagram food webs with a barn owl at the highest trophic level and grass seeds at the lowest level. The sequence of activities helps the students construct knowledge of diets of barn owls and other birds of prey, food webs showing that energy passes from one organism to another on a higher level through consumption of that lower organism, and other ecological concepts.

Learning Science Is an Active Process

In the fourth-grade classroom, Ms. Alexander brings books for her students to research owls. Can the students identify the contents of the owl pellets? Yes. In much the same ways that the university students identified prey, the children are able to identify the skulls of different animals. All the students—at the elementary school and university—solved the mystery of finding out the contents of the pellets. The students, by collecting information from the evidence (in this case, produced by barn owls about 12 hours after consuming a meal by casting, or regurgitating, indigestible hair and bones as a pellet) and using science process skills (in this activity, analyzing, communicating, observing, inferring, classifying, predicting, extrapolating, synthesizing, evaluating, measuring, interpreting information, and making conclusions) enjoyed participation in the active, intellectual process of science. Science surveys and interviews conducted by the instructors, after these lessons emphasized hands-on, inquiry-based science, revealed positive attitudes toward science (in both groups) and positive attitudes toward science teaching (in the university group).

Teachers of science—whether at the elementary school or the university—should believe that learning science must be an active process. Learning science is something students do, not something that is done to them. When an instructor focuses on actively engaging students in doing science, then a natural connection of learning concepts, scientific skills, and attitudes follows. In such classrooms, a focal question in planning science lessons is, “What will the students be doing?” They will be observing, classifying, measuring, predicting, inferring, collecting data, graphing, experimenting, and/or communicating. The better the teacher understands the level of skill development that the students have, the better she can choose activities to match the needs of her students.

Making Connections

Just as it is important for students to be active in their learning, it is equally important for the teacher to be an active inquirer and a visible partner to the students during the instructional process. Following are comments from Ms. Alexander, who taught the lesson on owl pellets.

“I approach teaching science in a way that empowers the students. The students will be given the power to create their own learning environment, and these ideas on what to teach come from discussions I have with my students many times a day.”

“When the children are working on activities that require an experimental design, I go to each group to discuss how they will set up the experiment. While the students are working on this task, I go from group to group and question the groups on why they chose to set up their experiment this way. Some experimental setups will be better than others. Each group of students will be working from what their group knows. They will be exposed
to all the other groups’ experiments, which will encourage them to consider other variables in their next exploration. I feel it’s also important for the students in the group to self-evaluate their group’s experiment. This helps me to know where the group is in the learning process and what they should be focusing on in the next experiment.”

“Before they begin the experiment, the groups predict what they think will happen; they may also predict why they think it will happen. When the children start the experiment, I go from group to group, asking each questions about their experiment so I can understand their thinking and/or explanations. I keep notes on each group and record their responses to questions and any misconceptions that I detect. Each group devises a plan and collects data according to that plan. Then the students explain what they think happened in the experiment and share any data collected and recorded with other groups.”

“In my class, I feel the students are in charge of their own learning. The teacher sets up and manages situations in which the students can discover and invent on their own to reach understanding. Science process skills are important in my classroom, as is development of critical thinking. The students are encouraged to reach understandings that allow them to be better able to explain their theories. I encourage students to reconsider any misconceptions they might have, and I have students discuss different opinions to see if a consensus can be reached.”

The classroom setting Ms. Alexander describes includes the following characteristics.

- Students are engaged in a motivating classroom environment that provides encouragement and frequent student–teacher interaction.
- Students can integrate science processes and problem-solving skills.
- Students are encouraged to actively construct knowledge and explanations.
- Students can use familiar objects in real-life settings.
- Students are given the opportunity to encounter natural phenomena through firsthand experiences.
- Students are involved in varied classroom settings, including individualized instruction, cooperative learning, whole-class demonstrations, and interest centers.
- Students employ risk taking, divergent thinking, and self-initiated questioning.
- Student activities are developmentally appropriate and capitalize on student interest.
- Students are encouraged to create a learning community where everyone’s opinions, questions, and conceptions are valued.

Obviously, an elementary or middle school teacher preparing a science lesson has to focus on the question, “What will the students do?” Just as important, however, the teacher needs to be aware of other vital factors, including the selection of instructional materials, physical limitations of the students (e.g., in using manipulatives), choice of management strategy, assessment techniques, cognitive developmental levels of the students, decisions on prerequisites and hierarchy of tasks, and relevant or related science misconceptions. The selection of the overall instructional strategy (e.g., learning cycle or constructivist learning model) is also an important part of inquiry-based hands-on/minds-on science (Flick, 1993).

**MAKING ACTIVE SCIENCE MEANINGFUL**

The Focus on Inquiry: Scientific Skill Development discusses how the use of scientific skills makes science active and meaningful. What did you notice about the use of the skills of observation, classification, measurement, communication, inference, prediction, and experimentation?
In 1929, John Dewey noted that education emphasized the learning of fixed conclusions rather than the advancement of intelligence as a method of action. He went on to say that schools separate knowledge from the very activities that would give the knowledge meaning. By this, he meant that teachers concentrated on teaching facts and conclusions. They were not teaching concepts through experimentation. Students were not developing the skills necessary to investigate facts or to develop new knowledge.

In a more recent discussion of how science should be taught, National Research Council (NRC) members explain the necessity and interaction of activities and content even more specifically. Their views are summarized as follows:

Those developing the national standards were committed to including inquiry as both science content and as a way to learn science. Therefore, rather than simply extolling the virtues of “hands-on/minds-on” or “laboratory-based” teaching as the way to teach “science content and process,” the writers of the Standards treated inquiry as both a learning goal and as a teaching method. (NRC, 2000, p. 18)

In this millennium, educators should take seriously the NRC’s suggestion and Dewey’s advice. Teachers need to continue the practice of inquiry teaching in their own classrooms. As the authors of both National Science Education Standards (NRC, 1996) and Benchmarks for Science Literacy (American Association for the Advancement of Science [AAAS], 1993) indicate, inquiry teaching is essential to scientific literacy for all students.

The Goal of a Science Program

The goal of all science programs should be problem solving and developing the inquiry skills necessary for competing effectively in the global marketplace. Scientific ventures such as genetic engineering, drug research, telecommunications, nuclear fusion, and environmental monitoring are increasingly done as cooperative ventures between many nations. Today, more than ever, educators must prepare a diverse workforce capable of scientific research, investigation, and informed decision making.

To paraphrase Dewey, intelligent action is the lone definitive resource of humankind (1929). This action of education refers to such entities as the science process skills. These are what scientists, adults, and children use to do science.

What skills were being taught in the owl pellet activity? How would you use this activity in your classroom? Are the instructional strategies consistent with the constructivist learning model as presented in Chapter 2? What is the learning cycle approach to inquiry mentioned in the owl pellet activity? How could the learning cycle be used in teaching skills to children?
USING THE LEARNING CYCLE

The learning cycle is based on an inquiry approach to learning consistent with the standards (see the Science Inquiry Standards Link) and an effective strategy for bringing explorations and questioning into the classroom (National Science Teachers Association [NSTA], 2004; Karplus & Their, 1967; Odom & Settlage, 1996). The learning cycle helps students develop a quest for knowledge, data, or truth. All students are naturally curious, and this approach to learning scientific skills leads to a conceptual understanding (Karplus, 1977). An advantage of the learning cycle is that it is a methodology that can translate the skills and vocabulary used by scientists into a more meaningful learning experience for students.

Barman (1989) has modified the original terminology of the learning cycle to make it more understandable for elementary and middle school teachers. He suggests the following three phases.

1. **Exploration Phase.** The first phase of the cycle is student centered; the teacher plays the role of a facilitator, observing, questioning, and assisting students as needed. The students interact with materials and each other during this phase.

   In our owl pellet story, this phase occurred when the students were interacting with the owl pellets. For example, they were observing the contents of the owl pellets, classifying the bones with a key, and communicating with each other what they had found. In both the elementary and university classrooms, students were actively involved in inquiry, with the teacher playing the role of facilitator.

2. **Concept Introduction Phase.** This teacher-centered phase is characterized by naming things and events. The teacher’s function is to gather information for students that pertains to their explorations in the first phase. The teacher works with students to develop vocabulary and to introduce pertinent information.

   During the owl pellet activity, Ms. Alexander brings in books for the students to begin naming things and events surrounding the formation of the pellet. Dr. O’Brien’s class also engages in learning new names such as Rodentia and Insectivora as students continue the lesson.

3. **Concept Application Phase.** This activity-oriented phase is, again, student centered and allows students to apply freshly learned information to new situations. The teacher presents a new problem to solve, allowing more time for the students to apply what they have learned.

   The university students depict this phase as they diagram food webs to illustrate the barn owl’s diet. They are applying what they have found out in the second phase. The fourth-grade students also begin to apply what they have learned as they further research the characteristics of the owl through children’s literature and nature books.

As shown in Figure 4–1, this cycle also has an evaluation and discussion aspect. This is an interactive component throughout each phase. The evaluation and discussion help identify current false beliefs and prevent the construction of new misconceptions. In each of the phases, the teacher may rely on various means of assessment (see Chapter 5) to assist in student understanding. Clearly, the cycle is supported by a continuous evaluation. That way, there can be a return to a previous phase, when needed, or an appropriate further application in a new phase.
In the previous examples, both Ms. Alexander and Dr. O’Brien facilitated discussions throughout the owl pellet activity. They were careful to monitor what the students were saying and to ask pertinent questions wherever they thought misconceptions were present. The ongoing assessment allows for a holistic, or complete, approach to evaluation that includes activity-based evaluation. Consider other possible evaluation strategies as we further explore the three phases.

**Exploration Phase**

As we discussed earlier, the **exploration phase** is a student-oriented phase. Remember the constructivist model presented in Chapter 2? The exploration phase of the learning cycle is similar to the exploration component of the constructivist learning model in which students are actively engaged. The teacher’s function in either model is to scaffold the learning environment based on the concepts she believes are important for the students to learn at that time.

Students can be involved in observing, classifying what they have observed, measuring, making informal inferences based on their observations, conducting experiments, collecting and organizing data, and communicating their findings to their peers in the learning cycle exploration phase. It is important for you as the facilitator to build the foundation by making the connections between the activities and the students’ everyday lives.

**Exploration Example**

For example, if you want to develop an understanding of floating and sinking, you could first discuss the students’ trips to a pool or the beach by asking, “What floated on the water? What sank?” Next, have the students observe pictures of various objects either floating or sinking. Then, ask a series of questions designed to engage the students in a discussion of the phenomena. Students will begin to make inferences about why objects float or sink. It is important for you to identify students’ inferences, noting similarities and differences in
The Learning Cycle—Exploration:
CD-ROM Connections

View the Exploration video in the “Model Inquiry Unit” section of the Companion CD. Mr. McKnight moves throughout the classroom facilitating student interaction as they observe earthworms and record their findings.

Review the video and ask yourself the following:
• What specific examples show this is a ‘student-oriented’ phase of the learning cycle?
• What is Mr. McKnight’s role in this lesson?

Reread the owl pellet activity at the beginning of this chapter. Compare and contrast Mr. McKnight’s explorations with those of Ms. Alexander. Record your ideas and the answers to these questions in your portfolio or use the Companion Website to share your ideas.

their perceptions or explanations. The students could even test several objects during this phase and make a chart of which ones float or sink. Assessment during this phase could be as informal as open questions or as structured as individual student interviews.

Concept Introduction or Invention Phase

During the concept invention phase, the teacher is a facilitator. She begins to focus the questioning, to organize the information, and to guide the class into an agreed-upon concept. This process of making connections and sense of things is termed concept invention. The teacher assists the students in naming the objects and concepts (vocabulary development) and in experimenting with the newly formed concepts, relating them to the experiences from the exploration phase. In terms of the constructivist model, students are now in the “proposing explanations and solutions” phase and are looking for ways to construct new explanations.

Concept Invention Example

In the floating and sinking example, the teacher would introduce terminology and concepts such as weight, surface tension, and density. Specific definitions would accompany these terms and relate to the students’ explorations. Questioning why the students think some objects float and some sink would be based on both the new vocabulary and definitions and the explorations. Students would measure various densities in support of concept development. Finally, the students would construct the notion that objects that are denser than water will sink in water and those that are less dense than water will float in water.

Concept Application Phase

Now it is time for the students to apply their new knowledge and skills in the concept application phase. Students are provided similar situations and challenged to implement their new concepts. In terms of the constructivist model, the students are now taking action on what they have learned. They make decisions about the new explorations and apply newly learned knowledge and skills.
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The Learning Cycle—Concept Invention:

CD-ROM Connections

View the Concept Invention video in the “Model Inquiry Unit” section of the Companion CD. Mr. McKnight questions the students and helps them to think about their earthworm explorations and to form concepts. Notice how students are making connections between their current activities and past observations and experiences.

Review the video and ask yourself the following:

• What concepts are the elementary or middle school students forming?
• What is the role of teacher questioning in a student’s concept development?
• Many times, elementary or middle school teachers have students engage in a fun science activity but then do not follow up with concept invention. Why is the concept invention stage so important?

In the NSTA’s Position Statement on Scientific Inquiry (2004), the authors make the statement, “Scientific inquiry is a powerful way of understanding science content.” Explain what they mean by this statement and the role that the concept invention stage of the learning cycle might play in supporting scientific inquiry and understanding science content. Use specific examples from the video on the Companion CD. Record your ideas and the answers to these questions in your portfolio or use the Companion Website to share your ideas.

Concept Application Example

In terms of the floating and sinking example, the teacher may provide new items for students to hypothesize about and test. The teacher may also complete a performance-based evaluation (see Chapter 5) at this point, checking how many objects the students can correctly identify as “floaters” and “sinkers.” Different experiments may test the new knowledge or lead back to the exploration phase of the cycle. For example, the teacher may ask the students to float a paper clip in a cup of water. The students know that the paper clip is denser than water, so now they have to experiment with surface tension, bringing them back to the exploration phase.

A Variation of the Learning Cycle

One way to make the learning cycle more complete is through the addition of stages to capture the students’ attention and assess what the students have learned after instruction (Staver & Shroyer, 1994). A variation of the learning cycle with these additions is the five-stage model developed by BSCS (Bybee et al., 1989). This five-stage model incorporates the engage, explore, explain, elaborate, and evaluate stages. The engage stage is matched with the invitation stage of the constructivist learning model. Students observing surroundings and looking for interesting phenomena are characteristics of both models. Here, teachers begin with questions to capture students’ attention.

The explore, explain, and elaborate stages are equivalent to the original learning cycle. The added evaluate stage provides additional opportunity for assessment. It allows the teacher to find out what the students have learned and sets the stage to begin the cycle once again.

The Learning Cycle and Textbooks

In many elementary and middle schools, a textbook series makes up the science program. Such books contain many activities whose purpose is to illustrate ideas presented in the
The Learning Cycle—Concept Application:  

CD-ROM Connections  

View the Concept Application video in the "Model Inquiry Unit" section of the Companion CD. Students gather again to discuss their newly developed concepts with Mr. McKnight. Later, they will engage in further earthworm activities to apply their knowledge in new ways.

Review the video and ask yourself the following:

- What activity would you do as a follow-up to the discussion shown in this video segment?
- As the students finish their study of earthworms, how could you transition into a study of round worms or flat worms as a way to apply what they have learned in previous explorations?

In the article, “Less Is More: Trimming the Overstuffed Curriculum,” Fratt (2002) supports the American Association for the Advancement of Science's Project 2061 position that teachers should teach fewer topics but teach them in greater depth to promote better understanding. Do you think that the learning cycle approach supports the idea of promoting better understanding? Explain your answer and include specific examples from the video on the Companion CD. Record your ideas and the answers to these questions in your portfolio or use the Companion Website to share your ideas.

books in concrete terms. Teachers sometimes call the worst of these activities “cookbook experiments,” because the problems, materials, directions, and even conclusions are furnished. Children are given little chance to construct meaningful knowledge or sharpen scientific skills. All that children are required to do is follow the recipe. Although more authors now use activities that require thinking, there are ways to modify cookbook activities into meaningful experiences. One way is to employ the learning cycle.

Do not start with reading the text. Rather, start with related explorations designed to invite students to want to explore more. Try an experiment out of the book as a discovery activity and not as a set of directions to follow. Then, use the text to develop the related language and reinforce the concepts. Finally, try some associated experiments from the text or supplemental materials.

If you are involved in selecting the textbook for your science program, pay attention to the ways authors lead into the activities and the comments following them. Look for questions that are posed before the experiment, with extending information following the experiment. This enables you to use the author's questions to explore beforehand, and then introduce the experiment, and finally use the book’s information to extend the children's learning after the experiment is completed.

The Learning Cycle and Skill Development

In short, we want to use the learning cycle to develop students’ scientific understandings and skills. The learning cycle is generalized as a do-talk-do cycle (Ramsey, 1993). In the “do” parts of the cycle, skills are being used. What specifically are the scientific skills? Which skills are appropriate for the elementary or middle school students? What are other ways to develop these skills?

In preparing for your own first elementary or middle school science unit, like the authors of Focus on Inquiry: Scientific Skill Development you may decide to use owls as a
theme. You will want to focus on scientific skills. You will probably begin to ask yourself the following questions about skills.

How will the scientific skills fit into my elementary or middle school curriculum?
Do I fully understand the skills?
Am I prepared to teach scientific skills to children?
What are some examples of activities I can do to promote specific scientific skill?

**Scientific Skills**

The learning cycle explains how you will teach scientific skills. In their respective publications, the NRC (1996) and the AAAS (1993) explain why you need to teach the how-tos of teaching scientific skills. Now we look at the what question. What are the scientific skills of observation, classification, measurement, communication, inference, prediction, and experimentation? Let’s begin with observation.

### Observing

The process of observation is the taking in of sense perceptions. It is our job to help students use all their senses when they observe similarities, differences, and changes in objects or events. Students can learn that each of the senses is a gateway to observing different properties of objects. Seeing allows them to notice properties such as size, shape, and color of objects and how the objects may interact. Hearing makes knowable properties of sounds, such as loudness, pitch, and rhythm. Touching teaches the meaning of texture and is another way to discover sizes and shapes of objects. Tasting shows how labels such as bitter, salty, sour, and sweet can be used to describe foods. Smelling allows students to associate objects with odors, such as smells “like perfume” or “like cigar smoke.”

Properties enable children to compare and describe likenesses and differences among objects. This leads to explorations that require several of the other processes, such as classifying and communicating. You can ask broad and narrow questions to guide learning in such science processes as observation.

In keeping with our owl theme, you may want to begin with a children’s literature approach to the study of owls. *Owl Eyes* (Gates, 1994) is a good starting point. This story describes a Mohawk legend in which animals can choose their own colors and body form. It assists the students in observations of the owl and its characteristics. *Owl Moon* (Yolen, 1987) is another story rich in observation that describes a walk in the woods in search of owls. *Good-Night Owl!* (Hutchins, 1972) is a story about animal noises and would be a good introduction to student observations of animal sounds in the schoolyard.

As you begin to explore the owl pellets with children in a primary-level class, invite everyone to observe by saying, for example:

What do you notice about the object wrapped in foil?
Does it make any noise?
What do you think you will see inside?
Is what you see inside different from what you expected to see?

Later, pose more questions:

How does the object feel?
How many bones did you find?
What do the bones look like?
What does it smell like?
In a middle-level class, begin to make observations more specific:

What animal skeletons in the guide compare to the skeletons that you found?
How many animal remains did you find in the pellet?

In an upper-level class, explore with even more specific observations:

In what specific ways are the bones alike?
How do the skulls that you found compare with the ones shown in the guide?

**Classifying**

Most primary students can select and group real objects by some common property. **Classification** imposes order on collections of objects or events through characteristics such as color, shape, and size. Dichotomous classifications divide objects or events into two groupings. Elementary students should be proficient at dichotomous classification and multi-group classifications in which they observe and group items on the basis of different properties.
With our owl lessons, we can introduce *The Book of North American Owls* (Sattler, 1995) and *Owls* (Kalman, 1987). The students can classify the owls on the basis of habitat or physical features. Through reading *Town Mouse & Country Mouse* (Brett, 1994), the students can set up a dichotomous key listing comparisons of the two types of habitats that the mice—and accompanying owl and cat—live in as presented in the story.

**Primary-Level Example**

In a primary-level class, students can look over the contents of the pellet and sort them by properties. The teacher can prompt the students with the following:

Think of one property, such as hardness. Sort all the objects that have that property into one pile. Leave what’s left in another pile.

Later, to expand on the activity, the teacher can say:

What other properties can you use to sort your objects?

In another primary-level class, students look over the contents of the pellet and sort them into animal and plant remains.

**Middle- and Upper-Level Examples**

Many middle-level students can classify an object into more than one category at the same time and hold this in mind. In a middle-level class, some students have classified owls into three groups, based on the geographic range of their habitat, with two subgroups each: urban and rural. They completed this independently in response to their teacher’s question:

How can you group owls by habitat?

Next, the teacher will explore owl coloration subgroups. Some upper-level students can also reclassify according to other properties that fit their purposes. In an upper-level class, students have a collection of pictures of animals that owls may prey upon. They start off by dividing them into groups by order but then decide that this will not fit their purpose. They have to reclassify according to the prey’s location on the food chain. This example demonstrates a major point about classification: It is done to fit a purpose. What works to fulfill the intent of the classifier is what counts. Objects can be classified in many ways.

**Measuring**

Thinking about properties in a quantitative way naturally leads to measuring them. *Measurement* is used to compare things. At first, at the primary level, children may be unable to compare an object with a standard measuring tool, such as a meterstick or yardstick. Instead, they find out who is taller by standing back to back. They find out which of two objects is heavier by holding each object in their hands. Eventually, they begin to use nonstandard measuring devices, such as paper clips or lengths of string, to measure their desks.

There is good reason to start off measuring in this way. Remember that primary students may not conserve several concepts that deal with quantity. Changing the appearance of an object still fools them. Children who think that merely spreading out some material gives them more, for example, have to be taught differently than children who conserve quantity. Most young children find it difficult to work meaningfully with standard units of measurement such as centimeters and inches until about age 7.

Primary students can build readiness for working with standard units by using parts of their bodies or familiar objects as arbitrary units to measure things. A primary child may say, “The classroom is 28 of my feet wide.”
Concrete Referents and Improvised Tools

One way to improve the ability of children to measure and estimate accurately is to have numerous concrete objects in your classroom for them to refer to as needed. Metersticks, yardsticks, and trundle wheels are useful for thinking about length. Containers marked with metric and English units are good for measuring liquid volumes.

Similar references are needed for other concepts involving quantity. A kilometer is a round trip from the school to the police station. A mile is the distance from the school to the post office. Meanings associated with time can be developed by many references to water or sand clocks (containers with holes punched in the bottom) and real clocks. Temperature differences become meaningful through using several kinds of thermometers.

Measurement Motivators: From Dinosaurs to Decimals (Palumbo, 1989) and Measurement: 35 Hands-On Activities (Garcia, 1997) can be helpful resources when developing meaningful measurement experiences with your students. The concept of measurement as a part of everyday life is also seen in How Big Is a Foot? (Myller, 1990), in which a foot is used to measure a bed. As students become interested in more detailed information, refer to such sources as The World of Measurements (Klein, 1974). This source contains details on units, their history, and their use.

By the time they leave elementary school, most children will have had some experience with a variety of measuring instruments such as the ruler, meterstick, yardstick, balance, clock, thermometer, graduated cylinder, protractor, directional compass, and wind gauge. When possible, children themselves should choose the right measuring tool for the activity underway. Sometimes they can make their own tools when they need them. Inventing and making a measuring instrument can be challenging and interesting.

Measurement and the Metric System

Scientists everywhere have long used the metric system because, like our number system, its units are defined in multiples of 10. The three basic units most commonly used in the metric system are the meter, liter, and gram.

A meter is used to measure length, a liter is used to measure liquid volume, and a gram is used to measure weight or mass. Strictly speaking, the terms mass and weight mean different things in science. Mass is the amount of material or matter that makes up an object. Weight is the gravitational force that pulls the mass. On the moon, for example, an astronaut’s weight is only about one sixth of what it is on the earth, but the astronaut’s mass stays unchanged.

The Celsius (C) thermometer, named after its inventor, Anders Celsius, commonly measures temperature in the metric system. It has a scale marked into 100 evenly spaced subdivisions.

Prefixes are used in the metric system to show larger or smaller quantities. The three most common prefixes and their meanings are as follows:

- milli-: one thousandth (0.001)
- centi-: one hundredth (0.01)
- kilo-: one thousand (1000)

Take a closer look at Figure 4–2 to see how prefixes are used in combination with basic units.

Before your students use different metric standards, have them consider the right standard for the job. Children will usually discover that the metric system is easier to use than the English system. Conversions from or to the English system should be avoided because they are confusing. If your curriculum calls for work with both metric and English measures, give your students a lot of practice with concrete materials for both systems. Try to treat each system separately instead of shifting back and forth. For example, when the students are comparing indoor and outdoor Fahrenheit temperatures as part of a weather
activity, do not automatically ask what the temperature would be in degrees Celsius. Instead, at a later time, develop a chart of Celsius temperatures outside over the period of a month and discuss the temperatures and any temperature changes.

The story *A Toad for Tuesday* (Erickson, 1998) can be a starting place for measurement activities related to the owl theme. Potential measurement activities could include the distance of the toad’s journey through the woods before meeting the owl, the time the owl waits before changing his mind about his vow to eat the toad, the potential temperatures of the woods, the relative sizes of the toad and owl, and the appropriate weights of the owl and toad.

**Communicating**

Communication is putting the information or data obtained from our observations into some form that another person can understand or some form that we can understand at a later date. Children learn to communicate in many ways. They learn to draw accurate pictures, diagrams, and maps; make proper charts and graphs; construct accurate models and exhibits; and use clear language when describing objects or events. The last of these activities is usually stressed in elementary science.
It is important to say things or show data in the clearest possible way. We can help our students learn this by giving them many chances to communicate and by helping them to evaluate what they have said or done.

The book *The Man Who Could Call Down Owls* (Bunting, 1984) is a good introduction to communication. *Turtle in July* (Singer, 1989) also involves month-by-month communication from animals’ points of view, including a poem from an owl.

Think of a primary-level class where some students are seated on a rug. They are viewing a series of pictures of the life cycle of an owl from an LCD projector. The teacher has scanned the pictures into the computer from *See How They Grow: Owl* (Ling, 1992) and is projecting them for all the students to see. She suggests a game in which a child communicates the properties of a life stage, such as “I am fluffy, hunched over, and my eyes are closed.” Others try to identify the stage. The child who identifies the growth period first gets to be the new describer. Reminding the children to carefully consider the description discourages guessing. After each student’s identification, the teacher asks questions, for example:

- *What did she say that helped you figure out this stage?*
- *What else would be helpful to say?*
- *Did anyone get mixed up?*
- *How do you think that happened?*

The teacher summarizes the communications activity by reading *Owl Babies* (Waddell, 1994) and having the children describe the owlets.

In an upper-level class, the students want to find out the locations of owls. They are collaborating with students from throughout the region via the Internet. Students are collecting real-time data on sightings of owls and hearing owls’ screeches. Together they will make maps, charts, and graphs on their findings and communicate the results.

In another upper-level class, students want to find out the warmest time of the day. Temperature readings are made on the hour from 10 A.M. until 3 P.M. for 5 days in a row and then averaged. They decide to record their results on a line graph, but they do not know whether to put the temperature along the side (vertical axis) or along the bottom (horizontal axis) of the graph. Is there a “regular” way? The teacher helps them see how graphs are arranged in their mathematics text. Scientists call the change being tested the *manipulated variable*. In this case, time is usually placed along the horizontal axis. The change that results from the test is called the *responding variable*. In this situation, temperature is the responding variable and is placed along the vertical axis.

**Defining Operationally**

Defining operationally is a subprocess of communicating, usually introduced after the primary grades. To define a word operationally is to describe it by an action (operation) rather than by other words. For example, suppose you invite some students to hold an evaporation contest: Who can dry water-soaked paper towels fastest? They begin to speculate excitedly. But there is just one thing they will have to agree on before the fun begins: How will everyone know when a towel is “dry”? This question stumps the students, so you pose another open question that hints at actions they could take: What are some things they could do to the towel to tell if it is dry? Now, they start coming up with the following operations (actions) to try.

- Squeeze the towel into a ball and see if water comes out. Rub it on the chalkboard; see if it makes a wet mark. Tear it and compare the sound to a dry towel you tear.
- Hold it up to the light and compare its color to an unsoaked towel.
- See if it can be set on fire as fast as an unsoaked towel. Put an unsoaked towel on one end of a balance beam; see if the other towel balances it.
Chapter 4  Developing Inquiry Skills

The children agree that the last operation is easiest to observe and the least arguable. It is stated as an operational definition: “A towel is dry if it balances an unsoaked towel from the same package.” Now the activity can begin.

Had the open question not worked, a narrow question such as, “How would squeezing the towel show if it is dry?” could have been posed, followed with a broad question such as, “What else could you do to the towel to tell if it is dry besides squeezing it?”

When operational definitions are not used, it is easy to fall into the trap of circular reasoning: What is the condition of a dry towel? It contains no moisture. What is the condition of a towel that contains no moisture? It is dry. Or, to borrow from children’s humor, consider this example:

He is the best scientist we’ve ever had.
Who is?
He is.
Who is “He”?
The best scientist we’ve ever had.

There are some predictable times when the need for operational definitions will come up. Watch the children’s use of relative terms such as tall, short (How tall? short?), light, heavy, fast, slow, good, and bad (What is “bad” luck?).

Creating a Record of Activities

Recording is another subprocess of communicating. When activities require time to gather data (e.g., growing plants over many weeks) or when there are many data to consider (e.g., discovering how much vitamin C many juices contain), it is often sensible to make a record of what is happening. Without a record, it is difficult to remember what has happened and to draw conclusions. In a way, recording can be considered communicating with oneself. Many teachers ask their students to make records in a notebook or data log. Records can be in picture or graph form, as well as in writing. Whichever way the data are recorded, they should be clear.

In a primary-level class, some children are recording the growth of their plants with strips of colored paper. Every other day, they hold a new strip of paper next to each plant and tear off a bit to match the plant’s height. They date the strips and paste them in order on large paper sheets. A growth record of the plants is clearly visible to all the students.

Other children in the class have drawn pictures of their plants at different stages, from seed to mature plant. These pictures are made into record booklets at the teacher’s suggestion. The children describe each picture for the teacher, who swiftly writes their short statements on paper slips. The children paste these beneath their pictures. The result is a “My Plant Storybook” for each child, who can proudly read it to impressed parents.

In a middle-level class, five groups are at work with narrow strips of litmus paper. (This chemically treated paper changes color when dipped into acidic or basic liquids.) The children want to find out whether five mystery liquids in numbered jars are acidic, basic, or neutral. Each group has a recorder who notes the findings on a data sheet. At the end of the work session, the teacher asks how the results of all the groups should be recorded on the chalkboard. It is decided as outlined in Table 4–1. Notice that by having a code (A: Acid, B: Base, N: Neutral) written to one side, the teacher cuts down on the time needed to record the findings. The data are now compared, differences noted, and possible reasons discussed. Careful retesting is planned to straighten out the differences.

In an upper-level class, some students want to find out whether there is a pattern to the clouds passing over the city in the spring. They have made a chart that has three columns: one each for March, April, and May. In each column is a numbered space for each day of that month. Next to about half of the days, the students have drawn the weather...
Inference is an explanation of an observation based on the available information.

bureau cloud symbols for the cloud cover, if any, on those days. Even though the record chart is only partly completed, a sequential pattern is taking shape. After the chart is completed, the students will compare it with data gathered by the local weather bureau office for the same months in previous years.

Inferring

The usual meaning of inference is to interpret or explain what we observe. If Wallie smiles when she greets us (observation), we may infer that she is pleased to see us (explanation). The accuracy of our inferences usually improves with more chances to observe. Several like observations may also lead us to the prediction that the next time we see her, Wallie will smile (observation) because she will be pleased to see us (explanation). For convenience, then, view the process of inferring as having two parts: We may make an inference from what we observe, and we may predict an observation from what we infer. Let’s now look at children explaining observations and then, later, in another section, predicting them.

Inferring as Explaining

In at least three common ways, we as educators can help children infer properly from observations. Primary-level students, however, may have a very limited overall understanding of this process.

First, we can get students to distinguish between their observation and an inference. In a middle-level class, two children are looking at a picture of shoeprints in the snow. One set of prints is much smaller than the other (observation). One child says, “One of these sets of shoeprints must have been made by a man and the other by a boy” (an inference). The other child says, “That’s true” (another inference). Hearing this, the teacher asks an open question to make them aware of other possibilities:

In what other ways could these prints have been made?

They think for a moment and come up with other inferences: Perhaps two children made the prints—one wore his father’s shoes; or maybe it was a girl and her mother; or it could have been a girl and her older brother.

The teacher points out that what they have observed is still the same but that there is more than one way to explain the observation. If the children look at the tracks closely, they may conclude that one of their inferences is more likely than the others. A conclusion is simply the inference in which one has the most confidence after considering all the evidence.

Second, we can get students to interpret data they have observed or recorded. Remember the students who were using litmus paper to identify mystery liquids? When several
groups recorded their data, they noticed that some data were inconsistent. Some liquids were labeled both acidic and basic. The children inferred from this that the litmus test was done incorrectly by one of the groups. After the tests were redone, all the data became consistent. So, the children inferred that their final labeling of the mystery liquids was probably correct.

Recall the cloud data study. The sequential pattern the children saw when they examined their data was an inferred pattern. Later, when they compare their pattern with the weather bureau's report, they will be able to evaluate the quality of their inference.

Third, we can let students observe and interpret only indirect evidence or clues. Scientists must often depend on clues rather than clear evidence in forming possible inferences. For example, no scientist has visited the middle of the earth, yet earth scientists have inferred much about its properties.

Children can learn to make inferences from incomplete or indirect evidence, and they can also learn to become wary of hasty conclusions. In a primary-level class, some students are working with two closed shoeboxes. One box contains a smooth-sided, cylindrical pencil; the other box contains a six-sided, cylindrical pencil. The children's problem is, “Which box contains which kind of pencil?”

They tip the boxes back and forth and listen intently, inferring correctly the contents of the two boxes. When the teacher asks students what made them decide as they did, one child says, “You could feel which one was the bumpy pencil when it rolled.” The other child says, “The bumpy one made more noise.”

Later, the teacher puts into the boxes two pencils that are identical except for length. The students now find that correct inferring is more difficult, so they become more cautious. What observations must they rely on now?

In the middle and upper grades, students can do an excellent job of inferring the identity or interactions of hidden objects from indirect observational clues. In science, this way of inferring is called model building.

Explore owl inferences with your students. Why is the owl's beak a particular shape? Why are the feathers of one owl different than those of another? How do owls differ from eagles or other birds of prey? Read *A First Look at Owls, Eagles, and Other Hunters of the Sky* (Selsam & Hunt, 1986) to follow up on your inferences.

**Predicting**

A prediction is a forecast of a future observation based on inferences from the available data. The more data that are available, the more confidence we have in the prediction; the reverse is also true. We can be confident that spring will follow winter, but not at all confident that spring fashions this year will be exactly like those of a year ago. Without some data, we can only guess about future observations; to predict is impossible. When students put their data in graph form, they usually have many chances to predict.

Upper-level students measure and record on a graph the time candles burn under inverted glass jars. After they have recorded the times for 100-, 200-, and 300-milliliter jars, the teacher asks, “How long do you think the candle will burn under a 250-milliliter jar?”

Notice that predicting the time for a 250-milliliter jar would require the students to read the graph between the current data—they have the times for a 200- and a 300-milliliter jar. This is called interpolating. If the teacher had asked the students to predict the candle-burning time of a 400-milliliter jar, the students would have needed to go beyond the current data. This is called extrapolating from data. Using these processes to predict is more accurate than guessing.

Children often need assistance when predicting. Simple diagrams can help them reason through data. If they cannot calculate precise predictions, just asking them to predict
the direction of change is useful to them. Primary-level students might be asked, “Will more or less water evaporate when the wind blows?” Middle-level students might be asked, “Will a higher, lower, or the same temperature result when these two water samples of different temperatures are mixed?”

**Experimenting**

Experimentation is the quintessence of inquiry teaching. Authors of the Inquiry Teaching Standard in the Standards Link box list investigations, inquiry, accessibility of science resources, and the learning environment as important teaching considerations. When we think of inquiry, we often think of experiments. But just what is involved with an “experiment”?

To a child, experimenting means “doing something to see what happens.” Although this definition is overly simple, it does capture the difference between experimenting and the other six science processes. In experimenting, we change objects or events to learn how nature changes them. This section is about how children can discover the various conditions of change. Experimentation builds on the concept of open investigations.

Experimenting is often called an integrated process skill because it may require us to use some or all of the other process skills: observing, classifying, inferring and predicting, measuring, and communicating. That is one reason some curriculum writers may reserve experimentation for upper-grade activities; but experimental investigations can vary in difficulty. With guidance, even primary students will benefit from experimentation. This does not mean any hands-on activity may properly be called experimenting. Two generally accepted criteria that separate hands-on activities from experimentation are as follows:

- Children should have an idea they want to test (hypothesizing).
- Children should vary only one condition at a time (controlling variables).

To many educators, almost any investigation is experimenting, as long as the child changes an object for a purpose and can compare its changed state to the original one. This is the position taken in this book.

**Hypothesizing**

How do we get students to form ideas they want to test before they manipulate objects? There are several ways of getting children to state operations that they want to try. For elementary students, stating operations as questions such as, “Will dropping a magnet make it weaker?” or “Does adding salt to water make objects float higher?” is a clear and easy way

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**Standards Link**

Inquiry Teaching Standard

Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers:

- Structure the time available so that students are able to engage in extended investigations.
- Create a setting for student work that is flexible and supportive of science inquiry.
- Ensure a safe working environment.
- Make the available science tools, materials, media, and technological resources accessible to students.
- Identify and use resources outside the school.
- Engage students in designing the learning environment.

(Teaching Standard D, National Research Council, 1996, p. 43.)
Students discover the properties of a parachute as part of an extension to a parachute lab.

for them to state hypotheses. It makes them focus on what they want to do to produce some effect, or on what effect to observe and connect to a cause.

In science, a hypothesis is often stated in an “if–then” manner: If I do this, then I believe this will happen. If a magnet is dropped, then it will get weaker. You may want to use the if–then form with upper-level students. For most children, however, stating a hypothesis as an operational question is easier and more understandable.

Allowing students to explore the properties of real objects stimulates them to suggest their own ideas for changing the properties. Their curiosity usually prompts them to state operations they want to try or to be receptive to broad or narrow questions that you ask. For example, in a primary-level class, some children have been making and playing with toy parachutes. They tie the four corners of a handkerchief with strings and attach these to a sewing spool. Some release their parachutes while standing on top of the playground slide and watch them fall slowly to the ground. Others simply wad the cloth around the spool and throw their parachutes up into the air.

A few children have made their parachutes from different materials. They are quick to notice that some parachutes stay in the air longer than others. After they go back to the classroom, they discuss their experiences. Then, the teacher says:

We have plenty of materials to make more parachutes on the science table. How can you make a parachute that will fall more slowly than the one you have now?

The children will respond in different ways: “Make it bigger,” “Make it smaller,” “Use a lighter spool,” or “Make it like Martha’s.” These are the children’s hypotheses. Some children may say nothing, but peer intently at the materials. They are hypothesizing, too, only nonverbally. The children’s ideas need testing so that they can find out what works. Now the children have purposes for doing further work with parachutes.
Where did the children’s hypotheses originate? When the children were first observing their parachutes in action, they did much inferring. (“Jimmy’s parachute is bigger than mine. It stays up longer.” “Corinne has a big spool. Her chute falls fast.”) It is natural for people to be curious about the correctness of their inferences. Hypotheses are simply inferences that people want to test.

Exploring the properties of concrete materials provides the background that most children need to construct new concepts. They may not be able to offer broad explanatory hypotheses to test concepts or theories. This calls for additional scaffolding and prior knowledge and experience. For this reason, some what questions (What makes a ship float?) are difficult for children to answer. Instead of broad, general hypotheses, elementary students are likely to offer limited hypotheses based on the objects they have observed or manipulated.

Primary students are far more limited in this ability than upper-elementary or middle school thinkers. Scaffolding is more effective with real materials to think about during their discussion, instead of relying on discussion alone. Most primary students can only think about one variable at a time. This limits the experimenting they can do, because they are unlikely to control other variables that might affect the outcome. So, primary-level investigations usually lean more heavily on the other six science processes.

**Controlling Variables**

To find out exactly what condition makes a difference in an experiment, we must change or vary that condition alone. Other conditions must not vary; in other words, they must be controlled during the experiment.

Suppose you think that varying the size of a parachute will affect its falling rate. A good way to test the variable is to build two parachutes that are identical in every way except size. These could then be released at the same time from the same height. After repeated trials, you can infer whether size makes a difference in the test.

**Grade 2 Example**

Do not expect primary-level students to reason in this way. They will not think of the many variables or conditions that can influence their experiment. They may unwittingly change several variables at the same time. Their intent is simply to make a parachute that will fall more slowly than another, not to isolate variable conditions. Older children, in contrast, will grasp the need to control some variables. Typically, they will insist on releasing their parachutes from the same height and at the same time. Otherwise, “It won’t be fair,” they will tell you.

The parachute experiment is more than just a trial-and-error activity. The children have observed parachutes and have done some inferring about their observations. The changes they try will reflect thinking we can call hypothesizing. And although they may not think of controlling all the possible variables, they are conscious of some. This is the nature of children. How well they do and how fast they progress is influenced by how we as teachers scaffold their experiences. Following are more examples of teachers helping their students construct the idea of experimentation.

**Grade 4 Example**

In Mr. Li’s fourth-grade class, the children have worked with seeds and plants for about 2 weeks. The teacher says:

We’ve done well in getting our plants started. But suppose we didn’t want our seeds to sprout and grow. Sometimes in nature seeds get damaged or conditions are not right for seeds to grow. What could you do to keep seeds from sprouting and growing?
The children begin suggesting operations to try, as shown in Figure 4–3. These are their hypotheses; at this point, they need not be framed as operational questions. The teacher writes all of these on the chalkboard, regardless of content. The teacher then has the class screen the hypotheses for those that may have possibilities:

With which conditions might the seed have some chance to live? Suppose Matoteng squashed his seed just a little. Would the seed sprout? Would the plant look squashed? Would this happen with any kind of a seed? How about some of the rest of these conditions?

This mixture of broad and narrow questions is posed slowly to give the children time to think. The children discuss a number of possibilities. After a while, the teacher says:

How can we test our ideas?

It soon becomes obvious that some children are going to do several things at one time to their seeds, so the teacher says:

Suppose Hongmei squashes her seed and also freezes it. How will she know which one stopped the seed from growing?

The children decide to change just one condition at a time. Pairs of children quickly form operational questions from hypotheses they want to test:

Will squashing a bean seed keep it from sprouting? Will cutting a bean seed in half keep it from sprouting?

Interest is high as experimenting begins.

Grade 6 Example

In Ms. Xu’s sixth-grade class, students are working in pairs. They are testing their reaction time by catching dropped rulers. In each pair, one student holds the ruler just above his partner’s hand. When he releases the ruler, the partner catches the ruler between her thumb and forefinger. The ruler number closest to the top of her pinched fingers is recorded. This is her “reaction time.” After a few minutes, the teacher asks the students to give their reaction times. He writes these on the board in the form of a histogram, as shown in Table 4–2. Histograms are used to classify data in a way that encourages thinking about the differences in the data.

After a few moments, in a discussion with the students on how the scores are distributed, Ms. Xu says:

Suppose everything and everyone were the same in our experiment. How would the histogram look? Well, are there differences that may have given us these results? What conditions might affect reaction time?

The students start forming hypotheses:

Not everybody did it the same way.
Some people have faster reaction times.
Reaction Time Histogram

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Some kids have more practice.
I was tired today.

After a discussion to narrow down and clarify different ideas, Ms. Xu says:

How are you going to test your ideas?

The students state their ideas as operational questions: Will people have the same reaction time if they do the experiment in exactly the same way? Does practice give you a faster reaction time? Do people who feel “tired” (defined as having fewer than 8 hours of sleep) have slower times than when they don’t feel tired? Everybody agrees that they must do the experiment in the same way each time to control the test variables. Then each question is tested separately under the controlled conditions.

**Experimentation and Scientific Attitudes**

According to the National Science Education Leadership Association (2001), “Teachers should base their teaching of elementary science on process and inquiry skills such as observing, classifying, measuring, interpreting data, proposing hypotheses and conclusions.” Experimentation incorporates all of the process and inquiry skills. Another positive outcome of promoting experimentation and scientific skills in your classroom is in the area of student attitudes toward science.

**Scientific Attitudes**

As seen in the Inquiry and Attitudes Standard in the Standards Link box, an important part of inquiry is acquiring positive scientific attitudes. Experimentation and other skills are not fully developed if they are completed in a negative framework or only finished to “get it over with.” Science is different from such activities as learning to spell, in which the task is simple and there is only one correct answer. Science includes developing attitudes and
Fluency refers to the number of ideas a child gives when challenged with a problem. We can promote fluency by asking open-ended questions.

Flexibility is the inclination to shift one’s focus from the usual.

Originality is shown when children generate ideas that are new to them. We can promote originality by encouraging children to use their imagination and combine others’ ideas in new ways, and by withholding evaluative comments until we have all the ideas.

In developing inquiry skills, teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers:

- Display and demand respect for the diverse ideas, skills, and experiences of all students.
- Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for learning of all members of the community.
- Nurture collaboration among students.
- Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.
- Model and emphasize the skills, attitudes, and values of scientific inquiry.

(Teaching Standard E, National Research Council, 1996, pp. 45, 46.)

Questioning those attitudes. The development of these attitudes is part of the job for elementary and middle school teachers. We will consider five categories related to attitudes.

**Curiosity**

“To be a child is to touch, smell, taste, and hear everything you can between the time you get up and when your parents make you go to bed. I don’t have to teach curiosity. It’s there already.” The kindergarten teacher who made this statement about curiosity echoes the feeling of many of her elementary school colleagues. Yet, in some classes, there are children who lack interest in science.

Walk into two adjoining classrooms: one with a hands-on science program and another where students just read and do worksheets during science time. Handing concrete materials to children is like rowing downstream or cycling with the wind at your back. Making children sit still and be quiet for long periods is like rowing upstream or riding into the wind: You can do it, but it is better to avoid it. Children lose much of their curiosity unless they are allowed to do what comes naturally.

Teachers who maintain or spark students’ curiosity apply science to everyday life. These teachers also use several open-ended investigations during a teaching unit. As you can see, we often use children’s literature as a way to initiate curiosity about a topic. For example, reading *Poppy* (Avi, 1995) explores the relationship between an owl and a deer mouse. Students will immediately begin to wonder about the relationship between these two animals.

**Inventiveness**

To be inventive is to solve problems in creative or novel ways. This is contrast to simply taking a known solution and applying it to a problem at hand: It’s good to apply what you know about a car jack to change a flat tire, but what do you do when there’s no jack? Inventive people may apply their knowledge to solve problems much as other persons do, but they are more likely to show fluency, flexibility, and originality in their thinking.

**Critical Thinking**

To think critically is to evaluate or judge whether something is adequate, correct, useful, or desirable. A judge does this when she decides whether the evidence is adequate to find guilt; the judge has a standard in mind against which she makes a judgment. This is the key to critical thinking: Know the accepted standard and decide whether or to what degree it is being met.
Curiosity:  
CD-ROM Connections

View the Curiosity and Interest video in the “Nature of Science” section of the Companion CD. Mr. McKnight asks students questions to stimulate their curiosity. More importantly, however, he has the students identify questions that they would like to explore.

Review the video and ask yourself the following:

• Why doesn’t Mr. McKnight simply provide a written question and have all the students explore that question?
• Mr. McKnight does not readily answer the question of “how do they have babies” but instead tells Josh, “When you learn the answer, you won’t believe it.” Why didn’t he simply provide a brief answer to this question?

Novak (1977) suggested that inquiry is a student behavior that involves activity and skills, but with the focus on the active search for knowledge or understanding to satisfy students’ curiosity. Explain why you agree or disagree with this idea. Record your ideas and the answers to these questions in your portfolio or use the Companion Website to share your ideas.

A problem we face as teachers of elementary and middle school children is the numerous standards of behavior in science. Many are highly sophisticated. Let’s see if we can reduce them to a manageable few and restate them on a level that makes sense to young minds.

Science has three overall standards for critical thinking that most children can gradually understand and learn to assimilate: open-mindedness, objectivity, and willingness to suspend judgment until enough facts are known.

The open-minded person listens to others and is willing to change his mind if warranted. An objective person tries to be free of bias, considers both sides in arguments, and realizes that strong personal preferences may interfere with the proper collecting and processing of data. Someone who suspend judgment understands that additional data may confirm or deny what first appears. Looking for further data improves the chances for drawing proper conclusions.

Try having several groups work on the same activity and then report and compare findings. The degree of open-mindedness soon becomes obvious when people refuse to listen to others, push their own ideas, or jump to conclusions before all groups have their say.

Critical and creative thinking go hand in hand—it is artificial to separate them. When problem solving or experimenting, for example, children should be encouraged to generate several possibilities, rather than just consider the first idea suggested. You also want them to appraise all the ideas critically so that they can tackle what looks most promising. Controlling variables in experimenting gives students another chance to generate suggestions, but they must also think: “Will these controls do the job?” Later, if groups come up with different findings, critical thinking is again needed to answer why. Perhaps one or more variables were not controlled after all. You can see that creative and critical thinking are different sides of the same coin.

When students seek information, a variety of sources are available to them, including each other, printed matter, audiovisual materials, electronic information, and knowledgeable adults. Certainly, students can be cautioned to check copyright dates and agreement with what is known, to consult more than one source, and to note conflicts in fact. This is especially important when exploring the Internet, where information can be posted from
anyone who has access to it. Children often do not critically appraise information. As educators, we can help children learn ways to consult these sources efficiently and to understand what the sources say.

Spend time reading fictional materials with your students. Owls in the Family (Mowat, 1981) is a humorous tale of two owls. Critical thinking is promoted as students begin to separate fact from fiction in this story.

**Persistence**

Most elementary and middle school science activities can be completed within a short time, but some require a sustained and vigorous effort. To do our best work often takes persistence. Children sometimes lack the persistence to stick with a worthwhile goal. Primary-level students often want instant results. Their short attention span and need for physical activity can easily convert into impatience. You can combat this impatience by arousing children’s interests with meaningful science activities.

**Uncertainty**

Another important attitude to develop is the ability to understand or accept uncertainty. Much of this attitude centers on students understanding the nature of elementary statistics. Some events can be predicted well; some cannot. We do not always know all the variables in a given situation, nor do we always have representative data of a population. For instance, the weather announcer on television only predicts rain tomorrow on the basis of the percentage of times it has rained with similar weather conditions (e.g., air pressure, wind patterns, cold and warm fronts).

Elementary and middle school students should be aware that evidence is not always complete and that therefore predictions may not always be precise. Experiments are influenced by the lack of an accurate observation, missing information of compounding factors, or a model to explain the variables effectively. Scientists do not always have all the answers, but must theorize on the observations and experimental results they do have.

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**Teacher Modeling of Attitudes:**

*CD-ROM Connections*

Watch Glen McKnight’s *Perspective with the Teacher Attributes* video in the “Nature of Science” section of the Companion CD. What does Mr. McKnight specifically say that indicates he possesses positive scientific attitudes and passes these on to his students?

Review the video segment and ask yourself the following:

- If I were being interviewed, what would I say about my attitudes toward science?
- We state that “early learning of attitudes begins with imitation” and that “the open-minded, accepting teacher who reflects positive attitudes is more likely to influence students in positive ways.” From your own experiences, do you find this to be true? Provide specific examples.

Corsaro (2003) discusses how we as a society may be losing our parental influences on children and that more influence may come from the school environment. If he is accurate with this idea, what would that suggest to you as a future elementary or middle school science teacher? Record your ideas and the answers to these questions in your portfolio or use the Companion Website to share your ideas.
Developing Attitudes

Early learning of attitudes begins with imitation and later comes from experiences with the consequences of having or not having the attitudes. The open-minded, accepting teacher who reflects positive attitudes is more likely to influence students in positive ways than one who lacks these qualities.

Open-ended activities bring out positive attitudes. Success in science is bound up with curiosity, inventiveness, critical thinking, persistence, and tolerance for uncertainty. Children learn, in a more limited way, the same habits of mind as scientists and other reflective people. Successfully practicing these attitudes helps build self-esteem.

Summary

- In observing, students learn to use all their senses, note similarities and differences in objects, and become aware of change.
- In classifying, students group things by properties or functions. Students may also arrange them in order of value.
- Measuring teaches students to use nonstandard and standard units to find or estimate quantity. Measurement is often applied in combination with skills introduced in the mathematics program.
- Communicating teaches students to put observed information into some clear form that another person can understand.
- By inferring, students interpret or explain what they observe. When students infer from data that something will happen, usually the term predicting is used. When people state an inference they want to test, usually the term hypothesizing is used. Therefore, predicting and hypothesizing are special forms of inferring.
- In experimenting, we often guide students to state their hypotheses as operational (testable) questions and help them control variables within their understanding.

Reflection

Companion CD

1. Look at “The Earthworm’s Body: Digging It” lesson linked to the Learning to Think video on the Companion CD. Can you rewrite this lesson to be more consistent with the learning cycle?
2. Look at “The Earthworm and Water” lesson linked to the Cognitive Apprenticeship video on the Companion CD. How could you modify the “Extended Practice” section to have students apply their new knowledge and skills as part of the concept application phase?
3. Look at “Mechanics of the Digestive System” lesson linked to the Scientific Method video on the Companion CD. Observation is not identified as a skill to be taught in this lesson. In what ways could you modify this lesson to include developing observational skills?

Portfolio Ideas

4. Safety is an important consideration when experimenting or developing other scientific skills in the elementary and middle school classrooms. Purchase a copy of Safety in the Elementary Science Classroom (National Science Teachers Association, 1997, at http://www.nsta.org) and identify potential safety hazards in your practicum classroom. Record these in your portfolio and discuss them with the teacher. Also visit the Companion Website (http://www.prenhall.com/peters) for more safety information.
5. What other scientific skills can you think of to teach children? What approaches could you take to develop these skills in elementary or middle school students? Record findings in your portfolio.
6. How well do you know the science processes? Experiment with one of the activities from the books listed in the Suggested Readings. Repeat your experiment with students at your practicum site, document findings in your portfolio, and compare their results with those of your classmates.

7. Interview an elementary or middle school student and compare her scientific attitudes with those in this chapter. Share these results in your portfolio and with the class or your instructor.

8. Try some activities in Floaters and Sinkers (Cordel & Hillen, 1995) as an initial source to learning cycle activities related to mass, volume, and density. Enter findings in your portfolio.

9. A fun way to introduce the metric system is to have a classroom or schoolwide Olympics. The book Math & Science: A Solution (Ecklund & Wiebe, 1987) has metric measurement activities related to the Olympics. Olympic Math (Vogt, 1996) also has measurement and graphing activities. The Math Counts series (Pluckrose, 1995) has titles that relate to introductory measurement, such as length, weight, time, and capacity, that can assist students in identifying concepts as part of the Olympics experience. Record how your event turned out in your portfolio.

10. Try using the “Deliver Woodsy’s Message” activity in the Woodsy Owl Activity Guide (Children’s Television Network, 1977) as a communication activity. Students can make posters, create mobiles, write poetry, or perform a play based on a “lend a hand—care for the land” theme. Record what you find in your portfolio.

References


Staver, J. R., & Shroyer, M. G. (1994). Teaching elementary teachers how to use the learning cycle for guided inquiry instruction in science. In L. Schafer (Ed.), *Behind the methods class door: Educating elementary and middle school science teachers* (pp. 1–11). Columbus, OH: ERIC Clearinghouse.

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**Suggested Readings**