
Inquiry and Scientific Literacy

WHAT IS SCIENCE?

How do you define science? How do you think your students define science, or how would they describe a scientist? Not too long ago, we had a group of seventh-grade students draw scientists. Overwhelmingly, the pictures depicted men (some with Einstein-like hair) standing behind lab tables using flasks or test tubes. The average person might define science as a body of scientific knowledge. Philosophers may regard science as a means to obtain the truth through questioning, while scientists probably see science as a means of exploring a hypothesis by following a set of procedures. In a classroom, the teacher may encourage students to think of science as problem solving, observation and description of the real world, discovery, seeking the truth, studying nature, turning facts into theories, organizing knowledge, using logic, or studying the universe.

While all of these statements have a connection with science, each is only a part of science—only when they are put together do they begin to represent science. Science is learning about the world. All dimensions of science rather than an emphasis on only science content, support this learning. Knowledge is obtained through observations and investigations that can be substantiated by others. According to the National Research Council (NRC; 1999), explanations that cannot be based on empirical evidence are not part of science. Science is one subject that encourages concrete action (Wright & Wright, 1998).

There are three aspects of science knowledge for which scientists are responsible—*understand*, *explain*, and *apply*. Careful observations, designed experimentation, and logical reasoning can accomplish these aspects. Scientists are also responsible for making understandings public. Generally, scientists make these public at professional meetings or in journals. Other scientists then carefully review these understandings, making critical comments and suggestions (Chiappetta & Koballa, 2002). Students who are scientifically literate are

able to not only follow scientific procedures, but they also understand, explain, and apply their knowledge.

WHAT IS SCIENTIFIC LITERACY?

According to the NRC (1996), a scientifically literate individual is able to

- experience the satisfaction of understanding the natural world;
- use scientific thinking in making personal decisions;
- participate intelligently in societal discussions on science and technology; and
- attain the skills and knowledge that are required for being productive in our current and future economies. (p. 13)

The characteristics of a scientific literate adult include being able to use clear and accurate communications skills determining differences between vague and unsubstantiated arguments with possible and relevant ones (American Association for the Advancement of Science [AAAS], 1993). People need to be able to apply problem-solving skills to everyday life (Wright & Wright, 1998).

While scientific knowledge is dependent upon texts, DeBoer (2000) noted that being able to read and write about science is rather broad and is not necessarily being scientifically literate. Just being able to memorize vocabulary is NOT being scientifically literate (Norris & Phillips, 2003). Students need to understand the vocabulary allowing them to read alternative views in articles and comprehending science ideas in the media (Miller, 1998).

There are obstacles that interfere with scientific literacy. Rather than teach in an inquiry fashion to promote scientific literacy, critics assert that students are being taught in preparation for standardized testing (Bentley, Ebert, & Ebert, 2002; Grossen, Romance, & Vitale, 1994; Rescher, 2000). On the other hand, others claim that science teachers have little or no concern for reading in science and do not see reading as an important part of science (Wellington & Osborne, 2001). To further complicate matters, while science departments are made up of qualified teachers who are socially respectful of each other, often there is little or no collaboration among departments. Not only is science taught separately from other academic areas, but it is also divided into separate compartments within its own department (Rubin & Wilson, 2001). How much more beneficial science and literature education could be if they were brought together by creating experiences where students use principles, theories, and generalizations from both academic areas to solve a particular problem or explore an area of interest (Howes, Hamilton, & Zaskoda, 2003).

Learning science is a personal and social exploration that promotes conceptual change. For there to be true science literacy, experiences must incorporate scientific inquiry and self-discovery (Wright & Wright, 1998). The more direct the student involvement, the better the experience is (King, 2007). Throughout this book, we hope to provide readers with ideas to increase science literacy through curriculum not traditionally associated with science—reading and writing.

HOW DO WE REACH SCIENTIFIC LITERACY?

There are many options for improvement in science education for high school students. Many contemporary reform ideas are based on advances in cognitive psychology and human development research (Wandersee, Mintzes, & Novak, 1998). As a result, the *National Science Education Standards* were developed to provide curriculum and instructional guidelines for all students that describe what students and teachers need to know in order to promote a science-literate society. States have implemented their own standards based on these national standards. Teachers and science curriculum coordinators need to be aware of their state's science standards to ensure that the standards are better met (NRC, 1996). As the final arbiters of any reform, teachers' perceptions about reform ideals are worthy of investigation (Crane, 1998). There is no single curriculum adequate for all students. Some have even turned students off science. Curriculum designers must take care to not adopt any one wholesale package program (Airasian & Walsh, 1997; Nordstrom, 1992).

Learners involved with a process of inquiry that allows them to answer questions that challenge their prior knowledge about themselves, the world around them, and the environment are growing in science literacy and knowledge. Students can then restructure their informal ideas to those consistent with the science community (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Unfortunately, in many science classrooms, inquiry has not achieved primacy over the traditional teaching method. Bentley and Alouf (2003) determined that

While leaders in the field of science education and science teacher educators continue to promote inquiry teaching, traditional didactic expository instructional methods; such as teacher-centered whole-class lecture and textbook-based read-about-science activities still make up much of the science instruction in American classrooms. (p. 3)

The environment found in an inquiry-based science classroom may blossom from the different abilities, attitudes, experiences, and interests that students bring. Mary Ellsworth (2002), model teacher for the Gallaudet University Model Secondary School for the Deaf in Washington, D.C., suggests that many teachers do not know the value of using activity-based activities with deaf students. We suggest that activity-based science has application for all students, including those with disabilities.

Good science inquiry involves learning through direct interaction with materials and a phenomenon (Kluger-Bell, 2000). It involves making observations, posing questions and researching with books and other resources to enhance what is already known, planning investigations to solve problems, and comparing what is already known along with the investigation's experimental evidence. It is important to use current scientific knowledge and understanding to guide the scientific investigation. Inquiry uses tools to gather, analyze, and interpret data. Technology used to collect the data can enhance the amount

of data, the speed with which it can be collected, and potentially the accuracy allowing the investigator to analyze and quantify the results. Communicating the results concludes the research. Researchers need to propose answers, explanations, and predictions throughout the investigation and use critical and logical thinking, identify assumptions, and consider alternative explanations. It is because of these last three activities that science distinguishes itself from other ways of knowing and provides for the best possible explanations of the natural world.

One of the benefits of inquiry-based instruction that has been observed is enhanced students' performances in laboratory skills and interpreting data (Mattheis & Nakayama, 1988). An inquiry-based classroom promotes critical-thinking skills. It empowers students to become independent and lifelong learners (Llewellyn, 2005). According to Regan, Case, and Brubacker (2000, p. 2), "inquiry-based classrooms promote critical thinking skills and habits of mind."

To urge educators to promote broader objectives in education, Ferrero (2005, p. 425) expanded on the four NRC (1999) principles necessary in a learning environment. He stated that

- Schools and classrooms could be learner centered with students setting their own learning by means of consulting with peers as well as the teacher.
- To ensure that students understand information and subject matter, classrooms should be knowledge centered with students knowing why it is important to know what is being taught.
- Assessments should be ongoing with both teachers and students guiding instruction and monitoring progress.
- There should be a strong sense of community with focus on career and connections to the outside world that help prepare students to identify social injustice and organize for political action.

Science, Technology, and Society (STS) programs have been particularly successful because topics are frequently related to students' lives. Activities are often conducted by groups, and there are often connections to other school subjects. Teachers who guide students to make connections with other subjects help the students go beyond learning isolated facts. Students can focus on processes for learning. Students who have difficulty in some areas often become problem solvers and have learned to develop other skills. Learning can be enhanced by tapping into these other learning modes (Caseau & Norman, 1997).

STS activities may help students identify with the science they are learning in their classrooms. Additionally, their environments and personal issues may provide an opportunity to develop questions for inquiry. By being aware of students' lives outside of school, teachers and curriculum developers may make decisions that provide for relevant and motivational learning experiences.

CLASSROOM STRATEGIES

We tend to teach the way we personally learn and often must make a determined effort to consider our students' preferences. Students learn better and enjoy their learning activities more when the teaching style closely matches their learning styles (She, 2005). It is beyond the scope of our discussion here to spend an inordinate amount of time on the many different learning-style theories. These theories can be synthesized into identifying three different kinds of learners—visual, auditory, and kinesthetic. Between 30% and 35% of students are probably visual learners. They relate to pictures more than words; they would rather view materials than read them. They learn vocabulary in context after having opportunities to hear the words. They use visual cues in texts; graphic organizers help them comprehend material. Approximately the same percentage are tactile-kinesthetic learners. They look at such things as the shape of words and understand concepts better if they have concrete examples at the beginning of the learning experience. Auditory learners like to hear and talk about their learning (Winebrenner, 1996). With so many different students, we can't be expected to meet every student's learning style every day. Instead, throughout a unit of study, we can include activities related to a variety of learning styles.

Most secondary classroom strategies fall into categories. According to Chiappetta and Koballa (2002) the strategies include *lectures* during which teachers present ideas to a large group of students. In these situations, there is little student involvement. *Discussions* allow students to clarify ideas; however, unless the discussions are carefully designed, teachers often do most of the talking, and student willingness to participate may vary according to the classroom climate. *Demonstrations* usually have minimal student participation but do help teachers explain ideas and guide thinking. *Laboratory* or *hands-on activities* are usually predictable and prearranged by the teacher. However, they may be designed to encourage process skills, inductive reasoning, or deductive reasoning. *Simulations* and *games* help students visualize events or objects they might otherwise not have the opportunity to experience. The availability of technology allows for rich learning experiences for students in many classrooms. The final strategy as outlined in Chiappetta and Koballa's work is *recitation*. While this does involve student participation, it is usually teacher directed and deals with rote memory of knowledge.

Inquiry, as recommended by Project 2061 of the AAAS (1993) engages students with productive questions, prompting them to become actively engaged in seeking a solution. Students are encouraged to work in cooperative groups testing ideas, collecting data, forming conclusions based on the evidence obtained, and communicating results. Teachers are encouraged to deemphasize rote memorization of vocabulary (Chiappetta & Koballa, 2002).

Teaching science by inquiry allows students to perform investigations using skills used by scientists. Productive questions to guide students from recitation of facts to being able to apply knowledge in new situations and then to making evaluations based upon knowledge promotes thinking. Students should be engaged in science process skills such as observation, classification,

measurement, mathematic calculations, making predictions, and designing investigations through the manipulation of controls. Use of these skills helps students become better problem solvers (Chiappetta & Koballa, 2002).

How are you smart? We're not asking how smart you are. What are you really good at doing? Look at your students. Do you have natural leaders, quiet thinkers, sports jocks, and artists? According to a theory proposed by Howard Gardner, there are at least eight "intelligences" or ways of being smart and we all have each of the intelligences in some degree. Multiple Intelligences theory has the potential to enhance conceptual understanding in science, foster positive attitudes toward science, increase enjoyment of and participation in science, and create more authentic learning experience in science (Goodnough, 2001; Thompson & MacDougall, 2002). If we design units during which many of the intelligences are addressed, students will not only have an opportunity to participate in an area of strength, but will also be challenged to expand their capabilities in other areas. For example, an inquiry unit that includes reading, field studies, problem solving in groups, an oral presentation with visual aids designed by students, and individual logs and reflections can meet the needs of a variety of students.

Figure 1.1 Howard Gardner's Intelligences

Verbal-linguistic—These are your students who are good talkers, readers, and writers.

Mathematical/Logical—These are your analytic thinkers who are comfortable with if . . . then statements and calculations.

Musical—These students are musical, and they are also those who can sense rhythms in nature or their environments.

Visual/Spatial—These students are your artists, ones who can organize space around them. They can visualize quantities and volumes.

Interpersonal—These are the students who work well in groups; they are often your leaders.

Intrapersonal—These students are your quiet thinkers; they may be shy and reluctant to speak out, but actually think things through and may come up with great ideas.

Bodily Kinesthetic—These students are physically aware and enjoy working with their hands and bodies.

Naturalist—These students are keenly aware of their environment. They can easily distinguish between different species or even the kinds of cars they see on the road.

SOURCE: Adapted from Manner, B. M. (2001). Learning styles and multiple intelligences in students: Getting the most out of your students' learning. *Journal of College Science Teaching*, 30(6), 390–393.

Discrepancies between goals for student achievement and what we actually see happening suggest that one-size-fits-all strategies are not the answer. Perhaps, in addition to identifying the features of materials that are not working, we should consider the needs and abilities of the students. Students may have different goals—some actually anti-achievement goals—that may be

based upon their backgrounds, interests, and abilities (Chamberlain, 2003). Inquiry-based science can help students identify goals and work toward achieving these goals.

Mastropieri and Scruggs (1992) suggest that the characteristics of science make science classes appropriate for inclusion of students with special needs. They suggest that the experiential hands-on approach can help develop skills and knowledge necessary for adult life. Experiences in science can help students develop problem-solving and decision-making skills. Although including students with exceptionalities may require some modifications of classroom procedures and strategies, students benefit from access to the same curriculum as other students and the opportunities for social interactions and friendships with their peers (Mastropieri & Scruggs, 2001).

Because science provides an opportunity for students to “develop reasoning skills and apply the scientific ‘process’ skills . . . to phenomena they encounter in their everyday lives” (Scruggs, Mastropieri, & Wolfe, 1995, p. 223), it is an important subject for students with mental retardation. Activity-based learning allows students to interact with phenomena and to manipulate equipment and materials. Practice with decision making and problem solving helps students achieve academic and social goals (Caseau & Norman, 1997).

Most of the students included in regular classes with individualized education plans (IEPs) will be labeled *learning disabled* (LD). However, this category is wide and has many variations. The common characteristic of students with learning disabilities is that a student is at or above average in general intellectual ability, but there are discrepancies in achievement among different academic areas. For instance, a student may have high achievement in mathematics but have difficulty reading. Individual students may have difficulty reading, expressing thoughts in writing or orally, or difficulty with focusing on tasks or calculations. Students with learning disabilities may exhibit inappropriate social behavior either from self-consciousness regarding academic deficiencies or from inappropriate interpretation of social cues. A student with a history of school failure or underachievement can be expected to lack motivation for future school tasks and may have attention problems (Scruggs & Mastropieri, 1993). Students with learning disabilities may require fewer accommodations in science classes that are well structured and activity based than in any other academic subject. In fact, classes that are well structured and activity based are particularly helpful to students with a learning disability (Caseau & Norman, 1997). Only careful scrutiny of a student’s IEP and consultations with special educators familiar with the student can identify adaptations that may be required in the classroom.

A student’s success is directly related to how the student sees himself or herself as a learner and how the student defines success. Success in science is also determined by how well the curriculum matches the needs of students—developmentally, culturally, and academically (Chamberlain, 2003). Inquiry-based science can be a vehicle to meet the challenges of diversity among students and the need for science literacy in a changing society. The task is not easy, but it is worth the effort. The National Science Teachers Association’s 2004 position statement supports the inclusion of special students in science. The organization’s

Web site (www.nsta.org), which provides background information and suggested strategies for many disabilities, is an excellent resource for teachers. The suggestions are practical and easy to use; they mirror many of the strategies already presented in this book. There are also other organizations that provide information for teachers. On the Rochester Institute of Technology's Web site (www.rit.edu), teachers can find information about the Clearinghouse on Mathematics, Engineering, Technology, and Science (COMETS) program; the site has many suggestions and provides support for those working with students who have hearing impairments.

QUESTIONING

We keep mentioning questions—student and teacher posed—that guide inquiry. Well-designed questions focus attention and help students move beyond facts to understanding and application. The lowest level of questions requires recitation of information students have acquired from sources. These literal questions encourage students to search for facts. Although facts may be important, questions that require students to make inferences, connect information, and apply information to new situations are necessary. At the highest level of questioning, the critical level, students are required to evaluate information, to challenge information by comparing several sources of information, and to use information to support conclusions (Gabler & Schroeder, 2003).

If the goal of a question is to focus students on facts or observations, one may use phrases such as “how many . . .” or “what happened when. . .” However, to move students to higher thinking, use questions that require students to compare and contrast ideas or results. Ask students “what if . . .” or “how could we . . .” or give reasons and explain phenomena. It may be necessary to start with lower-level questioning and guide students to more inquiry-focused questions. However, open-ended questions, ones that do not have just one right answer, are most productive in inquiry-focused science.

INQUIRY TEACHING MODELS

The most widely promoted approach to science instruction today is constructivism, which holds that knowledge is constructed within the human minds and social communities (Richardson, 1999). The teacher is no longer the controller of students (Tobin & Dawson, 1992). Learning is built upon knowledge from previous experiences, feelings, and skills. While constructivism does not neglect basic skills, it emphasizes thinking, reasoning, and applying knowledge (Moussiaux & Norman, 2005). Misconceptions are common and sometimes interfere with learning if students resist changing their own ideas (Schulte, 1996). Once learners assimilate or acquire new ideas to replace their old conceptions with new ones, then accommodation occurs. This happens when the learner becomes dissatisfied with existing conceptions (Wandersee et al., 1998). Often, a lot of time in science classrooms is spent on helping students

take in new information, but often with little attention to helping them learn to apply this information in real-life situations.

Students do not simply learn by listening to someone talk or by reading a textbook (Rakow, 1998). If students know the teacher will be testing on factual aspects of a reading assignment, they will adopt an apathetic stance, seeking only the factual information in their reading assignment (Rosenblatt, 1991). Mayer (1995) noted that this form of reading may actually interfere with the science process. Textbooks and illustrations may confuse students' understanding of concepts. Suggestions to help overcome these problems when using textbooks will be discussed in Chapter 2.

The constructivist model of learning is reflected in inquiry-based instruction and is characterized in a variety of ways (Collins, 1986; DeBoer, 1991). Teachers and students become partners in learning with students having a role in producing knowledge, not just receiving it from the teacher (Haury, 1993). Students are capable of providing insight into the effectiveness of curriculum (Chamberlain, 1999). Students are more apt to understand the natural world if they are given the opportunity to use their senses to directly observe natural phenomena. Sometimes scientific instruments are needed to extend the power of their senses (National Science Board, 1991).

5E Model for Lesson Design

The 5E Model is made up of five distinct parts and can be an extremely effective learning approach (Guzzetti, Taylor, Glass, & Gammas, 1993; Lawson, 1995). This model gives students the opportunity to raise questions and put abstract experiences in communicable form. They can expand on previously learned concepts making the connection to other concepts. This, in turn, leads to further inquiry and new understandings (not to answers, but more questions). The five parts of this lesson design are:

1. **Engage**—During this segment of the lesson, the intent is to capture students' interest, get them thinking about the subject matter, and stimulate their thinking.
2. **Explore**—Students are given the opportunity to design and implement their own investigation. Through observations, forming hypotheses, recording data, organizing their findings, creating graphs, and other forms of communicating their results, students then share their findings.
3. **Explain**—The teacher introduces facts, models, laws, and theories to the students during this phase. Students are helped with scientific vocabulary and guided in formulating questions to help them explain the results of their exploration.
4. **Elaborate**—At this point of the model, a transfer of learning from one concept to another should take place with students applying their new knowledge.
5. **Evaluate**—Students and teachers conduct assessments that are not only formative but are also summative of students' learning.

Teachers also look for understanding during the Explore and Explain phases. According to Colburn and Clough (1997), students can design experiments as part of their assessment. They can also create explanations and demonstrations of their knowledge. It is extremely important for students to have adequate time to discuss their findings, present their data, and listen to what is presented by others, as it is crucial to improve retention of the knowledge and concepts gained through the initial inquiry.

7E Model (An Expansion of the 5E)

Arthur Eisenkraft (2003), project director of the Active Physics program, expanded on the 5E by adding two additional phases. He divided the Engage phase to include an Elicit phase. While it is important to engage students in inquiry, it is also important for the teacher to understand students' prior knowledge. This can be accomplished by asking productive questions that elicit students' understanding about a concept. Eisenkraft also added the Extend phase at the end, which allows students to challenge what they have already learned. Students can then practice the transfer of learning.

While the 5E has been proven to be quite effective, the 7E can further help teachers to address the important, essential requirements for learning of eliciting prior understandings and transfer of concepts.

Generative Learning Model

Another model for effective inquiry-based lesson design is the Generative Learning Model (GLM; Osborne & Freyberg, 1985). There are four phases to this model. During the *Preliminary Phase*, the teacher discovers and classifies students' views about a topic. It is then determined what scientific views are necessary. The teacher also must consider the evidence necessary to lead the students to abandon old views. This is accomplished by having students complete surveys or participate in other activities designed to pinpoint their existing understandings.

The second phase is the *Focus Phase*. It is at this point the teacher establishes a context and provides motivating experiences to help students become familiar with materials. Students generally are active in explorations that help them think about what is happening. They generate questions related to the concept at task. Based on prior knowledge and the present experience, students can clarify their own views and share information with the class via discussions and/or displays. The teacher asks open-ended questions to interpret the students' responses and understand changes in students' views.

During the *Challenge Phase*, the teacher facilitates an exchange of views, allowing all interpretations at this time. If necessary, the teacher can encourage further procedures to help present evidence from a scientific viewpoint. Students, in this phase, conduct further testing to check for validity of their views, making comparisons with those of the other pupils in the class and those of the scientific community.

To complete the GLM, students begin the *Application Phase*. The teacher assists students by stimulating and contributing to discussions, and helps students solve advanced problems by directing them to places where they can obtain accurate information. Students are asked to clarify their new views by solving practical problems using the concept learned as a basis. They present solutions to others in the class and suggest further problems that arise from their experiences.

Figure 1.2 5E Lesson Plan—Erosion and Runoff

ENGAGE: Tell the students you are going for a walk outside. Have them discuss and explain what they might see if soil has moved from one place to another. Discuss why this might have happened (suggested responses: erosion, puddles, areas that are on a slant). Take students on a walk outside to make observations of the land. They are to make note of where the soil is worn away or collected in an area. Upon return to the classroom, have students make a list of sites where the soil was worn away or collected. Possible questions: What are the differences between the areas? What do you think caused the differences? Be sure to have students recognize that humans may also be a cause.

EXPLORE: Have students construct a model to investigate how changes may have occurred using suggestions below. Once the model is constructed, have students draw and label a diagram of their model. A prediction should be made about what would happen if it rains. Students should then use the watering can (one cup of water for each landscape model). Observations should be made after water is poured over each area. Wait several minutes and have the students make final observations on the effect of water on their landscape and in the quart jars. Make comparisons with their predictions.

EXPLAIN: Record student results on the board—predictions and final observations. Questions: What actually happened when it rained on your landscapes? What changes took place? What differences did you notice? What happened to the soil? Where did it go and why? Record key statements on the board. Some may include: dirt and water washed away, rain carried soil down the incline, sod held the water better than the other two. Relate students' observations to scientific knowledge. Using student models, have students label erosion and deposition. Students can then define these terms. Students should be aware that soil that has ground cover is less apt to erode and form deposits lower down a hill. Help students understand that water is not the only cause of erosion. It can be caused by wind, people, animals, and so forth. Discuss how crop rotation and how planting in a horizontal fashion will cut down on erosion.

(Continued)

Figure 1.2 (Continued)

EXTENSIONS: Have students use their poorest landscape models and design ways of decreasing or elimination erosion. Students should draw and label a diagram of their planned model and the materials they would use. They will then write a short explanation of why they think their ideas will work to curb erosion. They will need to submit a list of additional materials their models will need. Give students time to build their new landscapes. To enhance this activity with reading and writing, students could research a variety of areas in the country that are the result of erosion: the Grand Canyon, Mississippi River Delta, and so forth. Students could also read selections from *The Grapes of Wrath* by John Steinbeck or *Out of the Dust* by Karen Hesse.

EVALUATION: Take pictures of students' end models and have students do a classroom presentation identifying how and why their models work. As a homework assignment, students could walk around the area where they live looking for areas of erosion and deposition. They could draw, label, and write brief descriptions of their observations.

MATERIALS: Three plastic shoeboxes (cut a hole sized to fit tubing and sealed around the tubing with tape or other adhesive at the bottom of one short side in each container); flexible plastic tubing; quart jars; sod for one container; soil for one container covered with straw; soil for remaining container; watering can with water.

SETUP: Elevate one end of each container. Tubing hanging from each container should be placed in quart jar to collect runoff.

SOURCE: Environmental workshop activity developed by Christine Crane, Rich Gulyas, and Michael Lovegreen.

Figure 1.3 A Generative Learning Model Lesson—Pendulums

PRELIMINARY PHASE: To ascertain students' knowledge.

Begin by telling students a story about a young couple who were taking a stroll through the jungle when they heard a loud noise behind them. When the young man turned to look, he noticed that a herd of elephants was headed in their direction. Both began running to get away from the wild herd. All of a sudden, they came to the edge of a raging river. A quick decision had to be made! They really could not go around the river as it would take too long and there was the possibility of the elephants following. There were two vines hanging down from a tree to help them get to the other side of the river. One vine was shorter than the other. Here is the problem for your group to solve: Which vine should the young man take to get across the pit the quickest? Should he take the short vine or the long vine? Should he take his girlfriend with him or go alone?

Students are encouraged to come up with their own ideas, writing them in their science journals or lab sheets. They must also explain why they made their decisions. The teacher can then ascertain students' views and understanding of pendulums.

FOCUS PHASE: Students should be actively involved in explorations helping them think about the material.

Students are placed in groups selecting materials, collecting data, and placing data in charts in preparation to share with the whole group. Upon completion of their explorations, they will share their conclusions with the whole group.

CHALLENGE PHASE: An exchange of views and interpretations is made at this time. Further procedures may be necessary to present the evidence from a scientific point of view.

Students begin sharing final results. A discussion of pendulums takes place. The group may design a uniform procedure for each group to follow. At this time, the teacher can present a discrepant event with chains and other pendulums to demonstrate change in the center of mass.

APPLICATION PHASE: Advanced problems are given to ascertain students' new understanding of pendulums.

Remind students of times when as children they swung on tree swings. Show them a picture of a swing in a tree. (Two vines hang from the branch of a tree. One side of the branch is higher than the other. The board to sit on is level with the ground.) Explain to the students that unfortunately it swings crooked. In groups, they are to fix the problem by making the board swing straight. They cannot make a tire swing!

SUGGESTED MATERIALS: metric rulers, fishing weights, string, calculators, masking tape, stopwatches

SOURCE: Adapted from Kyle, W., Bonnestetter, R., McCloskey, S., & Fults, B. (1985). What research says: Science through discovery: Students love it. *Science and Children*, 23(2), 39–41.

ASSESSING INQUIRY

Standards-based assessments that specify what students need to know by a specific grade level have become the norm in schools across the country; thus, teachers can match standards to skills that are developed in the curriculum. Assessments can take two basic forms: *traditional assessments* (generally paper-and-pencil tests or quizzes) and *performance/authentic assessments* (require students to demonstrate their knowledge in different formats). For example, in Chapter 4, students' writing projects and, in Chapter 5, students' multimedia projects are ways to demonstrate knowledge. Other examples include:

- **Inquiry-based investigations at the conclusion of a group activity**—The whole group could hand in one report based on group results. A student who disagrees could submit an individual report for

separate grading, or the whole group could work together with each student submitting a written report for grading. Finally, the whole group could work together on an investigation with each student keeping his or her own data and submitting individual reports.

- **Teacher observation**—Checklists of students' accomplishments based on instructional objectives make this more manageable.
- **Interviews with students**—This form may be time consuming. Teachers may find it easier to interview a group while they are working on an investigation. Berenson and Carter (1995) suggest that the teacher provide questions and tape student-to-student interviews to review later.
- **Journals**—While there is no specific format, teachers can guide the writing, initially giving focus on what is to be included. These are more fully discussed in Chapter 4.
- **Concept maps**—Students graphically construct relationships of topic. This could be done as a pre-evaluation and then upon completion to show growth of students' understanding. Concept maps may also demonstrate students' misconceptions (Roth, 1992).
- **Drawings**—Drawings done before an activity or lesson can reveal students' initial perceptions and then be compared to final drawings for changes of understanding.
- **Portfolios**—Long-term documentation of students' classroom work is kept in folders or files. Students and teacher have input creating a partnership in the assessment process, and the contents of the portfolio also allow the teacher to assess students' growth. Students can reflect on their work (Paulson & Paulson, 1990). Additionally, portfolios can be vehicles for communication between parents and teacher (Nickelson, 2004).

STANDARDS

When compared with other nations, the United States lags behind in the understanding of science knowledge (Third International Mathematics and Science Study, 1996). Because of federal requirements related to the No Child Left Behind Act, many contemporary reform ideas in science education are reaching practitioners. These ideas are based on advances in cognitive psychology and human development research (Rakow, 1998; Wandersee et al., 1998). The ideas have promoted much debate by those who wish to contest the epistemological basis for learning science present in those reports (Crane, 1998). As a result, the *National Science Education Standards* were developed to provide curriculum and instructional guidelines for quality science education for all students. States have implemented their own standards based on these national standards. Standards describe what students and teachers need to know in order to promote a science-literate society. While some seem intimidated by the standards, most were already being addressed in curriculum before they became formal standards (Rakow, 1998). It is essential that teachers and

curriculum coordinators are aware of standards to ensure that standards are met (NRC, 1996).

SUMMARY

Standards are written for teachers to encourage students to become proficient by setting their own personal goals under the guidance of a skilled and knowledgeable teacher. As students mature, their capacity to inquire changes, becoming more sophisticated (Rakow, 1998). Students are more apt to understand the natural world if they are given opportunities to work directly with natural phenomena. They are also more likely to be interested in curriculum if it relates to their own lives. By using their senses to observe and by using scientific instruments, students are capable of extending the power of their senses (National Science Board, 1991) and learn science content more effectively. A student's success is directly related to how the student sees himself or herself as a learner and how the student defines success. Success in science is also determined by how well the curriculum matches the needs of students—developmentally, culturally, and academically (Chamberlain, 2003). Inquiry-based science can be a vehicle to meet the challenges of diversity among students and the need for science literacy in a changing society. The task is not easy, but it is worth the effort.

Whether the 5E or GLM lesson design is used by teachers to frame inquiry lessons in science classrooms, the goals include science literacy and understanding. Throughout this book, the examples provided can be adapted to either model. As you continue reading the following chapters, connections to the proposals of the *National Science Education Standards* (NRC, 1996) may become apparent as we ask you to consider different approaches to teaching science content.

Figure 1.4 Changing Emphases in Science Education

Less emphasis on:

- Memorizing facts and information
- Isolated learning of subject matter disciplines (physical, life, earth science)
- Separating science knowledge and process
- Covering many science topics in a course
- Implementing inquiry as a set of processes
- Activities to demonstrate and verify science content
- One class period investigations
- Emphasis on process skills rather than the overall picture
- Looking for one right answer
- Teacher providing answers
- Doing investigations without defending a conclusion
- Covering a large amount of material allowing for only a few investigations
- Private communication of students' ideas and conclusions to teacher

More emphasis on:

- Understanding science concepts and developing abilities of inquiry
- Integrating all aspects of science content
- Studying a few fundamental science concepts
- Investigative and analytical science questions
- Extended periods of time for investigation
- Allowing for the development or revisions of an explanation
- Communication of students' scientific explanations, ideas, and information
- Allowing more time for investigations in order for students to develop understanding
- Groups of students working together to solve problems
- Coordinating planning, teaching, and assessments

SOURCE: Adapted from National Science Education Standards, NRC, 1996.