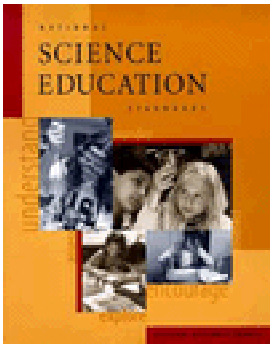
National Science Education Standards



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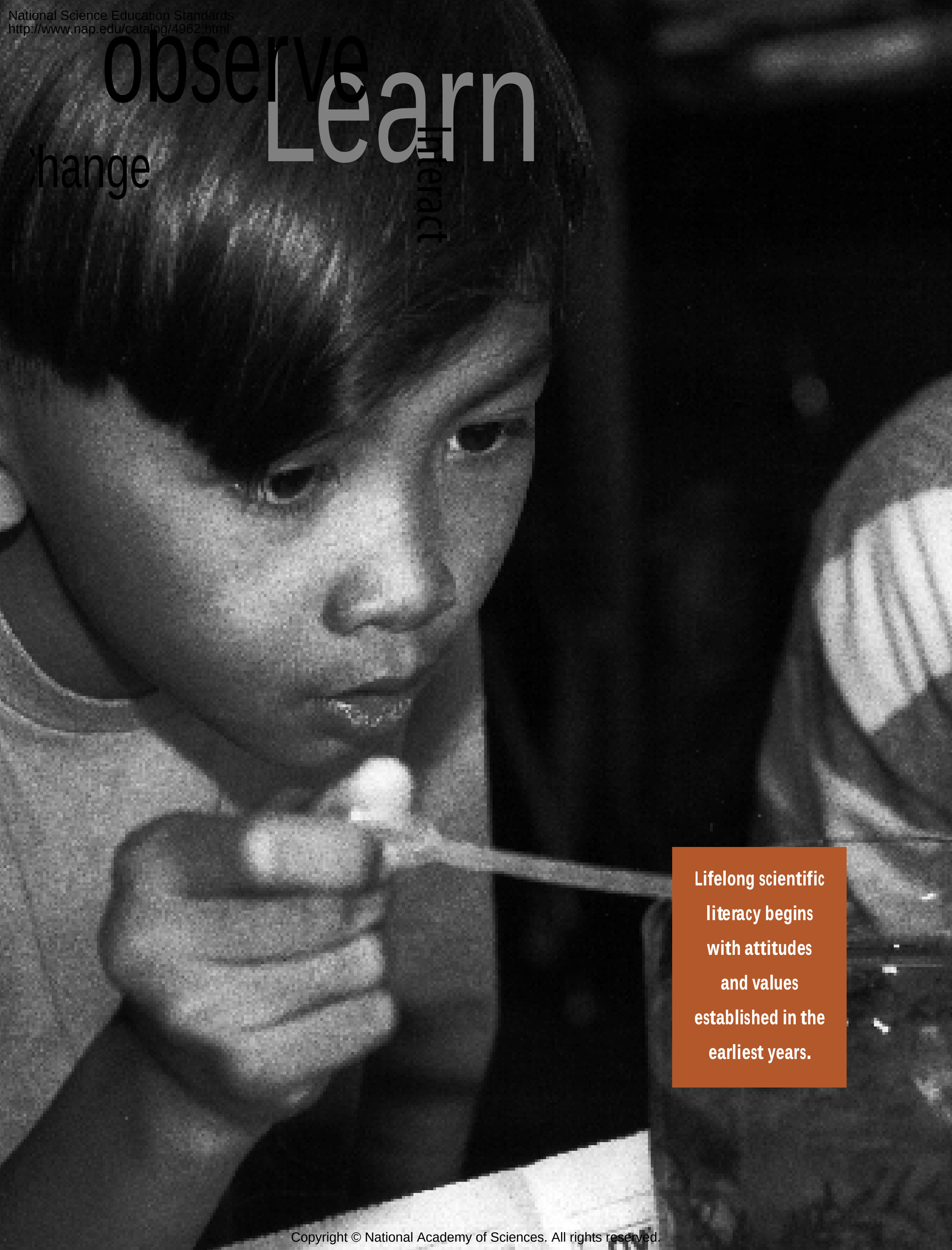
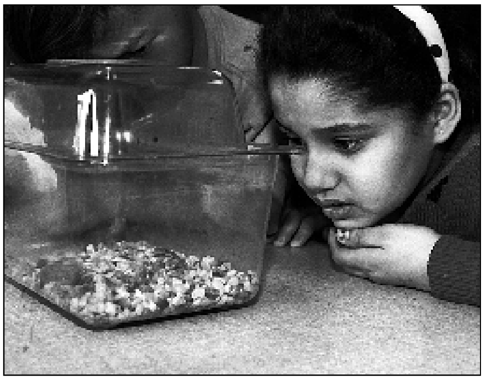


Lifelong scientific literacy begins with attitudes and values established in the earliest years.

Principles and Definitions



The development of the *National Science Education Standards* was guided by certain principles. Those principles are

- **Science is for all students.**
- **Learning science is an active process.**
- **School science reflects the intellectual and cultural traditions that characterize the practice of contemporary science.**
- **Improving science education is part of systemic education reform.**

Tension inevitably accompanied the incorporation of these principles into standards. Tension also will arise as the principles are applied in school science programs and classrooms. The following discussion elaborates upon the principles and clarifies some of the associated difficulties.

See Teaching Standard B, Assessment Standard D, Program Standard E, and System Standard E

SCIENCE IS FOR ALL STUDENTS. This principle is one of equity and excellence. Science in our schools must be for all students: All students, regardless of age, sex, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science, should have the opportunity to attain high levels of scientific literacy.

The *Standards* assume the inclusion of all students in challenging science learning opportunities and define levels of understanding and abilities that all should develop. They emphatically reject any situation in science education where some people—for example, members of certain populations—are discouraged from pursuing science and excluded from opportunities to learn science.

Excellence in science education embodies the ideal that all students can achieve understanding of science if they are given the opportunity. The content standards describe outcomes—what students should understand and be able to do, not the manner in which students will achieve those outcomes. Students will achieve understanding in different ways and at different depths as they answer questions about the natural world. And students will achieve the outcomes at different rates, some sooner than others. But all should have opportunities in the form of multiple experiences over several years to develop the understanding associated with the *Standards*.

See Program Standard D and System Standard D

The commitment to science for all students has implications for both program design and the education system. In particular, resources must be allocated to ensure that the *Standards* do not exacerbate the differences in opportunities to learn that currently exist between advantaged and disadvantaged students.

See Teaching Standard B

LEARNING SCIENCE IS AN ACTIVE PROCESS. Learning science is something students do, not something that is done to them. In learning science, students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others.

In the *National Science Education Standards*, the term “active process” implies physical and mental activity. Hands-on activities are not enough—students also must have “minds-on” experiences. Science teaching must involve students in inquiry-oriented investigations in which they interact with their teachers and peers. Students establish connections between their current knowledge of science and the scientific knowledge found in many sources; they apply science content to new questions; they engage in problem solving, planning, decision making, and group discussions; and they experience assessments that are consistent with an active approach to learning.

Learning science is something students do, not something that is done to them.

Emphasizing active science learning means shifting emphasis away from teachers presenting information and covering science topics. The perceived need to include all the topics, vocabulary, and information in textbooks is in direct conflict with the central goal of having students learn scientific knowledge with understanding.

SCHOOL SCIENCE REFLECTS THE INTELLECTUAL AND CULTURAL TRADITIONS THAT CHARACTERIZE THE PRACTICE OF CONTEMPORARY SCIENCE. To develop a

Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture.

rich knowledge of science and the natural world, students must become familiar with modes of scientific inquiry, rules of evidence, ways of formulating questions, and ways of proposing explanations. The relation of science to mathematics and to technology and an understanding of the nature of science should also be part of their education.

An explicit goal of the *National Science Education Standards* is to establish high levels of scientific literacy in the United States. An essential aspect of scientific literacy is greater knowledge and understanding of science subject matter, that is, the knowledge specifically associated with the physical, life, and earth sciences. Scientific literacy also includes understanding the nature of science, the scientific enterprise, and the role of science in society and personal life. The *Standards* recognize that many individuals have contributed to the traditions of science and that, in historical perspective, science has been practiced in many different cultures.

See definition of science literacy

Science is a way of knowing that is characterized by empirical criteria, logical argument, and skeptical review. Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture.

IMPROVING SCIENCE EDUCATION IS PART OF SYSTEMIC EDUCATION REFORM. National goals and standards contribute to state and local systemic initiatives, and the national and local reform efforts complement each other. Within the larger education system, we can view science education as a subsystem with both shared and unique components. The components include students and teachers; schools with principals, superintendents, and school boards; teacher education programs in colleges and universities; textbooks and textbook publishers; communities of parents and of students; scientists and engineers; science museums; business and industry; and legislators. The *National Science Education Standards* provide the unity of purpose and vision required to focus all of those components effectively on the important task of improving science education for all students, supplying a consistency that is needed for the long-term changes required.

Perspectives and Terms in the *National Science Education Standards*

Although terms such as "scientific literacy" and "science content and curriculum" frequently appear in education discussions and in the popular press without definition, those terms have a specific meaning as used in the *National Science Education Standards*.

SCIENTIFIC LITERACY. Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the *National Science Education Standards*, the content standards define scientific literacy.

Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

Individuals will display their scientific literacy in different ways, such as appropriately using technical terms, or applying scientific concepts and processes. And individuals often will have differences in literacy in different domains, such as more understanding of life-science concepts and words, and less understanding of physical-science concepts and words.

Scientific literacy has different degrees and forms; it expands and deepens over a lifetime, not just during the years in school. But the attitudes and values established toward science in the early years will shape a person's development of scientific literacy as an adult.

CONTENT AND CURRICULUM. The content of school science is broadly defined to include specific capacities, understandings, and abilities in science. The content standards are not a science curriculum. Curriculum is the way content is delivered: It includes the structure, organization, balance, and presentation of the content in the classroom.

See Program Standard B

The content standards are not science lessons, classes, courses of study, or school science programs. The components of the science content described can be organized with a variety of emphases and perspectives into many different curricula. The organizational schemes of the content standards are not intended to be used as curricula;

instead, the scope, sequence, and coordination of concepts, processes, and topics are left to those who design and implement curricula in science programs.

Curricula often will integrate topics from different subject-matter areas—such as life and physical sciences—from different content standards—such as life sciences and science in personal and social perspectives—and from different school subjects—such as science and mathematics, science and language arts, or science and history.

Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed.

KNOWLEDGE AND UNDERSTANDING. Implementing the *National Science Education Standards* implies the acquisition of scientific knowledge and the development of understanding. Scientific knowledge refers to facts, concepts, principles, laws, theories, and models and can be acquired in many ways. Understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events. Understanding encompasses the ability to use knowledge, and it entails the ability to distinguish between what is and what is not a scientific idea. Developing understanding presupposes that students are actively engaged with the ideas of science and have many experiences with the natural world.

INQUIRY. Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.

See Content Standards A & G (all grade levels)

See Teaching Standard B

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.

Although the *Standards* emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry. Attaining the understandings and abilities described in Chapter 6 cannot be achieved by any single teaching strategy or learning experience.

SCIENCE AND TECHNOLOGY. As used in the *Standards*, the central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs. Technology as design is included in the *Standards* as parallel to science as inquiry.

Technology and science are closely related. A single problem often has both scientific and technological aspects. The need to answer questions in the natural world drives the development of technological products; moreover, technological needs can drive scientific research. And technological products, from pencils to computers, provide tools that promote the understanding of natural phenomena.

See Content Standard E (all grade levels)

The use of "technology" in the *Standards* is not to be confused with "instructional technology," which provides students and teachers with exciting tools—such as computers—to conduct inquiry and to understand science.

Additional terms important to the *National Science Education Standards*, such as "teaching," "assessment," and "opportunity to learn," are defined in the chapters and sections where they are used. Throughout, we have tried to avoid using terms that have different meanings to the many different groups that will be involved in implementing the *Standards*.

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Although open exploration is useful for students when they encounter new materials and phenomena, teachers need to intervene to focus and challenge the students, or the exploration might not lead to understanding. Premature intervention deprives students of the opportunity to confront problems and find solutions, but intervention that occurs too late risks student frustration. Teachers also must decide when to challenge students to make sense of their experiences: At these points, students should be asked to explain, clarify, and critically examine and assess their work.

ORCHESTRATE DISCOURSE AMONG STUDENTS ABOUT SCIENTIFIC IDEAS. An important stage of inquiry and of student science learning is the oral and written discourse that focuses the attention of students on how they know what they know and how their knowledge connects to larger ideas, other domains, and the world beyond the classroom. Teachers directly support and guide this discourse in two ways: They require students to record their work—teaching the necessary skills as appropriate—and they promote many different forms of communication (for example, spoken, written, pictorial, graphic, mathematical, and electronic).

Using a collaborative group structure, teachers encourage interdependency among group members, assisting students to work together in small groups so that all participate in sharing data and in developing group reports. Teachers also give groups opportunities to make presentations of their work and to engage with their classmates in explaining, clarifying, and justifying what they have learned. The teacher's role in these small and larger group interactions is to listen, encourage broad participation, and judge how to guide discussion—determining ideas to follow, ideas to question, information to provide, and connections to make. In the hands of a skilled teacher, such group work leads students to recognize the expertise that different members of the group bring to each endeavor and the greater value of evidence and argument over personality and style.

CHALLENGE STUDENTS TO ACCEPT AND SHARE RESPONSIBILITY FOR THEIR OWN LEARNING. Teachers make it clear that each student must take responsibility for his or her work. The teacher also creates opportunities for students to take responsibility for their own learning, individually and as members of groups. Teachers do so by supporting student ideas and questions and by encouraging students to pursue them. Teachers give individual students active roles in the design and implementation of investigations, in the preparation and presentation of student work to their peers, and in student assessment of their own work.

RECOGNIZE AND RESPOND TO STUDENT DIVERSITY AND ENCOURAGE ALL STUDENTS TO PARTICIPATE FULLY IN SCIENCE LEARNING. In all aspects of science learning as envisioned by the *Standards*, skilled teachers recognize the diversity in their classes and organize the classroom so that all students have the opportunity to participate fully. Teachers monitor the participation of all students, carefully determining, for instance, if all members of a collaborative group are working with materials or if one student is making all the decisions. This monitoring can be particularly important in classes of diverse students, where social issues of status and authority can be a factor.

Teachers of science orchestrate their classes so that all students have equal opportunities to participate in learning activities. Students with physical disabilities might require modified equipment; students with limited English ability might be encouraged to use their own language as well as English and to use forms of presenting data such as pictures and graphs that require less language proficiency; students with learning disabilities might need more time to complete science activities.

Teachers who are enthusiastic, interested, and who speak of the power and beauty of scientific understanding instill in their students some of those same attitudes.

ENCOURAGE AND MODEL THE SKILLS OF SCIENTIFIC INQUIRY, AS WELL AS THE CURIOSITY, OPENNESS TO NEW IDEAS, AND SKEPTICISM THAT CHARACTERIZE SCIENCE. Implementing the recommendations above requires a range of actions based on careful assessments of students, knowledge of science, and a repertoire of science-teaching strategies. One aspect of the teacher's role is less tangible: teachers are models for the students they teach. A teacher who engages in inquiry with students models the skills needed for inquiry. Teachers who exhibit enthusiasm and interest and who speak to the power and beauty of scientific understanding instill in their students some of those same attitudes toward science. Teachers whose actions demonstrate respect for differing ideas, attitudes, and values support a disposition fundamental to science and to science classrooms that also is important in many everyday situations.

The ability of teachers to do all that is required by Standard B requires a sophisticated set of judgments about science, students, learning, and teaching. To develop these judgments, successful teachers must have the opportunity to work with colleagues to discuss, share, and increase their knowledge. They are also more likely to succeed if the fundamental beliefs about students and about learning are shared across their school community in all learning domains. Successful implementation of this vision of science teaching and learning also requires that the school and district provide the necessary resources, including time, science materials, professional development opportunities, appropriate numbers of students per teacher, and appropriate schedules. For example, class periods must be long enough to enable the type of inquiry teaching described here to be achieved.

TEACHING STANDARD C: Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers

- **Use multiple methods and systematically gather data about student understanding and ability.**

- **Analyze assessment data to guide teaching.**
- **Guide students in self-assessment.**
- **Use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice.**
- **Use student data, observations of teaching, and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.**

The word "assessment" is commonly equated with testing, grading, and providing feedback to students and parents. However, these are only some of the uses of assessment data. Assessment of students and of teaching—formal and informal—provides teachers with the data they need to make the many decisions that are required to plan and conduct their teaching. Assessment data also provide information for communicating about student progress with individual students and with adults, including parents, other teachers, and administrators.

USE MULTIPLE METHODS AND SYSTEMATICALLY GATHER DATA ON STUDENT UNDERSTANDING AND ABILITY. During the ordinary operation of a class, information about students' understanding of science is needed almost continuously. Assessment tasks are not afterthoughts to instructional planning but are built into the design of the teaching. Because assessment information is a powerful tool for monitoring the development of student understanding, modifying activities, and promoting student self-reflection, the effective teacher of science carefully selects and uses assessment tasks that are also good learning experiences. These assessment tasks focus on important content and performance goals and provide students with an opportunity to demonstrate their understanding and ability to conduct science. Also, teachers use many strategies to gather and interpret the large amount of information about student understanding of science that is present in thoughtful instructional activities.

Classroom assessments can take many forms. Teachers observe and listen to students as they work individually and in groups. They interview students and require formal performance tasks, investigative reports, written reports, pictorial work, models, inventions, and other creative expressions of understanding. They examine portfolios of student work, as well as more traditional paper-and-pencil tests. Each mode of assessment serves particular purposes and particular students. Each has particular strengths and weaknesses and is used to gather different kinds of information about student understanding and ability. The teacher of science chooses the form of the assessment in relationship to the particular learning goals of the class and the experiences of the students.

ANALYZE ASSESSMENT DATA TO GUIDE TEACHING. Analysis of student assessment data provides teachers with knowledge to meet the needs of each student. It gives them indicators of each student's current understanding, the nature of each student's thinking, and the origin of what each knows. This knowledge leads to decisions about individual teacher-student interactions, to modifications of learning activities to meet diverse student needs and learning approaches, and

See *Assessment in Science Education* in Chapter 5

Science Olympiad

This example illustrates the close relationship between teaching and assessment. The assessment tasks are developmentally appropriate for young children, including recognition of students' physicals skills and cognitive abilities. The titles in this example (e.g., "Science Content") emphasize some important components of the assessment process. As students move from station to station displaying their understanding and ability in science, members of the community evaluate the students' science achievement and can observe that the students have had the opportunity to learn science. An Olympiad entails extensive planning, and even when the resources are common and readily available, it takes time to design and set up an Olympiad.

[This example highlights some elements of Teaching Standards A, C,and D; Assessment Standards A, B, C, and E; K-4 Content Standards A and B; Program Standards D and F; and System Standards D and G.]

SCIENCE CONTENT: The K-4 Content Standard for Science as Inquiry sets the criterion that students should be able to use simple equipment and tools to gather data. In this assessment exercise, four tasks use common materials to allow students to demonstrate their abilities.

ASSESSMENT ACTIVITY: Students make and record observations.

ASSESSMENT TYPE: Performance,public, authentic, individual.

ASSESSMENT PURPOSE: This assessment activity provides the teacher with information about student achievement. That information can be used to assign grades to students and to make promotion decisions. By involving the community, parents, and older siblings in the assessment process, the activity increases the community's understanding of and support for the elementary school science program.

DATA: Student records in science laboratory notebooks
Teachers' observations of students
Community members' observations of students

CONTEXT: Assessment activities of this general form are appropriate as an end-of-the-year activity for grades 1-4. The public performance involves students engaging in inquiry process skills at several stations located in and around the science classroom. Parents, local business persons, community leaders, and faculty from higher education act as judges of student performance. Benefits to the students and to the school and the science program, such as increased parental and community involvement,are well worth the costs of the considerable planning and organization on the part of the teacher. Planning includes 1) selecting appropriate tasks, 2) collecting necessary equipment, 3) making task cards, 4) checking the equipment, 5) obtaining and training judges, and 6) preparing students for public performance.

Assessment Exercise:

STATION A. Measuring Wind Speed

a. Equipment

1. Small, battery-operated fan
2. Wind gauge
3. Table marked with a letter-by-number grid
4. Task cards with directions

b. Task

1. Place the wind gauge at position D-4 on the grid.
2. Place the fan at position G-6 facing the wind gauge.
3. Turn the fan on to medium speed.
4. Record the wind speed and direction in your laboratory notebook.

STATION B. Rolling Cylinders

a. Equipment

1. Four small clear plastic cylinders—one filled with sand, one empty, one 1/4 filled with sand, and one 1/2 filled with sand
2. Adjustable incline
3. Strips of colored paper of various lengths
4. Task cards with directions

b. Task 1

1. Roll each cylinder down the incline.
2. Describe the motion of the cylinders and their relation to each other.

c. Task 2

1. Place the blue strip of paper at the bottom of the incline.
2. Select one of the cylinders, and adjust the angle of the incline so that the cylinder consistently rolls just to the end of the blue strip.

STATION C. Comparing Weights

a. Equipment

1. Balance
2. Collections of objects in bags (Teachers select objects that have irregular shapes and are made of materials of different densities so that volume and mass are not correlated.)
3. Task card with directions

b. Task

1. Arrange the objects in one bag in order of their weights.
2. Describe how you arranged the objects.

STATION D. Measuring Volumes

a. Equipment

1. Graduated cylinder, calibrated in half cubic centimeters.
2. Numbered stones of various colors, shapes, and sizes but small enough to fit into the cylinder.
3. Several containers marked A, B, C, and D.
4. Task cards with directions

b. Task 1

1. Measure the volume of container A.
2. Record your measurement in your laboratory notebook.

c. Task 2

1. Measure the volume of the stone marked 1.
2. Record your measurement in your laboratory notebook.

EVALUATING STUDENT PERFORMANCE

Aspects of a student's performance and criteria for evaluation include:

PERFORMANCE INDICATOR	EVIDENCE
Following directions	Student follows the directions.
Measuring and recording data	Measurements are reasonably accurate and include correct units
Planning	Student organizes the work: (1) observations of the rolling cylinders are sequenced logically, (2) student selects the cylinder with the most predictable motion for Part 2 of the rolling-cylinders task,(3) student records the weights of the objects before attempting to order them in the ordering-by-weight task.
Elegance of approach	Student invents a sophisticated way of collecting, recording, or reporting observations.
Evidence of reflection	Student comments on observations in ways that indicate that he/she is attempting to find patterns and causal relationships.
Quality of observations	Observations are appropriate to the task, complete, accurate,and have some basis in experience or scientific understanding.
Behavior in the face of adversity	The student seeks help and does not panic if sand or water is spilled or glassware is broken, but proceeds to clean up, get replacements,and continue the task.

to the design of learning activities that build from student experience, culture, and prior understanding.

See *Improving Classroom Pratice* in Chapter 5

GUIDE STUDENTS IN SELF-ASSESSMENT. Skilled teachers guide students to understand the purposes for their own learning and to formulate self-assessment strategies. Teachers provide students with opportunities to develop their abilities to assess and reflect on their own scientific accomplishments. This process provides teachers with additional perspectives on student learning, and it deepens each student's

Skilled teachers guide students to understand the purposes for their own learning and to formulate self-assessment strategies.

understanding of the content and its applications. The interactions of teachers and students concerning evaluation criteria helps students understand the expectations for their work, as well as giving them experience in applying standards of scientific practice to their own and others' scientific efforts. The internalization of such standards is critical to student achievement in science.

Involving students in the assessment process does not diminish the responsibilities of the teacher—it increases them. It requires teachers to help students develop skills in self-reflection by building a learning environment where students review each other's work, offer suggestions, and challenge mistakes in investigative processes, faulty reasoning, or poorly supported conclusions.

USE STUDENT DATA, OBSERVATIONS OF TEACHING, AND INTERACTIONS WITH COLLEAGUES TO REFLECT ON AND IMPROVE TEACHING PRACTICE. In the science education envisioned by the *Standards*, teachers of science approach their teaching in a spirit of inquiry—assessing, reflecting on, and learning from their own practice. They seek to understand which plans, decisions, and actions are effective in helping students and which are not. They ask and answer such questions as: "Why is this content important for this group of students at this stage of their development? Why did I select these particular learning activities? Did I choose good examples? How do the activities tie in with student needs and interests? How do they build on what students already know? Do they evoke the level of reasoning that I wanted? What evidence of effect on students do I expect?"

As teachers engage in study and research about their teaching, they gather data from classroom and external assessments of student achievement, from peer observations and supervisory evaluations, and from self-questioning. They use self-reflection and discussion with peers to understand more fully what is happening in the classroom and to explore strategies for improvement. To engage in reflection on teaching, teachers must have a structure that guides and encourages it—a structure that provides opportunities to have formal and informal dialogues about student learning and their science teaching practices in forums with peers and others; opportunities to read and discuss the research literature about science

See Program Standard F

content and pedagogy with other education professionals; opportunities to design and revise learning experiences that will help students to attain the desired learning; opportunities to practice, observe, critique, and analyze effective teaching models and the challenges of implementing exemplary strategies; and opportunities to build the skills of self-reflection as an ongoing process throughout each teacher's professional life.

USE STUDENT DATA, OBSERVATIONS OF TEACHING, AND INTERACTIONS WITH COLLEAGUES TO REPORT STUDENT ACHIEVEMENT AND OPPORTUNITIES TO LEARN TO STUDENTS, TEACHERS, PARENTS, POLICY MAKERS, AND THE GENERAL PUBLIC. Teachers have the obligation to report student achievement data to many individuals and agencies, including the students and their parents, certification agencies, employers, policy makers, and taxpayers. Although reports might include grades, teachers might also prepare profiles of student achievement. The opportunity that students have had to learn science is also an essential component of reports on student achievement in science understanding and ability.

TEACHING STANDARD D: 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

See Program Standard D and System Standard D

- **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.**

Time, space, and materials are critical components of an effective science learning environment that promotes sustained inquiry and understanding. Creating an adequate environment for science teaching is a shared responsibility. Teachers lead the way in the design and use of resources, but school administrators, students, parents,

Teachers of science need regular, adequate space for science.

and community members must meet their responsibility to ensure that the resources are available to be used. Developing a schedule that allows time for science investigations needs the cooperation of all in the school; acquiring materials requires the appropriation of funds; maintaining scientific equipment is the shared responsibility of students and adults alike; and designing appropriate use of the scientific institutions and resources in the local community requires the participation of the school and those institutions and individuals.

This standard addresses the classroom use of time, space, and resources—the ways in which teachers make decisions about how to design and manage them to create the best possible opportunities for students to learn science.

STRUCTURE THE TIME AVAILABLE SO THAT STUDENTS ARE ABLE TO ENGAGE IN EXTENDED INVESTIGATIONS. Building scientific understanding takes time on a daily basis and over the long term. Schools must restructure schedules so that teachers can use blocks of time, interdisciplinary strategies,and field experiences to give students many opportunities to engage in serious scientific investigation as an integral part of their science learning. When considering how to structure available time, skilled teachers realize that students need time to try out ideas, to make mistakes, to ponder, and to discuss with one another. Given a voice in scheduling, teachers plan for adequate blocks of time for students to set up scientific equipment and carry out experiments, to go on field trips, or to reflect and share with each other. Teachers make time for students to work in varied groupings—alone, in pairs,in small groups, as a whole class—and on varied tasks, such as reading, conducting experiments, reflecting, writing, and discussing.

See Program Standard F

CREATE A SETTING FOR STUDENT WORK THAT IS FLEXIBLE AND SUPPORTIVE OF SCIENCE INQUIRY. The arrangement of available space and furnishings in the classroom or laboratory influences the nature of the learning that takes place. Teachers of science need regular, adequate space for science. They plan the use of this space to allow students to work safely in groups of various sizes at various tasks, to maintain their work in progress, and to display their results. Teachers also provide students with the opportunity to contribute their ideas about use of space and furnishings.

ENSURE A SAFE WORKING ENVIRONMENT. Safety is a fundamental concern in all experimental science. Teachers of science must know and apply the necessary safety regulations in the storage, use,and care of the materials used by students. They adhere to safety rules and guidelines that are established by national organizations such as the American Chemical Society and the Occupational Safety and Health Administration, as well as by local and state regulatory agencies. They work with the school and district to ensure implementation and use of safety guidelines for which they are responsible, such as the presence of safety equipment and an appropriate class size. Teachers also teach students how to engage safely in investigations inside and outside the classroom.

See Program Standard D

Effective science teaching depends on the availability and organization of materials, equipment, media, and technology.

MAKE THE AVAILABLE SCIENCE TOOLS, MATERIALS, MEDIA, AND TECHNOLOGICAL RESOURCES ACCESSIBLE TO STUDENTS. Effective science teaching depends on the availability and organization of materials, equipment, media, and technology. An effective science learning environment requires a broad range of basic scientific materials, as well as specific tools for particular topics and learning experiences.

See Program Standard D and System Standard D

Teachers must be given the resources and authority to select the most appropriate materials and to make decisions about when, where, and how to make them accessible. Such decisions balance safety, proper use, and availability with the need for students to participate actively in designing experiments, selecting tools, and constructing apparatus, all of which are critical to the development of an understanding of inquiry.

It is also important for students to learn how to access scientific information from books, periodicals, videos, databases, electronic communication, and people with expert knowledge. Students are also taught to evaluate and interpret the information they have acquired through those resources. Teachers provide the opportunity for students to use contemporary technology as they develop their scientific understanding.

IDENTIFY AND USE RESOURCES OUTSIDE THE SCHOOL. The classroom is a limited environment. The school science program must extend beyond the walls of the school to the resources of the community. Our nation's communities have many specialists, including those in transportation, health-care delivery, communications, computer technologies, music, art, cooking, mechanics, and many other fields that have scientific aspects. Specialists often are available as resources for classes and for individual students. Many communities have access to science centers and museums, as well as to the science communities in higher education, national laboratories, and industry; these can contribute greatly to the understanding of science and encourage students to further their interests outside of school. In addition, the physical environment in and around the school can be used as a living laboratory for the study of natural phenomena. Whether the school is located in a densely populated urban area, a sprawling suburb, a small town, or a rural area, the environment can and should be used as a resource for science study. Working with others in their school and with the community, teachers build these resources into their work with students.

The school science program must extend beyond the walls of the school to include the resources of the community.

ENGAGE STUDENTS IN DESIGNING THE LEARNING ENVIRONMENT. As part of challenging students to take responsibility for their learning, teachers involve them in the design and management of the learning environment. Even the youngest students can and should participate in discussions and decisions about using time and space for work. With this sharing comes responsibility for care of space and resources. As students pursue their inquiries, they need access to resources and a voice in determining what is needed. The more independently students can access what they need, the more they can take responsibility for their own work. Students are also invaluable in identifying resources beyond the school.

TEACHING STANDARD E:

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 the 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.**

The focus of this standard is the social and intellectual environment that must be in place in the classroom if all students are to succeed in learning science and have the opportunity to develop the skills and dispositions for life-long learning. Elements of other standards are brought together by this standard to highlight the importance of the community of learners and what effective teachers do to foster its development. A community approach enhances learning: It helps to advance understanding, expand students' capabilities for investigation, enrich the questions that guide inquiry, and aid students in giving meaning to experiences.

See Teaching Standard B and Program Standard F

An assumption of the *Standards* is that all students should learn science through full participation and that all are capable of making meaningful contributions in science classes. The nature of the community in which students learn science is critical to making this assumption a reality.

DISPLAY AND DEMAND RESPECT FOR THE DIVERSE IDEAS, SKILLS, AND EXPERIENCES OF ALL STUDENTS.
Respect for the ideas, activities, and thinking of all students is demonstrated by what teachers say and do, as well as by the flexibility with which they respond to student interests, ideas, strengths, and needs. Whether adjusting an activity to reflect the cultural background of particular students, providing resources for a small group to pursue an interest, or suggesting that an idea is valuable but cannot be pursued at the moment, teachers model what it means to respect and value the views of others. Teachers teach respect explicitly by focusing on their own and students' positive interactions, as well as confronting disrespect, stereotyping, and prejudice whenever it occurs in the school environment.

Science is a discipline in which creative and sometimes risky thought is important. New ideas and theories often are the result of creative leaps. For students to understand this aspect of science and be willing to express creative ideas, all of the members of the learning community must support and respect a diversity of experience, ideas, thought, and expression. Teachers work with students to develop an environment in which students feel safe in expressing ideas.

See Content Standards A & G (all grade levels)

ENABLE STUDENTS TO HAVE A SIGNIFICANT VOICE IN DECISIONS ABOUT THE CONTENT AND CONTEXT OF THEIR WORK AND GIVE STUDENTS SIGNIFICANT RESPONSIBILITY FOR THE LEARNING OF ALL MEMBERS OF THE COMMUNITY. A community of science learners is one in which students develop a sense of purpose and the ability to assume

Musical Instruments

This example includes a description of teaching and an assessment task, although the assessment task is indistinguishable from the teaching activity. The example begins with the teachers at King School working as a team involved in school reform. The team naturally builds on previous efforts; for example, the technology unit is modified from an existing unit. Other indicators that King School is working toward becoming a community of learners is the availability of older students to help the younger students with tasks beyond their physical abilities and the decision for one class to give a concert for another class. In her planning, Ms. R. integrates the study of the science of sound with the technology of producing sound. Recognizing the different interests and abilities of the students, Ms. R. allows students to work alone or in groups and plans a mixture of whole-class discussions and work time. She encourages the students in planning and communicating their designs. She imposes constraints on materials and time.

[This example highlights some elements of all of the Teaching Standards; Assessment Standard A; K-4 Content Standards B, E, and F; and Program Standards A, D, and E.]

The King School was reforming its science curriculum. After considerable research into existing curriculum materials and much discussion, the team decided to build a technology piece into some of the current science studies. The third-grade teacher on the team, Ms. R., said that she would like to work with two or three of her colleagues on the third-grade science curriculum. They selected three topics that they knew they would be teaching the following year: life cycles, sound, and water.

Ms. R. chose to introduce technology as part of the study of sound. That winter, when the end of the sound study neared, Ms. R. was ready with a new culminating activity—making musical instruments. She posed a question to the entire class: Having studied sound for almost 6 weeks, could they design and make musical instruments that would produce sounds for entertainment? Ms. R. had collected a variety of materials, which she now displayed on a table, including boxes, tubes, string, wire, hooks, scrap wood, dowels, plastic, rubber, fabric, and more. The students had been working in groups of four during the sound study, and Ms. R. asked them to gather into those groups to think about the kinds of instruments they would like to make. Ms. R. asked the students to think particularly about what they knew about sound, what kind of sound they would like their instruments to make, and what kind of instrument it would be. How would the sound be produced? What would make the sound? She suggested they might want to look at the materials she had brought in, but they could think about other materials too.

Ms. R. sent the students to work in their groups. Collaborative work had been the basis of most of the science inquiry the students had done; for this phase, Ms. R. felt that the students should work together to discuss and share ideas, but she suggested that each student might want to have an instrument at the end to play and to take home.

As the students began to talk in their groups, Ms. R. added elements to the activity. They would have only the following 2 weeks to make their instruments. Furthermore, any materials they needed beyond what was in the boxes had to be materials that were readily available and inexpensive.

Ms. R. knew that planning was a challenge for these third graders. She moved among groups, listening and adding comments. When she felt that discussions had gone as far as they could go, she asked each group to draw a picture of the instruments the children thought they would like to make, write a short piece on how they thought they would make them, and make a list of the materials that they would need. Ms. R. made a list of what was needed, noted which children and which groups might profit from discussing their ideas with one another, and suggested that the children think about their task, collect materials if they could, and come to school in the next week prepared to build their instruments.

Ms. R. invited several sixth graders to join the class during science time the following week, knowing that the third grade students might need their help in working with the materials. Some designs were simple and easy to implement; e.g., one group was making a rubber-band player by stretching different widths and lengths of rubber bands around a plastic gallon milk container with the top cut off. Another group was making drums of various sizes using some thick cardboard tubes and pieces of thin rubber roofing material. For many, the designs could not be translated into reality, and much change and trial and error ensued. One group planned to build a guitar and designed a special shape for the sound box, but after the glued sides of their original box collapsed twice, the group decided to use the wooden box that someone had added to the supply table. In a few cases, the original design was abandoned, and a new design emerged as the instrument took shape.

At the end of the second week, Ms. R. set aside 2 days for the students to reflect on what they had done individually and as a class. On Friday, they were once again to draw and write about their instruments. Where groups had worked together on an instrument, one report was to be prepared. On the next Monday, each group was to make a brief presentation of the instrument, what it could do, how the design came to be, and what challenges had been faced. As a final effort, the class could prepare a concert for the other third grades.

In making the musical instruments, students relied on the knowledge and understanding developed while studying sound, as well as the principles of design, to make an instrument that produced sound.

The assessment task for the musical instruments follows. The titles emphasize some important components of the assessment process.

SCIENCE CONTENT: The K-4 science content standard on science and technology is supported by the idea that students should be able to communicate the purpose of a design. The K-4 physical science standard is supported by the fundamental understanding of the characteristics of sound, a form of energy.

ASSESSMENT ACTIVITY: Students demonstrate the products of their design work to their peers and reflect on what the project taught them about the nature of sound and the process of design.

ASSESSMENT TYPE: This can be public, group, or individual, embedded in teaching.

ASSESSMENT PURPOSE: This activity assesses student progress toward understanding the purpose and processes of design. The information will be used to plan the next design activity. The activity also permits the teacher to gather data about understanding of sound.

DATA: Observations of the student performances.

CONTEXT: Third-grade students have just completed a design project. Their task is to present the product of their work to their peers and talk about what they learned about sound and design as a result of doing the project. This is a challenging task for third-grade students, and the teacher will have to provide considerable guidance to the groups of students as they plan their presentations. The following directions provide a framework that students can use to plan their presentations.

1. Play your instrument for the class.
2. Show the class the part of the instrument that makes the sound.
3. Describe to the class the purpose (function) that other parts of the instrument have.
4. Show the class how you can make the sound louder.
5. Show the class how you can change the pitch (how high or how low the sound is) of the sound.
6. Tell the class about how you made the instrument, including
    a. What kind of instrument did you want to make?
    b. How like the instrument you wanted to make is the one you actually made?
    c. Why did you change your design?
    d. What tools and materials did you use to make your instrument?
7. Explain why people make musical instruments.

EVALUATING STUDENT PERFORMANCE: Student understanding of sound will be revealed by understanding that the sound is produced in the instrument by the part of the instrument that *vibrates* (moves rapidly back and forth), that the *pitch* (how high or how low) can be changed by changing how rapidly the vibrating part moves, and the loudness can be changed by the force (how hard you pluck,tap, or blow the vibrating part) with which the vibrating part is set into motion. An average student performance would include the ability to identify the source of the vibration and ways to change either pitch or loudness in two directions (raise and lower the pitch of the instrument or make the instrument louder and softer) or change the pitch and loudness in one direction (make the pitch higher and the sound louder). An exemplary performance by a student would include not only the ability to identify the source of the vibration but also to change pitch and loudness in both directions.

Student understanding of the nature of technology will be revealed by the students' ability to reflect on why people make musical instruments—e.g., to improve the quality of life—as well as by their explanations of how they managed to make the instrument despite the constraints faced—that is,the ability to articulate why the conceptualization and design turned out to be different from the instrument actually made.

See *Improving Classroom Practice* in the Assessment Standards

responsibility for their learning. Teachers give students the opportunity to participate in setting goals, planning activities, assessing work,and designing the environment. In so doing, they give students responsibility for a significant part of their own learning, the learning of the group, and the functioning of the community.

See Content Standards A & G (all grade levels)

NURTURE COLLABORATION AMONG STUDENTS. Working collaboratively with others not only enhances the understanding of science,it also fosters the practice of many of the skills, attitudes,and values that characterize science. Effective teachers design many of the activities for learning science to require group work, not simply as an exercise, but as essential to the inquiry. The teacher's role is to structure the groups and to teach students the skills that are needed to work together.

STRUCTURE AND FACILITATE ONGOING FORMAL AND INFORMAL DISCUSSION BASED ON A SHARED UNDERSTANDING OF RULES OF SCIENTIFIC DISCOURSE. A fundamental aspect of a community of learners is communication. Effective communication requires a foundation of respect and trust among individuals. The ability to engage in the presentation of evidence, reasoned argument, and explanation comes from practice. Teachers encourage informal discussion and structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another.

See Content Standard A (all grade levels)

MODEL AND EMPHASIZE THE SKILLS, ATTITUDES, AND VALUES OF SCIENTIFIC INQUIRY. Certain attitudes, such as wonder, curiosity, and respect toward nature are vital parts of the science learning community. Those attitudes are reinforced when the adults in the community engage in their own learning and when they share positive attitudes toward science. Environments that promote the development of appropriate attitudes are supported by the school administration and a local community that

Effective teachers design many activities for group learning, not simply as an exercise but as collaboration essential to inquiry.

has taken responsibility for understanding the science program and supports students and teachers in its implementation.

Communities of learners do not emerge spontaneously; they require careful support from skillful teachers. The development of a community of learners is initiated on the first day that a new group comes together, when the teacher begins to develop with students a vision of the class environment they wish to form. This vision is communicated, discussed, and adapted so that all students come to share it and realize its value. Rules of conduct and expectations evolve as the community functions and takes shape over the weeks and months of the school year.

Some students will accommodate quickly; others will be more resistant because of the responsibilities required or because of discrepancies between their perceptions of what they should be doing in school and what is actually happening. The optimal environment for learning science is constructed by students and teachers together. Doing so requires time, persistence, and skill on everyone's part.

TEACHING STANDARD F:
Teachers of science actively participate in the ongoing planning and development of the school science program. In doing this, teachers

- **Plan and develop the school science program.**
- **Participate in decisions concerning the allocation of time and other resources to the science program.**
- **Participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.**

See Teaching Standard E

PLAN AND DEVELOP THE SCHOOL SCIENCE PROGRAM. The teaching in individual science classrooms is part of a larger system that includes the school, district, state, and nation. Although some teachers might choose involvement at the district, state,and national levels, all teachers have a professional responsibility to be active in some way as members of a science learning community at the school level, working with colleagues and others to improve and maintain a quality science program for all students. Many teachers already assume these responsibilities within their schools. However, they usually do so under difficult circumstances. Time for such activities is minimal, and involvement often requires work after hours. Resources are likely to be scarce as well. Furthermore, the authority to plan and carry out necessary activities is not typically in the hands of teachers. Any improvement of science education will require that the structure and culture of schools change to support the collaboration of the entire school staff with resources in the community in planning, designing, and carrying out new practices for teaching and learning science.

Although individual teachers continually make adaptations in their classrooms, the school itself must have a coherent program of science study for students. In the vision described by the *National Science Education Standards*, the teachers in the school and school district have a major role in designing that program, working together across science disciplines and grade levels, as well as within levels. Teachers of science must also work with their colleagues to coordinate and integrate the learning of science understanding and abilities with learning in other disciplines. Teachers working together determine expectations for student learning, as well as strategies for assessing, recording, and reporting student progress. They also work together to create a learning community within the school.

Although individual teachers continually make adaptations in their classrooms, the school itself must have a coherent program of science study for students.

PARTICIPATE IN DECISIONS CONCERNING THE ALLOCATION OF TIME AND OTHER RESOURCES TO THE SCIENCE PROGRAM. Time and other resources are critical elements for effective science teaching.

See Program Standard D

Teachers of science need to have a significant role in the process by which decisions are made concerning the allocation of time and resources to various subject areas. However, to assume this responsibility, schools and districts must provide teachers with the opportunity to be leaders.

See Professional Development Standard D

PARTICIPATE FULLY IN PLANNING AND IMPLEMENTING PROFESSIONAL GROWTH AND DEVELOPMENT STRATEGIES FOR THEMSELVES AND THEIR COLLEAGUES. Working as colleagues, teachers are responsible for designing and implementing the ongoing professional development opportunities they need to enhance their skills in teaching science, as well as their abilities to improve the science programs in their schools. Often they employ the services of specialists in science, children, learning, curriculum, assessment, or other areas of interest. In doing so, they must have the support of their school districts.

CHANGING EMPHASES

The *National Science Education Standards* envision change throughout the system. The teaching standards encompass the following changes in emphases:

LESS EMPHASIS ON	MORE EMPHASIS ON
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

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