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ABSTRACT

The National Research Council is coordinating the development of national standards for science education in grades K through 12. By the fall of 1994, National Science Education Standards will be completed and published. The standards will contain narrative descriptions of what all students should be able to do to engage and understand the natural world. The standards will address science curriculum, teaching, and assessment and will represent the consensus of teachers and other science educators, scientists, and the general public. Chapters include: (1) Introduction; (2) "The Goals of School Science Education"; (3) "The Character of School Science"; and (4) "The Standards for School Science." (PR)

National Committee on Science
Education Standards and Assessment

NATIONAL SCIENCE EDUCATION STANDARDS: A SAMPLER

National Research Council
Washington, D.C.

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CONTENTS

FOREWORD

The National Research Council (NRC), the principal operating agency of the National Academy of Sciences and the National Academy of Engineering, is coordinating the development of national standards for science education in grades K through 12. By the fall of 1994, National Science Education Standards will be completed and published. The standards will be narrative descriptions of what all students should be able to do to engage and understand the natural world. The standards will address science curriculum, teaching, and assessment and will represent the consensus of teachers and other science educators, scientists, and the general public.

The History of the National Science Education Standards Project

The NRC was commissioned to lead this undertaking in 1991 by the board of directors of the National Science Teachers Association, the presidents of several scientific societies, the United States Secretary of Education, the Assistant Director for Education and Human Resources of the National Science Foundation, and the co-chairs of the National Education Goals Panel. Dr. James Ebert, vice president of the National Academy of Sciences, presides as chair of the National Committee on Science Education Standards and Assessment. An advisory committee was established to help plan and advise the enterprise, and 89 individuals representing a wide range of perspectives and expertise in science, science education, and teaching at all levels were invited to serve on the national committee or on one of the three working groups (on curriculum, teaching, and assessment). The names and affiliations of the members of the advisory committee, the national committee, and the working groups are listed on Table 1 in Appendix D. Science teachers from grades K through 12 constitute a plurality on each working group. Broad participation by the science and education communities is ensured through oversight by a national committee, the participation of scientists and educators in the development process, and a critique and consensus procedure.

The task of the National Science Education Standards Project was initiated with the collection and analysis of over 150 documents from professional organizations, states, other countries, and other projects. The three working groups began their deliberations in the summer of 1992, while the critique and consensus activity began establishing liaisons with scientific, educational, and other interested organizations. Table 2 in Appendix D enumerates the organizations with which liaison has been established and the person who is the point of contact.

Activities scheduled for 1993 include additional meetings of the national committee and continuing work on drafting documents. Working group efforts will result in the first draft of the National Science Education Standards in the fall of 1993. Widespread distribution and requests for comments will lead to further revision and discussion, culminating in the release of the standards by late fall, 1994.

The Charges to the Working Groups

The overall charge to the working groups on National Science Education Standards is to develop, in cooperation with the larger science, science education, and education communities, standards for school science. The standards, founded in exemplary practice and contemporary views of science, society, and schooling, will provide a vision of excellence to guide the science education system in productive and socially responsible ways. Standards for science curriculum, teaching, and assessment will be integrated in a single document. The standards will specify criteria to judge the quality of school science and to guide the future development of the science education enterprise.

Science curriculum standards will define:

- the nature of school science experiences that exemplary practice and learning research propose are effective in producing valued science learning;
- the scientific information (facts, concepts, laws, and theories), modes of reasoning, and proficiency in conducting scientific investigations that all students are expected to attain as the result of their experiences; as well as
- the attitudes and inclinations to apply outside the formal education system the scientific principles and ways of thinking that all students are expected to attain.

Science assessment standards will define:

- the methods for assessing and analyzing students' accomplishments and the opportunities that programs afford students to achieve the valued outcomes of school science;
- the methods for obtaining appropriate correspondence between assessment data and the purposes that the data will serve; as well as
- the characteristics of valid and reliable science assessment data and appropriate methods for collecting them.

Science teaching standards will define:

- the skills and knowledge that teachers need in order to provide students with school experiences that will achieve the valued outcomes of learning science;
- the preparation and professional development needed by teachers in order to fulfill their roles; as well as
- the support systems and resources needed to teach science effectively.

The National Science Education Standards will be descriptive, not prescriptive. A narrative form, rather than checklists, will support thoughtful consideration and application of the substance of the standards. The curriculum standards will not define a specific curriculum, syllabus, or course of study; the teaching standards will not be certification or licensure specifications; the assessment standards will not be an examination. In each case, examples will be used to illustrate the broad range of what is possible, not define the "best" approach.

Implementation

Concurrent with the development of the National Science Education Standards, other NRC activities will address the assistance needed by teachers and schools if the standards are to be translated into action. The Committee on a National Education Support System for Teachers and Schools (NESSTS) will consider teacher education and professional development; obstacles created by the local environment and by the need for new materials, equipment, and consulting services; and the attitudes and roles of state and local administrative structures, parents, local business communities, colleges, and universities. Others will work with such constituencies as corporations, community groups, and appropriate interested parties.

An Invitation

This document is one in a series of precursors to the volume that will contain the National Science Education Standards. The purpose of this document is to invite the education community to comment on the proposed substance and form of the standards. It should be stressed that both substance and form are under review.

In Appendix C, you will find two surveys that will help in collecting feedback. Please note the deadline of January 15, 1993, for responses and capitalize on this opportunity to communicate your concerns and advice.

I. INTRODUCTION

This document contains:

- o the intellectual foundations that will direct the development of the National Science Education Standards;
- o the frameworks for the science curriculum;
- o samples of curriculum standards.

These unique aspects of the conceptualization of the National Science Education Standards are drawn to readers' attention:

- o Standards for curriculum, teaching, and assessment will be integrated in one publication.
- o Standards for science content will specify what all students should attain for:
  - a limited number of fundamental subject matter understandings;
  - the ability to inquire;
  - the ability and inclination to use scientific knowledge and reasoning when making decisions;
  - an awareness of how science is practiced and of the interactions of science, technology, and society.
- o The standards will project a vision of science education in which teachers create learning environments that enable students to acquire a body of knowledge while developing the intellectual skills that will equip them to use and increase their understanding of science throughout their lives.
- o The standards will broaden the purposes of assessment from making judgments about students' performance and setting policy to guiding teaching and giving students ample opportunities to demonstrate what they know and are able to do.
- o The standards will represent a dramatic shift in the emphasis of school science from what students know to how they know it and, consequently, how they spend their time. Instead of accumulating information passively, students will build understanding of fundamental ideas. Thus, the standards will focus on the quality and usefulness of knowledge, rather than on how much students know.

Standards in the Service of Science Education

Science education standards that have broad national consensus and are imbued by a sense of ownership are essential to bringing about the changes in the practice of science education that will result in scientific literacy for all.

The standards will serve several important purposes. They will:

- **Create a Compelling Vision of School Science**
  The new vision of school science will portray its excitement and the power of scientific knowledge and reasoning strategies. The poor image of school science must be dispelled. Far too many adults in positions to effect changes in school science education recall dull hours spent in class memorizing unconnected technical terms. Because they have been successful without good preparation in the sciences, they neither value school science nor act as advocates for it in the school curriculum. This new vision of school science is essential to bringing about the necessary revolution in school science education.

- **Give Direction and Goals to Science Education**
  The standards will contain criteria to guide educators, government officials, policy-makers, concerned citizens, and business and industry leaders who are trying to improve school science education. With widely accepted goals for school science and clear direction for achieving them, science will be able to command its place in the school curriculum for all students at all levels.

- **Support Exemplary Practice and Encourage and Direct Changes in Science Education**
  The standards will provide exemplary teachers with the authority to use nontraditional methods that meet the standards' spirit and intent and will give direction and encouragement to those contemplating changes.

- **Ensure Quality and Accountability**
  The public's ability to judge the quality of school science education, in terms of both the effectiveness of the experience and what students have accomplished, is limited. The standards will provide the education community and the public with the information to make valid judgments and to hold education systems accountable.

II. THE GOALS OF SCHOOL SCIENCE EDUCATION

School science education makes essential contributions to the individual and social good. Along with other areas of human endeavor, each of which plays a unique role, a knowledge of science is an essential part of an individual's abilities to:

- function well and make informed decisions in the home, community, and workplace;
- continue to learn for personal, professional, and civic reasons;
- understand the relatedness of the spheres of human activity and the influences of culture and context on human understanding.

Scientific Literacy

School science education contributes to the broader goals of education by providing students with a scientific understanding of the natural world through knowledge of the basic concepts of science, scientific modes of inquiry, the nature of the scientific endeavor, and the historical, social. and intellectual contexts within which science is practiced. The ability to apply such scientific knowledge to aspects of one's life is called "scientific literacy."

Thus, the goals of school science education are to prepare students who understand:

- a limited number of the basic concepts of science and the fundamental principles, laws, and theories that organize the body of scientific knowledge and can apply them;
- the modes of reasoning of scientific inquiry and can use them;
- the nature of the scientific endeavor and its ways of knowing;
- the history of scientific development, the relationship of science to technology, and the historical, cultural, and social contexts in which this relationship is embedded.

To contribute to the broad social goals of education, school science must attend to not only students' understanding of the knowledge base, but also opportunities for them to practice using their knowledge outside formal educational settings. Furthermore, in combination with the skills and knowledge obtained from other fields, the goals of school science education will address the need for students to enrich their lives; become empowered to take appropriate action in personal, professional, and civic endeavors; and be equipped for the changing world of work.

Therefore, school science programs must provide experiences that:

- o are personally and socially relevant;
- o call for a wide range of knowledge, methods, and approaches to analyze personal and societal issues critically;
- o encourage students to act in ways that reflect their understanding of the impact of scientific knowledge on their lives, society, and the world;
- o encourage students' appreciation of the scientific endeavor and their excitement and pleasure in its pursuit;
- o develop in students an appreciation of the beauty and order of the natural world.

Few school science programs offer these experiences now, and very few students come close to demonstrating these abilities today.

Social Commitment

The National Science Education Standards will define the level of understanding of science that all students, regardless of background, future aspirations, or interest in science, should develop. The standards will be based on the belief that all can learn science.

The science standards will encourage all students--including members of populations defined by race, ethnicity, economic status, gender, and physical and intellectual capacity--to study science throughout their school years and to pursue careers in science. By adopting the goal ***science for all***, the standards will promote the participation of all students in challenging opportunities to learn science and will define a level of understanding that all should develop.

The standards will advocate forcefully the inclusion of those who traditionally have not received encouragement and opportunities to learn science--women and girls, all racial and ethnic groups, the physically and educationally challenged, and those with limited proficiency in English--as well as those who have.

Various ways of learning and different sources of motivation will be accommodated because the curriculum, teaching, and assessment standards will take into account the diversity of the student population, disparate interests, motivation, experience, and ways of understanding science. The standards will define criteria for high-quality instructional experiences that will engage all students in the full range of science content. These experiences will teach the nature and processes of science in addition to the subject matter, will reinforce the belief that men and women of diverse backgrounds can engage and participate in science, and will uphold the premise that all have a claim on this common human heritage.

The development of National Science Education Standards is essential to achieving the goal of school science education for all students.

III. THE CHARACTER OF SCHOOL SCIENCE

The essential character of school science is consistent with the disciplines of science. The science disciplines contribute the content while the characteristics of programs are influenced by the disciplines and by ideas about how students learn science.

The Intellectual Foundations of School Science

The science disciplines--drawn from the life sciences, the physical sciences, and the earth and space sciences--together with the philosophy,[1] history, and sociology of science are the intellectual foundations of school science education and the National Science Education Standards. The subject matter of school science is drawn from the body of scientific knowledge. Philosophers of science consider the activities undertaken and the procedures used in the practice of the scientific disciplines--the modes of inquiry, rules of evidence, and forms of argumentation--as well as the values and assumptions of the scientists conducting the activities. The product of these activities is scientific knowledge. Historians and sociologists of science contribute information about the relationship of science to the social and cultural contexts in which it is practiced, including its relationships to other disciplines such as technology and mathematics.

In Figure 1, the contributions of each discipline to the intellectual foundations of school science education are elaborated. It would be easy to translate the substance of this figure directly into the content of school science. However, the disciplines contribute to more than merely the substance of the curriculum content. They also define standards of quality for the content as well as the spirit of inquiry that must be reflected in school science programs.

Three principles relate the disciplines of science to the content of school science and the characteristics of its programs:

- The subject matter of school science must be consistent with the body of scientific knowledge from which it derives.
- School science education must reflect science as it is practiced.
- School science must convey a sense of the time and the culture in which science has developed.

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[1] See Appendix A for a discussion of contemporary views of the philosophy of science.

DISCIPLINES	KNOWLEDGE PRODUCTS	SCHOOL SCIENCE DOMAINS	SCHOOL SCIENCE ORGANIZERS
Science Disciplines	Body of Scientific Knowledge	Life sciences	(see Figure 2)
		Physical sciences	(see Figure 2)
		Earth and space sciences	(see Figure 2)
Philosophy of Science	Nature of Science	Modes of inquiry	(see Figure 3)
		Habits of mind	(see Figure 3)
		Attitudes and dispositions	(see Figure 3)
History of Science Sociology of Science	Context in Which Science Functions	Historical	(see Figure 4)
		Social and cultural	(see Figure 4)
		Relationship to other disciplines	(see Figure 4)
	Applications of Science	Decision-making	(see Figure 5)

Figure 1

Intellectual Foundation of the Knowledge Base for School Science

The Frameworks for School Science

Figures 2 through 5 reflect the frameworks, derived from Figure 1, that will guide the development of specific standards for the content and for the characteristics of programs of school science.

Figure 2 depicts the body of scientific knowledge and how it relates to the content and the program characteristics of school science. Often, the body of knowledge is regarded as being located within the basic domains of science--the life sciences, the physical sciences, and the earth and space sciences. Figure 2 indicates that this knowledge also can be classified into "organizers" that reflect important areas of study and suggest movement away from these traditional domains. Within the "organizers," the National Science Education Standards will identify the fundamental concepts, laws, and theories that will form a common basis of understanding for all students. The fundamental ideas of the social sciences and technology[2] will not be included. Rather, only those aspects of the social sciences and technology that relate directly to the historical development of the natural sciences will be part of the content of school science as will be the complementary influences of science and technology on each other and on contemporary society.

Figure 3 provides the detail for the nature of science. Under science content, an important distinction is made between students knowing about the nature of scientific inquiry and being able to conduct inquiries. Both are necessary. The same distinction holds for forms of argumentation. The domain of values and habits of mind is represented in the standards for programs. It also is represented in the ways in which teachers model, through their behaviors and the environment and programs they create, the values and habits of mind of the scientific community.

Figure 4 depicts the varied contexts (historical, social, and cultural) of science and the relationships of science to other disciplines. Knowing about these aspects of science is a part of the science curriculum and is reflected in the content and in the structure and characteristics of school science programs. It is in studying the contexts of science that students learn about those aspects of the social sciences and technology that are related directly to historical and contemporary developments in science.

[2]**Technology** encompasses a range of distinctly different concepts. Sometimes, technology refers to the devices used to provide instruction (e.g., computers and instructional software) or the devices used to gather, display, and analyze data (e.g., thermometers, telescopes, graphing calculators, and mainframe computers). In this document, technology means those endeavors whose goals are improvement of the human condition. Such endeavors range from the practice of a craft such as knitting to activities associated with engineering.

BODY OF SCIENTIFIC KNOWLEDGE		CURRICULUM			
		School Science Content Standards			Standards for Programs
Domain	Organizers	9-12	5-8	K-4	
Life Sciences	Organisms				
	Ecology				
	Evolution				
Physical Sciences	Matter and its interactions				
	Forces of nature				
	Motion				
	Energy				
Earth and Space Sciences	Forces that shape the Earth				
	Space and astronomy				

Figure 2

The Relationship of Scientific Knowledge to the Science Curriculum

NATURE OF SCIENCE		CURRICULUM			
		School Science Content Standards			Standards for Programs
Domain	Organizers	9-12	5-8	K-4	
Modes of Inquiry	Formulate questions				
	Plan experiments				
	Make systematic observations				
	Interpret and analyze data				
	Draw conclusions				
	Communicate				
	Understanding of inquiry				
Habits of Mind	Intellectual honesty				
	Skepticism				
	Tolerance of ambiguity				
	Openness to new ideas				
	Communication and sharing				
Attitudes and Dispositions	Curiosity				
	Reflection				
	Pleasure in understanding				
	Empowered to participate				

Figure 3

The Relationship of the Nature of Science to the Science Curriculum

CONTEXTS OF SCIENCE		CURRICULUM			
		School Science Content Standards			Standards for Programs
Domain	Organizers	9-12	5-8	K-4	
Historical	People				
	Events				
	Interactions of technology and science				
Social and Cultural	Political impact				
	Economic impact				
	Cultural impact				
Relationships to Other Disciplines	Technology				
	Social science				
	Mathematics				

Figure 4

The Relationship of the Contexts of Science to the Science Curriculum

New technological devices allow scientists to understand the natural world further, and new scientific discoveries form the basis of new devices. For example, physicists have applied principles of quantum mechanics to the design of new types of microscopes that permit the direct observation and manipulation of individual atoms. These microscopes have been engineered into powerful new instruments that are sold for use in chemistry and biology, as well as in physics research. These new microscope technologies open new fields of scientific endeavor because they provide a direct view of individual atoms in matter. This is an illustration of the complementary interactions between science and technology.

Just as scientific disciplines overlap and interact, so do the activities of scientists and engineers in the development of new areas in the sciences, new products, and new technologies. For instance, in biotechnology, new understandings of biological functions at the molecular level have generated new concepts for the treatment of diseases. This leads to the design of specific drugs, their production on a laboratory scale, and then their testing. Subsequently, bulk production methods are designed and full-scale production facilities are built. Ultimately, people are affected as new treatments for diseases are established. The process begins with chemists and biologists working together; later, it involves engineers, doctors, patients, and, ultimately, citizens.

Studying the history of science not only highlights the relationship between technology and science, but also shows students how science has evolved and that the drive to understand the natural environment and to predict the course of natural events is fundamental to the human race.

Figure 5 depicts another aspect of the content of school science--the application of scientific knowledge to personal and societal decision-making. The ability to use relevant scientific knowledge in clarifying and addressing issues and problems from many areas of modern life is vital to informed decision-making in our society. This ability is an important goal of science education and contributes to the goals of general education. In the science curriculum standards, informed decision-making is considered from the viewpoints of a set of interrelated skills and an understanding of how these skills can contribute to sound decisions.

APPLICATIONS OF SCIENCE		CURRICULUM			
		School Science Content Standards			Standards for Programs
Domain	Organizers	9-12	5-8	K-4	
Decision-Making	Formulate problem statement				
	Identify dimensions of the issue				
	Gather information				
	Generate and evaluate alternative solutions				
	Recommend a preferred solution				
	Participate in decision-making				
	Understand decision-making				

Figure 5

The Relationship of the Applications of Science to the Science Curriculum

The Learning Dimensions

The review of the intellectual foundations of school science and the frameworks indicates a rich body of content for school science. However, rather than being defined by a large collection of facts and information, the territory of school science will cover a body of fundamental ideas, the nature of science, the contexts of science, and the applications of science. The school science program also is defined by what is known from cognitive learning theories,[3] which indicate that for students to develop an active body of scientific knowledge, there must be extensive physical and mental engagement with the natural world. In other words, inquiry must be at the heart of learning science.

It also is known that discussion is important in the development of understanding. The incorporation of discussion transforms a class from a collection of individuals seeking personal understanding to a community of learners seeking common understanding. Individual students participating in a community of learners communicate their observations and interpretations of the natural world to their peers and, in doing so, test the extent to which their points of view are shared. As they communicate, students refine and elaborate their personal understanding while contributing to the communal body of knowledge of the class. During the process, the community of learners, with the guidance of their teacher, develops rules of evidence and modes of argumentation that guide its inquiry procedures.

The findings of research on student motivation also impact strongly on the design of school science programs. A major rationale for including technology (both as the application of scientific principles to the betterment of the human condition and as engineering principles that guide personal and societal decision-making) in the science curriculum is its relevance to science. In other words, students will be engaged more fully in learning science when they appreciate fully its relationships to their daily lives. The motivating power of relevance is the basis of science programs organized around the theme of decision-making and science, technology, and society.

Motivation also is one of the reasons for including in the science curriculum the history of science and examples of the contributions of other cultures to the growth of scientific knowledge. Through such examples, students will see that the drive to understand the natural environment is a basic, common, human one and that individuals from all ethnic groups and cultures have engaged in the process, thus making their contributions to the growth of modern scientific knowledge.

[3] The cognitive view of learning science is considered further in Appendix B.

If the school science program is to reflect the richness of content and what is known about learning, the implications are clear:

- the amount of information and the body of knowledge to be learned must be reduced substantially; and

- adequate time must be given to the development of understanding.

These insights about content and how students learn have many other implications for curricula and teaching, as well as assessment, which will be described in the science education standards when they are developed more fully.

IV. THE STANDARDS FOR SCHOOL SCIENCE

The National Science Education Standards will contain criteria for judging the quality of school science from kindergarten through grade 12 and for guiding the future development of the nation's science education enterprise. Although all three of the working groups (on curriculum, teaching, and assessment) have started their work, to date more attention has been given to the framework for the curriculum standards, as mentioned earlier. Thus, the focus in this section is on science education standards from a curriculum perspective.

Program Standards Expectations for the overall school science curriculum will be conveyed through program standards. These standards will deal with such diverse concerns as the interweaving of inquiry (as a mode of instruction) with content, the learning environment, criteria for selection of additional subject matter beyond that specified as fundamental, and the effective use of instructional technologies.

Content Standards Expectations of what all students should understand (knowledge) and be able to do (skills) as a result of their science education will be expressed in the school science content standards. The standards for content will be accompanied and amplified by illustrations of the multiple ways in which students can demonstrate their understanding (assessment perspectives) and by examples of appropriate activities for students (teaching perspectives).

Observations on the Body of Scientific Knowledge

Science textbooks and school science programs have become increasingly overburdened with information and facts. Such an approach does not reflect the growing knowledge of how conceptual understanding of science develops and the need to enhance such understanding through investigations, through attention to applications of science, and through understandings of the nature of science and the role of science in social and cultural contexts.

The curriculum standards for content are based, in part, on the principle that the amount of scientific knowledge that students are expected to learn must be reduced substantially. This does not imply a lowering of expectations; rather, it offers students the prospect of developing deeper understandings of the central ideas of science through the extended use of inquiry and through opportunities to apply scientific knowledge. Consequently, the content standards will identify, from the body of scientific knowledge, a limited number of the important concepts, laws, and theories that provide a foundation for understanding science. All students can be expected to know, understand, and use this knowledge if they are given appropriate educational opportunities that address their particular learning needs.

The curriculum standards will not and should not specify the full science program. Although school science content standards will specify the fundamental understandings that all students should gain, teachers and school systems must continue to construct thought-provoking, engaging lessons that build on local resources and environments, reflect their particular interests and expertise, and stimulate their students. All students must be encouraged and challenged to go beyond the fundamental understandings specified in the curriculum standards. Thus, the program standards also will include criteria for the selection of additional subject matter and activities. These criteria will address such considerations as developmental appropriateness, linkages to students' experiences, enhancement of students' understanding of science applications, connections to other scientific knowledge, and weighing the "benefits" of the increased knowledge and skills that students will acquire against the instructional "costs" involved in offering these additional learning opportunities.

The Categories of Content

The prototype standards presented in this document focus on the content of school science. The general categories of content are consistent with the four major components of science summarized in Figure 1, which are related to the science curriculum in Figures 2 through 5.

- **Nature of Science** includes content standards for the understandings and skills associated with scientific modes of inquiry and forms of argumentation, as well as with students' understandings of the values and habits of mind that characterize the practice of modern science. (See Figure 3.)

  In this document, this category of content is illustrated by the prototype standards for Modes of Inquiry for grades 9 through 12. These standards address the development of abilities to plan, implement, and interpret scientific investigations.

- **Fundamental Understandings of Science**, selected from the body of knowledge of the natural sciences, are the fundamental ideas (concepts, laws, and theories) of natural science that all students should know and be able to use. These ideas, drawn from the life sciences, physical sciences, and the earth and space sciences, are organized (according to current Curriculum Working Group thinking) in nine general categories: Organisms, Ecology, Evolution, Matter and Its Interactions, Forces of Nature, Motion, Energy, Forces That Shape the Earth, and Space Science/Astronomy. Representative activities that can help students to understand these ideas are included, accompanied by suggestions of various ways in which students can demonstrate their understanding. (See Figure 2.)

In this document, this category of content is illustrated by prototype standards for a segment of Matter and Its Interactions for grade levels K through 4 and 5 through 8.

- **Contexts of Science** include what students should know about science from historical, social, and cultural perspectives. What students should know about the relationships of science to other disciplines and to other areas of human endeavor (particularly to technology, the social sciences, and mathematics) is included also. (See Figure 4.)

  No prototype standards for this category are in this document because detailed work has not started on this dimension.

- **Applications of Science** include content standards related to the scientific understandings and skills needed to make personal, professional, and civic decisions about issues and problems that contain scientific and technological aspects. (See Figure 5.)

  Prototype content standards for Decision Making in grades 9 through 12 are included herein.

The above-mentioned prototype standards for school science content are presented in the following section. The focus in all three prototype categories is on specifying the desired understandings and skills associated with each standard.

Comments and suggestions on the format, scope, and substance of these prototype standards are invited. Response forms in Appendix C can be used for this purpose.

The Nature of Science
Prototype Standard for Modes of Inquiry

Note: As does the prototype Standard for Decision-Making, this prototype focuses on grades 9 through 12. Standards for Modes of Inquiry for grades K through 4 and 5 through 8, not drafted yet, will reflect the same general perspectives, but will address the relevant skills and understandings at developmentally appropriate levels.

Grades 9 Through 12: Modes of Inquiry

A. Comments on This Standard

Inquiry is the process by which scientists pose questions about the natural world and seek answers and deeper understanding, rather than knowing by authority or other processes. Approaching the study of school science in a questioning mode is, therefore, in harmony with the practice of science, as compared with presenting science by talking about it.

Inquiry in science follows no single pathway. Exploration can lead to many questions. Carefully planned experiments can proceed in a predictable fashion or yield startling data that lead to new questions and new investigations. On the other hand, the process of inquiry is not random; once a question is posed, the search for answers follows a purposeful sequence of experimentation, data collection, analysis, and the drawing of conclusions.

When students engage in inquiry, they use a wide range of tools and skills, make choices among alternatives, and determine what events are important. They use both practical, hands-on skills and thinking skills. Inquiry in the classroom can and should engage students in inquiry as it really is--a series of creative, iterative, and systematic procedures.

Inquiry in the classroom is a means of promoting and supporting students' curiosity and questioning spirit. Inquiry is a critical component of the science curriculum at all grade levels and in every domain of science. It serves four essential functions:

- to assist in the development of an understanding of scientific concepts;
- to develop an understanding of the nature of scientific inquiry;

- o to develop the skills--and the disposition to use them--necessary to become independent inquirers about the natural world;

- o as a model of how we know what we know in science.

B. **Inquiry Skills**
By the end of grade 12, all students should be able to use the following inquiry skills. They should be able to:

1. **Formulate usable questions by:**
   - o generating a number of possible questions;
   - o recognizing which questions are in the domain of scientific inquiry; and
   - o being aware of the complexity of the questions being generated.

2. **Plan experiments by:**
   - o selecting a question that can be explored through experimental procedures;
   - o designing a procedure for the systematic collection of data; and
   - o choosing appropriate measuring tools.

3. **Conduct systematic observations by:**
   - o choosing and/or designing and building tools and apparatus;
   - o using tools and apparatus;
   - o collecting and recording data (judging their precision and accuracy);
   - o organizing data; and
   - o representing data.

4. **Interpret and analyze data by:**
   - o graphing data; and
   - o retrieving, using, and comparing data from other investigations.

5. **Draw conclusions by:**
   - o relating conclusions to data and their analysis;
   - o relating their experiment to other experiments;
   - o relating their experiment to models and theories; and
   - o suggesting further investigations (formulating new questions).

6. **Communicate by:**
   - o using words, graphs, pictures, charts, and diagrams to describe the results of their experiments;
   - o producing summaries or abstracts of their work;
   - o using technology to improve communication; and
   - o analyzing critically other people's experimental work.

7. **Coordinate and implement a full investigation by:**
   - o formulating questions;
   - o planning experiments;
   - o conducting systematic observations;
   - o interpreting and analyzing data; and
   - o drawing conclusions and communicating the entire process.

   (Skills 1 through 6 should be illustrated in a single extended inquiry.)

   Students should be able to demonstrate each skill in a new experiment. Evidence of individual skills and the ability to conduct a full investigation will be documented in the reports that students will write during the communication skill (no. 6) segment of a major experiment similar to the one described in Part D.

C. **Understanding the Inquiry Processes**

The ability or skill of students to carry out an investigation is linked to their understanding of inquiry processes. In addition to the ability to conduct an investigation, by the end of grade 12 students will have developed the following understandings:

- o Inquiry processes can be analyzed to determine if they are well designed and have the potential to produce results that are likely to answer the original question.

- o The basic ideas of science are a result of the inquiry processes and can be used by anyone to gain new information and understandings.

In demonstrating their understanding of inquiry processes, students should be able to describe the contribution of each part of the process and evaluate examples of work using the skills, to determine how well it was done.

D. Activities That Can Help Students to Develop the Skills and Related Understandings Associated With This Standard

By the time that students have reached high school, they should have become familiar with inquiry skills. At times during their high school science experiences, they will focus on individual skills, and at least once a year they will conduct a self-directed full investigation that provides opportunities to use all of their inquiry skills. An example of such an activity in the biological sciences is described below.

Preparing for the Activity

The teacher raises the question, "What are the effects of acid rain on organisms?" The class discusses the relevance and importance of the question and reviews what it knows and has heard about acid rain.

In their small groups, students generate some possible investigations that could help them tackle this broad question about the effect of acid rain on organisms. The teacher explains to the students that materials associated with a more focused question are available to them. The more focused question is, "What is the effect of pH on the eggs, larvae, and pupae of fruit flies?"

The Activity

Students return to their small groups to plan their investigation to address the question. Each group will work on a different experiment and use a different experimental design. One team of students may choose to look at the effect of pH on the three separate stages of the fruit fly. In the first sample, the eggs will receive a single exposure of acid rain. In the second sample, the eggs will not be exposed to acid rain but the larvae will receive the exposure. In the third sample, the egg stage and the larva stage will not receive the exposure, but the pupa stage will. The same group will provide an exposure of acid rain to the egg, larva, and pupa stages. This group may give each stage one third of the acid exposure during each phase or may give a full exposure three times.

A second team of students may decide to focus on the effect of pH changes. A third team may concentrate on the frequency of exposure to the acid during each stage. A fourth group may decide to design an ambitious experiment that takes into account several of these variables.

Different groups also have to decide what the output variable will be. For instance, one team may look at the survival of the fruit fly. Another team may focus on the fertility of the surviving fruit flies. Completion of the inquiry will require students to review (or learn about) pH, statistical significance, and other areas of the science and mathematics curricula.

Students keep journals of their investigation, which includes decisions, observations, data, analyses, conclusions, and proposals for further investigations. The report to the class will be critiqued by other students. The class is responsible for evaluating each group's work. Students discuss with the presenting team their systematic observations (including the organization of data) and their drawing of conclusions (including the synthesis of ideas) and offer suggestions.

Representative Inquiry

If students are regarded as members of a community of learners, the next step would be for different classes in the same school to share the results of parallel studies on, say, fruit flies, daphnia, and beetles. Different classes in different schools also might share and compare results with other schools through the use of telecommunications. The different schools might compose and publish a science journal as a final report.

Fundamental Understandings
Prototype Standards for Matter and Its Interactions

Note: This prototype standard represents expectations for students' experiences with and understandings of objects and materials for grades K through 4. Along with helping children to understand basic aspects of things that they encounter daily, these experiences (and many more in other parts of the school science program for grades K through 4) will build and extend a foundation that will lead later toward ideas about matter and its interactions and the usefulness of a particle model to account for matter's properties.

Grades K through 4: Objects and Materials

A. **Comments on This Standard**

During their early years, children acquire information about their world by examining and exploring common objects and materials in their environment. Their natural curiosity leads them to take advantage of the many opportunities in their daily lives to manipulate objects and materials, to compare, to contrast, and to describe them. Young children bring these experiences to the school setting where they are given opportunities to continue their explorations in expanded and more focused ways, using all of their senses as well as simple tools such as magnifiers and measuring devices.

This standard addresses the need for students to understand important characteristics of the objects and materials that they encounter daily and to begin seeing the usefulness of classifying them into various categories. Simple comparisons build gradually into measurable comparisons. Drawings and single words lead to the development of increasingly detailed sketches and descriptions. The observation, manipulation, and classification of common objects provide children with an experiential foundation that leads them to reflect, as they move through the early grades, on similarities and differences in the materials that compose various objects.

Students' understanding of the characteristics of objects and materials and the usefulness of description and classification should not occur through isolated activities but, rather, in the context of broader explorations of the world. Young children are gaining experiential understanding of the characteristics and properties of objects and materials when they study what their senses tell them, when they examine and sort different kinds of seeds before planting, when they measure and graph the heights of all of the students in their class, when they investigate the changes of state in water, and when they study objects sinking and floating in different liquids. These and many other experiences contribute to the experiential foundation upon which explanations of properties and materials can be built starting in grades 5 through 8.

B. In grades K through 4, activities such as the following, supplemented by other experiences in daily life, can help young children to develop fundamental ideas about objects and materials.

The episode below illustrates one way in which children can begin to develop concepts of objects, materials, and properties.

Preparing for the Activity
A first-grade teacher has developed an instructional unit on the local environment that offers challenging activities to help children focus on the nature and interactions of living and nonliving things in their environment. A major thread running through the unit concerned the description and classification of the objects students collected as a way to understand differences between living and nonliving things, the diversity of living and nonliving things, and the variation within a particular set of things such as stones or leaves.

The following experience is one of many that students had over an extended period of time. Prior to this, they had taken several field trips around the block, for which they had developed a map of the important areas to be investigated (e.g., a small weed patch, a maple tree, a pothole, and a vacant lot). They had discussed and listed various kinds of objects that they had noticed on their trips and had categorized them as living and nonliving. The day before the instructional unit was to start, an interesting discussion took place about whether twigs lying on the ground were living or nonliving. The discussion led to the acceptance of a new category, "once alive and not alive."

The Activity
Today, the teacher had planned to take the class for a walk around the block, with the specific purpose of collecting rocks for study. Before going out, the teacher told the students about the purpose of the walk and asked them what they thought they might find and where they might find them. Divided into pairs and equipped with a copy of the map of the block on a clipboard and a bag, the children circled the block, stopping to collect stones as they went. Once back in the classroom, the students, now in groups of four, examined their rocks closely, using hand-held magnifying lenses. They were asked to think about how they might describe their rocks, making some drawings if they wished, and then to sort their rocks into groups that made sense to them.

Within their groups, the students discussed their observations and agreed and disagreed about categories. The teacher moved from group to group, listening to the discussions, asking for descriptions, pointing out interesting features, and querying the reasons for the groupings. Then, the students were asked to place their groupings in a prescribed place until the following day.

The next day, the teacher gathered the students together. Each group was asked to explain the basis for the grouping of their rocks. Other students were asked to comment. The teacher picked up a new rock and asked that it be placed in the proper pile. After each group of four students had completed their explanations, the teacher and the class constructed a list of all of the characteristics that the students had used in sorting their rocks. They discussed the relative usefulness of some versus others and talked about other tools that might be useful, such as a balance for comparing weights or a hammer for looking inside.

Representative Inquiry

This unit will continue. The students will pursue the study of rocks as well as other parts of the environment. In the process, they will continue to study the properties and characteristics of objects and materials and apply their abilities to observe, describe, and classify.

Other examples of creative activities that can enable students to understand objects, materials, and their properties include:

- observing, comparing, and describing the sizes, shapes, and weights of common objects (such as rocks, blocks, chairs, water, buttons, fossils, juices, soil);
- measuring and weighing various objects, using both nonstandard (beans, paper clips, pennies) and standard (centimeters, grams) units;
- grouping or classifying common objects based on observable properties such as things that are round, things that are smooth, and things that have wheels;
- observing and comparing water in its solid and liquid forms;
- grouping or classifying objects according to the kinds of material of which they are composed (such as wood, metal, glass, or clay);

- o comparing the properties of various types of material (such as color, texture, magnetic characteristics, behavior when heated or cooled, the ability to float or sink in water);

- o comparing the weight of a piece of clay before and after it is divided into smaller pieces and a Lego toy before and after it is taken apart.

C. As a result of their activities in grades K through 4 and everyday experiences away from school, all students should be able to demonstrate their understanding of certain fundamental ideas about objects and materials; namely, that:

- o **Common objects have observable properties (size, shape, volume, and weight) that can be compared and measured. Such properties can be used to describe, group, and classify objects.**

  In demonstrating their understanding of these ideas, students should be able to classify or order a set of objects according to a specified property, such as weight or volume. They also should be able to devise one or more ways to classify or order a set of objects and be able to explain their classification scheme.

- o **Objects are made up of different kinds of materials. Materials have observable properties (color, texture, magnetic characteristics, and different behaviors when heated or cooled) that can be compared and measured. Such properties are useful in describing, grouping, and classifying materials.**

  In demonstrating their understanding of these ideas, students should be able to group a set of objects according to the materials from which the objects were made (such as wood, metal, glass, and clay). They also should be able to describe differences in the observable properties of such materials.

- o **Materials can exist in different states (solid, liquid, gaseous). Each state has characteristic properties.**

  In demonstrating their understanding of these ideas, students should be able to describe observable properties that given materials have in common or that distinguish them from each other.

- **Some properties of a material may change when it experiences some external change; other properties do not. In particular, if the temperature of a sample of material is changed, the material may change from one state to another (liquid to solid, liquid to gas, etc.). However, the weight of an object remains unchanged when it is broken into smaller parts.**

  In demonstrating their understanding of these ideas, students should be able to predict and describe the effects of temperature changes on water or ice. They also should be able to provide evidence that the weight of a sample of material remains the same even though its shape, location, or appearance may change.

Grades 5 through 8: The Particle Model for Matter

Note: This prototype standard represents fundamental understandings for one part of Matter and Its Interactions only, namely, the particle model of matter. Standards for other aspects of Matter and Its Interactions, not developed yet, will cover the general categories of physical and chemical changes.

A. Comments on This Standard

During their middle school years, students continue to observe, measure, and compare the properties of matter, building on experiences and understandings gained in grades K through 4. However, during their years in grades 5 through 8, they also begin to address the challenge of devising explanations (models) to account for these properties.

Constructing and testing possible models (or "pictures in the mind") of how matter might be composed introduces students to a fundamental activity in the natural sciences--accounting for facts, phenomena, and data about the natural world in terms of rich explanatory models or theories. Grades 5 through 8 can be regarded as a transition period in school science from the experiential focus of grades K through 4 to the more serious emphasis on principles and theories in grades 9 through 12. Students' work toward a particle model for matter in grades 5 through 8 provides them with important insights about how science functions, a useful explanation for differences in the three states of matter, and, ultimately, a particle view of matter that can be extended and refined in later studies of science.

The ability to explain observable properties in terms of the behavior of minute imagined particles is a major accomplishment for most middle-level students.

Such an accomplishment depends on extensive learning experiences over considerable time as well as on multiple opportunities to experiment with materials, determining their properties under various conditions and during changes in state.

The existence of atoms and molecules will be accepted all too readily, without question or evidence, unless students are challenged continuously to reflect upon "Why do you believe that there are particles?" or "How can this property be explained in terms of a particle model?"

B. **As a result of their activities in grades 5 through 8, all students should be able to demonstrate their understanding of certain fundamental ideas regarding the common properties of matter and to develop a model of matter that accounts for these properties--the particle model.**

- o **It is possible to devise a model for matter that will represent the properties and behaviors observed in materials. According to the particle model, matter can be viewed as being composed of very small particles. Particles in solid materials are close together and not moved about easily, particles in liquid materials are close together, but moved about easily and they tend to stick together; particles in gaseous materials are quite far apart and move about freely.**

In demonstrating their understanding of these ideas, students should be able to develop a model for matter that will explain common properties and behaviors of materials, including differences observed in the properties of solids, liquids, and gases; changes involved in melting, freezing, evaporating, and boiling; the movement of perfume odor from an open bottle to all parts of a room; dissolving a solid to make a drink; and blowing up a balloon. Students should be able to compare features of their own model (or one described to them) with those of the particle model. Also, given a description of the features of the particle model, students should be able to explain any of the properties of materials described above.

- o **The total mass of materials involved in any observed change remains the same. For example, mass is conserved when changes in state (such as solid to liquid or liquid to gas) and reactions occur.**

In demonstrating their understanding of this idea, students should be able to describe and conduct a laboratory investigation to find out whether mass is conserved in a simple chemical reaction or in a change of state.

- **Conservation of mass can be understood by regarding the changes as involving rearrangements among the component particles. Since the number of these particles remains the same, the total mass of the materials remains unchanged.**

In demonstrating their understanding of these ideas, students also should be able to show--using a concrete model involving units such as Lego blocks, dried peas, rice grains, or a system involving components such as bolts, washers, and nuts--why the total mass remains the same even though the system may undergo a chemical or physical change.

C. **These examples illustrate the kinds of activities that can help students to develop the understandings and related skills associated with this standard.** (It must be recognized, however, that the development of understanding of a fundamental idea requires in-depth study over time and many coordinated experiences based on phenomena that are part of students' experiences.)

The following activity illustrates one way in which an introductory activity might contribute toward students' understanding of the conservation of mass.

Preparing for the Activity
Students are divided into groups. Each group is given an ice cube in a jar. Visible to the classroom is a large jar of ice.

The Activity
Working in their groups, students share their observations of the ice cube melting and make as many observations as possible. They also watch a time-lapsed video of some ice melting, to enable them to make more time-dependent observations than would be possible in one class session. (Ideally, this video should be developed by the students.)

The groups discuss their observations, then are invited to describe the things that changed and the things that did not change in this activity. Such a list might include comments on color, wetness, temperature, mass, shape, volume, and size.

Next, the students work in their groups to identify one factor that they regard as critical to the melting process. They define a question that they believe is important and can be investigated and proceed to plan and conduct an investigation.

As each group conducts its investigation, the teacher serves as a resource for supplies and helps with procedures, data collection, and interpretation.

The teams are asked to summarize their results and draw their conclusions. Then, these are shared and discussed with the whole class.

Representative Inquiry
Another activity might be in the form of a challenge to the whole group to find out whether the mass of the water changes as the ice cube melts. In small groups, students will design and conduct an investigation and analyze and present their work to the class. Students should be given minimal direction in terms of tools and planning steps.

Some groups likely will realize that they need a container so that water does not spill off the balance. They also may recognize that they should cover the ice cube system with a lid.

The groups may use a variety of balances. An electronic balance, if available, could be coupled to a computer so that graphs can be generated during the experiments. A timing device will be needed if students decide to record possible changes over time rather than record only a measurement at the beginning and end of the change.

A Possible Scenario: One teams reveals that the mass of the melted ice is greater than the mass of the original ice. A second team was aware of condensation on the outside of the container and removed it as it appeared during the experiment. This team found that the mass did not change. The first team objects to this procedure, saying that the condensation represents some water inside the jar that passed through the wall of the container.

The students are led to further experimentation and investigation. Discussion prior to the new experiment may reveal that some of the students have had experience with condensation in everyday life. A new investigation with styrofoam cups (where little condensation forms) is conducted. This experiment helps the class to converge on a conclusion to the question of whether mass changes.

Students' acceptance of the notion of conservation of mass will depend, in part, on allowing them to explore a variety of systems and changes during successive class sessions. Once the notion is accepted, students can be challenged to explain how constancy of mass in such a variety of systems is possible. Their explanations will reflect their own thinking regarding aspects of how matter might be composed. A particle model of matter can be derived from their model-building efforts eventually or offered as a useful way to account for this important generality.

Examples of other activities that support the development of understanding of the particle model of matter include:

- identifying and comparing the characteristic properties of samples of typical solids, liquids, and gases;
- investigating the qualitative effects of temperature, volume, and pressure changes on a sample of gas;
- investigating changes of state for common substances.

Applications of Science: Prototype Standard for Decision-Making

Note: As does the prototype Standard for Modes of Inquiry, this prototype focuses on grades 9 through 12. Standards for Decision-Making for grades K through 4 and 5 through 8, not drafted yet, will reflect the same general perspectives, but will address the relevant skills and understandings at developmentally appropriate levels.

Grades 9 Through 12: Decision-Making

A. Comments on This Standard

Many of the critical and complex issues facing the world today involve individual and social values and group decision-making processes as well as scientific understandings. Including "real world" decision-making opportunities in the curriculum will motivate and engage students more successfully in learning science when they understand its relationship to their daily lives and can reinforce their knowledge of scientific principles by applying it to making decisions.

The development of students' decision-making skills and their ability to apply scientific knowledge, principles, and thinking to making decisions is both a challenge and an opportunity for science educators. Decision-making requires complex and high-level cognitive skills that can be improved with guided experience and practice.

Numerous aspects--beyond the purely scientific--must be considered when addressing many issues in today's rapidly changing, highly technical society. This challenges educators to integrate material across subject area boundaries. The initial focus in science classes is on identifying and stating the issue, separating the scientific and technical aspects, and gathering relevant information. Supporting activities will be under way in other classes such as language arts, history, social studies, and technical education. Coordination among the classes will lead to refinement and amplification of the issue, identification of its important dimensions, and an appreciation and understanding of the complexity of the problem.

The decision-making processes outlined here are broad-based and rational, but they should not be considered formalistic or rigidly linear. The general steps can be entered at different points, and one or more elements or sequences may be repeated in an iterative way. In addition to flexibility, focusing on particular aspects of decision-making has value and may be preferred at times to completing the entire decision-making procedure. As an example, evaluating a proposed solution for its scientific feasibility can be done without having to make a final decision.

The ability to make an informed rational approach to decision-making will be a major accomplishment for most students in grades 9 through 12. It will depend on the development of a foundation of scientific knowledge and inquiry skills and on having numerous opportunities to apply the knowledge and the skills in making decisions. In turn, the decision-making activities will provide a motivational context for learning science and for students' to develop an understanding of the scientific knowledge involved.

A particularly challenging task for students is cultivating the open-mindedness necessary for considering and formulating multiple alternative solutions. Students must be encouraged continuously to examine a problem from different perspectives. Discussions in small groups can formulate alternative solutions, which individuals can investigate further.

B. Decision-making Skills

By the end of grade 12, all students should have developed the following decision-making skills. They should be able to:

- o identify and state clearly an issue of personal, civic, national, or global significance that is of high interest to them. The statement must be in a form that requires a decision; for example: "How will the county dispose of its garbage after the present landfill has reached capacity?"
- o identify important dimensions of the issue such as the scientific, political, ethical, cultural, technological, and economic impacts.
- o gather information about the scientific and technological aspects of the issue, including relevant principles, concepts, and data.
- o generate a set of alternative solutions that address all dimensions of the issue.
- o evaluate each proposed solution in light of its scientific and technological aspects and recognize when an incomplete knowledge base may result in uncertainty and ambiguity.

- o decide which alternative is preferred and justify the choice based on its scientific and technological merits. Attention should be paid to the limitations and constraints introduced by nontechnical aspects of each alternative solution.

- o present a solution and participate in a consensus-building activity to arrive at a group decision. Consideration must be given to the competing solutions and to the constraints introduced by the values and information from the other dimensions.

To demonstrate their development of these skills, students should be able to carry out each step of the process if the content of the preceding steps is provided. In addition, students or a group of students should be able to carry out the entire process and document it in writing or on a video recording.

C. Understanding Decision-making Processes

The ability of students to use the decision-making process outlined in this standard is related to their understanding of it. By the end of grade 12, students should have developed the following understandings:

- o Each part of the process has an important function and contributes to the total process. The total process can occur in different ways (orders), but all of the parts play important roles.

- o Many complex problems can be made more manageable by breaking them into small subproblems or dimensions.

- o It is important to consider multiple perspectives or dimensions of a question in order to reach the highest quality and most widely accepted solution. The goal of public decision-making should be to produce the greatest amount of good for the greatest number of people without denying the rights of majorities and minorities.

- o Often, decisions must be made with less information than desired or with an inadequate understanding or agreement (even by the experts) of the scientific principles involved.

- o Scientific understanding is an essential, but not a sufficient, ingredient for decision-making; however, science alone cannot provide the decision. It can help to clarify some of the issues and to determine scientific or technological feasibility. Nevertheless, in the end, social, political, economic, and ethical values will influence the decision significantly.

- o In complex, real-life situations, there seldom is an easily-agreed-upon, ideal decision. Instead, the "best" decision should be considered the one made by a group in a cooperative democratic way using the best information available.

To demonstrate their understanding of decision-making, students should be able to describe the role and purpose of each step and how their combination of steps produces a quality decision. To do so, they can analyze a written or video-recorded account of a decision-making episode and critique the appropriateness of the actions taken in each step. Students also will be able to evaluate the accuracy of the science used in the process and the contributions it made to the decision.

D. Experiences That Can Help Students to Develop the Skills and Related Understandings Associated With This Standard

In selecting or developing a science-related, decision-making activity, such as the example given below, these criteria should be considered in selecting the issue or problem:

- o The problem should have a large science component, for which information is readily available.
- o The problem should have relevance to students.
- o The science ideas associated with the problem should depend upon and reinforce other school science content and the students' experience.
- o The scope of the problem should be sufficiently limited so that students can reach a decision in a reasonable amount of time.

The Activity

1. An industrial park is planned on a local, undeveloped, flood plain. Debate in the community rages around the question, "Should the industrial park be built?"

2. What are the dimensions of the problem? Local experts can visit the class and discuss the significance of the flood plain to the community--economics, zoning, the history of past flood events, and the like. Students will prepare lists of topics on these points for further investigation, identifying those that are scientific and technical and those that represent other values and dimensions, such as economic, political, social, religious, and ethical viewpoints. (These other dimensions may be considered in other parts of the curriculum.)

3. Small groups in the science class will be assigned the tasks of identifying the local flood plain, analyzing hydrologic and precipitation records for the region in order to estimate the recurrence intervals of floods and precipitation events, and confirming current and planned uses for the flood plain. They will consider the history of past floods and their impact on the community (which, again, may be addressed in non science subject matter classes). They will conduct investigations at the river; for example, measuring discharge, determining the dimensions of the flood plain, and examining the sedimentary structure (graded bedding) of the flood plain.

4. The small groups will generate alternatives for current and future uses of the local flood plain. These alternatives may range from the continuation of current practice to controlled development such as relocating the residents or rerouting the river, developing parks, or leaving the river in a natural state. The students will be asked to consider possible alterations to the river to protect or allow development.

5. The groups will evaluate the alternatives based on scientific principles and on information they have collected such as the recurrence intervals of floods and the probability of a flood occurring during any given year. (Consideration of other dimensions such as economics, politics, and social concerns should be brought in from other content areas at this point.)

6. Each group will decide on a preferred alternative and prepare a presentation justifying its choice. The presentation will reflect scientific, technical, and other dimensions.

7. Each group will present its recommendation to the class in a seminar like setting. The teacher may use this as an opportunity to build consensus.

APPENDIX A:

THE PHILOSOPHY OF SCIENCE

THE PHILOSOPHY OF SCIENCE

Philosophers of science examine the nature of science, the characteristics of scientific knowledge, and assumptions about the natural world that guide the work of scientists.

Philosophers recognize that science is complex and multifaceted. However, common responses to the question, "What is science?" usually focus on a single facet. Many school science programs today mirror a single-faceted view of the subject. The National Science Education Standards set expectations for school science that acknowledge the complexity of science. These are the facets of science that will be reflected in the standards:

- a body of information and a collection of theories, laws, and principles (usually expressed mathematically) that have been verified by the scientific community and are used by it to explain and predict natural phenomena;
- a method of inquiry that is practiced by a community of scholars called scientists;
- the rules of evidence and argumentation used by scientists to verify the body of information, theories, laws, and principles;
- the search for understanding and control of the natural environment that preoccupies much of humanity.

This last facet illustrates the close association of science and technology in the public's mind. Making explicit this relationship as well as making distinct these two activities are appropriate tasks for school science.

Philosophers hold different views of the nature of reality and whether scientific knowledge is true or simply valid. These views include such perspectives as:

- scientific observations can be entirely objective;
- scientific observations are not totally objective;
- a scientific theory is not "proved" to try to establish its truth, existence, or validity; rather, it is accepted if there is an adequate fit or conformity between the theory and existing scientific knowledge.

Two competing paradigms of science have been the focus of disagreements among historians, philosophers, and sociologists. The older, referred to as logical positivism, is characterized by arguments for the objectivity of scientific observation and the truth of scientific knowledge.

A more contemporary approach, often called postmodernism, questions the objectivity of observation and the truth of scientific knowledge. Advocates of this position argue that scientific observations are not totally objective because the observations to be made, the topics to be investigated, and the hypotheses to be tested are affected by the values, experiences, language, and culture in which scientists operate. This concept asserts that knowledge is a mental representation of the natural world. This concept differs from logical positivism in that it acknowledges that the mental representation constructed by the individual is influenced by prior experiences, understandings, language, and culture. In this view, a scientific theory is not "proved" true; rather, the fit between the theory and the existing knowledge base, as well as the goals of the individual or of the intellectual or social community, are examined.

Knowledge is both personal and public in that it belongs to the individual and to society. Personal knowledge is viable to the individual knower, while communal knowledge is judged viable by a community of individuals according to the principles of logic and rules of evidence that the community has accepted. Both personal and communal knowledge are provisional and subject to amendment or modification if the knowledge does not remain viable.

The National Science Education Standards are based on the postmodernist view of the nature of science.

APPENDIX B:

THE PSYCHOLOGY OF LEARNING SCIENCE

THE PSYCHOLOGY OF LEARNING SCIENCE

Learning science is epitomized by a process of making sense of new experiences that are interpreted by the learner in light of previous information and then consolidated into his or her knowledge base. Several areas of research in cognitive science have contributed to this understanding of how science is learned and are discussed below.

The Language of Science

One line of research has probed discrepancies between the knowledge that a teacher presents to students and the information that is received by them. For example, the definitions that scientists have for certain words differ significantly from their everyday meanings. Beginning physics students use the everyday meaning of "velocity," which involves only the speed of an object, rather than the physicist's definition of "velocity," which involves both speed and direction. Students may define the word appropriately, but they apply the everyday meaning and misunderstand the interactions between force and velocity.

"Alternative Frameworks"

Scientific language is not the only source of confusion between the personal knowledge of the learner and scientific knowledge. Students also bring their own preexisting theories, or "alternative frameworks," into the science classroom. These spontaneous theories of the natural world are results of the learner's previous experiences and have not been subjected to the rigorous examinations for viability, internal consistency, and fit that scientific theories have.

These "alternative frameworks" are remarkably persistent. There is evidence that students can succeed in schooling through the college level without acquiring an understanding of underlying scientific principles. The existence and persistence of students' previous knowledge have serious implications for their instruction and for the assessment of what they have learned in school.

At best, scientific theories survive this mismatch by being relegated to information that is applicable only in the school setting and acceptable only as a mechanism for getting a high mark in the appropriate class. Students are frequently very explicit about this relegation of scientific knowledge as they talk about "cramming for the test and then dumping the information."

There is evidence that "alternative frameworks" must be addressed directly. Students must have, and reflect on, experiences that cannot be explained by their "alternative frameworks."

Context

The culture of the learning environment has a major effect on how willing students are to learn and on how much they assimilate. Several researchers have concluded that knowledge taught and learned in school is of limited value in the world outside school. Many of the general skills and much of the knowledge acquired in the school setting are used only in formal tests, even though it has been shown that the context in which situation-specific knowledge and skills are learned improves their applicability. Several aspects of school culture have been the focus of research on motivation and achievement.

Numerous studies have demonstrated that people are more successful at work-related tasks than they are in applying algorithms to similar academic tasks. Frequently, even adults manipulate objects in the environment to solve practical problems. Unfortunately, the use of physical objects in the solution of academic tasks is denigrated in favor of mental manipulations. Reasoning strategies developed in the context of the workplace are more adaptable to new situations than are algorithms learned in school.

Social Interactions

The degree of social interactions is another distinction between tasks performed in the workplace and those done in the school setting. In most work situations, many tasks are solved by interacting with others, which widens the information base brought to bear on the task and provides social support and encouragement to complete the task. Working cooperatively in groups has been reported to increase achievement, retention, and critical reasoning skills.

Interactions with others while completing a shared task in school result in the learner improving understanding of the concept, reflecting on the learning processes, increasing his or her level of thinking, and enhancing the quality of reasoning strategies. It has been demonstrated that students achieve more and retain more information if they are given the task of resolving different ideas together.

Social interactions in the classroom can be orchestrated in various ways. Some group interactions call for the assignment of specific roles to students while others involve the entire class. Some strategies allow the teacher to model the correct method and give students the opportunity to practice the desired skills, which are improved by feedback from the teacher and from class peers. One strategy to teach students to perform complex tasks calls for the teacher to provide intellectual scaffolding early in the learning process in order to make the structure of the solution clear to the student. As the student gains proficiency in the components of the larger task, the scaffolding is reduced.

The focus on social interactions in the classroom is important and is consistent with material presented in Appendix A on the postmodernist view of learning. A major goal of school science education is to facilitate the transition of the learner's personal knowledge of the natural world into knowledge that is accepted by the scientific community. One psychologist has demonstrated that children's ideas about the natural world change as they come into contact with scientifically accepted ones during conversation. This is the principle behind restructuring the science class into a community of inquirers.

APPENDIX C:

CRITIQUE AND CONSENSUS: CALL FOR FEEDBACK

FAST PASS

THANK YOU FOR PROVIDING US WITH YOUR FEEDBACK. Please take a few moments and complete the form below. In order to provide us ample time to consider your comments before the distribution of the next document, **PLEASE RETURN TO US BY JANUARY 15TH.**

This is the first of two feedback forms, both constructed in ways as to gather the information we want, both general and specific, in the format most convenient for you--checklist and open ended.

If you have time only to read the document and fill out your responses quickly, please fill out this page only. If you have time for a thorough reading and/or critique, please complete the second survey. Some of the questions ask you about yourself. All information is optional, of course, but it will help us to identify patterns in the responses.

Did you see the October Discussion Document? ☐yes ☐no

If so, did you give us feedback? ☐yes ☐no

If so, do you see any progress in the direction you hoped? ☐yes ☐no
Please describe:

Occupation____________________________

State of Residence?_____________________

How did you hear about the National Science Education Standards effort (e.g. conference, publication, word of mouth)?________________

What I like **best** about the document:

What I like **least** about the document:

An area which I feel needs clarification:

Please rate the following prototype standards:

	excellent	very good	fair	poor
Prototype Standard for Modes of Inquiry	○	○	○	○
Prototype Standards for Matter and Its Interactions	○	○	○	○
Prototype Standard for Decision-Making	○	○	○	○

Please Mail to: **NCSESA Critique & Consensus**
National Research Council
2101 Constitution Ave., NW
HA486
Washington, DC 20418

LONG FORM

Please take this time to provide us with further input and comments on the science education standards document. Again, in order to ensure that we consider your comments before we distribute our next document, please return them to us as soon as possible, but no later than **JANUARY 15TH**. Responses received after this date, are certainly welcome; however, we may not be able to review your concerns prior to distribution. **THANK YOU!!!**

If you have time only to read the document and fill out your responses quickly, please fill out the ***fast pass*** survey. If you have time for a thorough reading and/or critique, please complete this survey, the ***long form***. Some of the questions ask you about yourself. All information is optional, of course, but it will help us to identify patterns in the responses.

Did you see the October Discussion Document? ☐yes ☐no
If so, did you give us feedback? ☐yes ☐no
If so, do you see any progress in the direction you hoped? ☐yes ☐no
Please describe:

Name______________________________

Address______________________________
____

Telephone Number______________________

Occupation__________________________

How did you hear about the National Science Education Standards effort (e.g. conference, publication, word of mouth)?________________

What I like **best** about the document:

What I like **least** about the document:

An area which I feel needs clarification:

The following group of questions correspond to the Sections in the document. For each Section please indicate how carefully you read the document, and give us a quick rating of how you think we addressed the section. Then, provide any additional comments or advice for improvement in the space provided.

SECTION I: INTRODUCTION

I read the section: very carefully ☐, fairly carefully ☐, skimmed it ☐

I think you addressed the topics in this section: well ☐, adequately ☐, poorly ☐

Additional comments:

SECTION II: THE GOALS OF SCHOOL SCIENCE EDUCATION

I read the section: very carefully ☐, fairly carefully ☐, skimmed it ☐

I think you addressed the topics in this section: well ☐, adequately ☐, poorly ☐

Additional comments:

SECTION III: THE CHARACTER OF SCHOOL SCIENCE

I read the section: very carefully ☐, fairly carefully ☐, skimmed it ☐

I think you addressed the topics in this section: well ☐, adequately ☐, poorly ☐

Additional comments:

SECTION IV: THE STANDARDS FOR SCHOOL SCIENCE

I read the section: very carefully ☐, fairly carefully ☐, skimmed it ☐

I think you addressed the topics in this section: well ☐, adequately ☐, poorly ☐

Additional comments:

The following questions pertain to important issues which the science standards will address. Please state your views on each of the topics.

One reaction we heard from many people regarding the October discussion document was that technology should be part of the science curriculum. We are trying to understand what people mean when they say this. Some people think that the boundaries between science and technology are fuzzy or nonexistent. Others make distinctions between science and technology and among the different kinds of technology–applied science, principles of engineering, and design. Do you see the distinctions? Why or why not?

If the distinctions are a helpful way to think about the territory of school sciences, please indicate how you would allocate 100% of the science instructional time among these categories of emphasis:

natural sciences__________
applied science__________
principles of engineering__________
design__________

Please rate the following prototype standards:

	excellent	very good	fair	poor
Prototype Standard for Modes of Inquiry	○	○	○	○
Prototype Standards for Matter and Its Interactions	○	○	○	○
Prototype Standard for Decision-Making	○	○	○	○

What comments and suggestions do you have regarding these prototype standards?

Please return to:
NCSESA Critique & Consensus
National Research Council
2101 Constitution Avenue, NW
HA 486
Washington, DC 20418

APPENDIX D:

PROJECT PERSONNEL AND ORGANIZATIONAL LIAISONS

Table 1
NATIONAL COMMITTEE ON SCIENCE EDUCATION STANDARDS AND ASSESSMENT

EBERT, James D. (Chair), Vice-President, National Academy of Sciences, Washington, D.C.; President, Marine Biological Laboratory, Woods Hole, Massachusetts.

ALBERTS, Bruce M., American Cancer Society Research Professor of Biochemistry, University of California, San Francisco, California.

ALEXANDER, JR., Joseph K., Assistant Associate Administrator, NASA Office of Space Science and Applications, Washington, D.C.

ARCENEAUX, Janice M. H., Chair, Chemistry Department, Milby High School Science Academy, Houston, Texas.

ATKIN, J. Myron, Professor of Education, Stanford University, Palo Alto, California.

BARTON, Jacqueline K., Professor of Chemistry, California Institute of Technology, Pasadena, California.

BELTER, Catherine A., Chair, National Parent Teachers Association Education Commission, Springfield, Virginia.

BROWN, Rexford G., Executive Director, State Systems Change Initiatives; Director, Policy and Higher Literacies Project, Education Commission of the States, Denver, Colorado.

BRUNKHORST, Bonnie J., Professor of Science Education/Geology, Institute for Science Education, California State University, San Bernadino, California.

BUGLIARELLO, George, President, Polytechnic University, Brooklyn, New York.

CHAMOT, Dennis, Executive Assistant to the President, Department for Professional Employees, AFL-CIO, Washington, DC.

DELACOTE, Goery, Executive Director, The Exploratorium, San Francisco, California.

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GLASER, Robert, Director, Learning Research and Development Center, University of Pittsburgh.

GLASHOW, Sheldon Lee, Mellon Professor of Science, Harvard University, Cambridge, Massachusetts.

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MILLS, Richard P., Commissioner of Education, State of Vermont, Montpelier.

MOHLING, Wendell G., Instructor, Space Education Workshops for Teachers; Director, Outdoor Laboratory at Shawnee Mission Northwest High School, Shawnee Mission, Kansas.

OAKES, Jeannie, Professor of Education, University of California, Los Angeles, California.

OGLESBY, James R., Assistant to the Chancellor, and Professor of Education, University of Missouri-Columbia, Columbia, Missouri; Former President, National School Boards Association.

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WORTH, Karen, Chair, Working Group Science Teaching Standards

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McWETHY, Patricia, Executive Director, National Association of Biology Teachers, Reston, Virginia.

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Table 2
National Committee on Science Education Standards and Assessment
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Aboriginal Science and Math Pilot Project (Brenda LaFrance)
American Federation of Labor-Congress of Industrial Organizations (Dennis Chamot)
American Association for the Advancement of Science (F. James Rutherford)
American Association for Higher Education (Kati Haycock)
American Association of Physics Teachers (James Stith; Carol-ann Tripp, Task Force Chair)
American Association of Publishers (Don Eklund)
American Astronomical Society (Mary Kay Hemenway)
American Chemical Society (Sylvia Ware)
American Council of Learned Societies (Michael Holzman)
American Geological Institute (Marcus Milling)
American Geophysical Union (Frank Ireton)
American Indian Science and Engineering Society (Norbert Hill)
American Institute of Aeronautics and Astronautics (Beth Katzoff)
American Meteorological Society (Ira Geer)
American Physiological Society (Robert Carroll/Frank Powell/Martin Frank)
American Society for Biochemistry and Molecular Biology (David Brautigan)
American Society for Cell Biology (Elizabeth Marincola)
American Society for Microbiology (David Scott)
Arkansas Network of Academic Alliances (Bonnie Moody)
Association of Astronomy Educators (Katherine Becker)
Association for Supervision and Curriculum Development (Brian Curry)
Association for the Education of Teachers of Science (Catherine Yeotis)
Association of Mexican American Educators (Theresa Montaño)
Association of Science Technology Centers (Andrea Anderson)
Association for Women in Science (Harlee Strauss)
Astronomical Society of the Pacific (Andrew Fraknoi)
Board and Education Standards Program, Department of Education (Debra Nolan)
Board on Physics and Astronomy (Don Shapero)
California Science Implementation Network (Kathy DiRanna)
Center for Applied Biotechnology and Agriculture (Susan Spencer)
Center for Applied Linguistics (Deborah Short)
Center for Civic Education (Margaret Branson)
Centers for Disease Control (Peter Cortese)
Center for the Study of Evaluation (Brenda Sugrue)
Center on Organization and Restructuring of Schools (Fred Newmann)
Challenger Center for Space Science Education (Amy Bordeaux)
Chemical Education for Public Understanding Program (Herb Thier)
Coalition for the Advancement of Science Education in Massachusetts (Michael Zapantis)
Coalition for Education in the Life Sciences (Amy Chang)
Coalition of Essential Schools (Joseph McDonald/Mary Hibert)
Consortium for Policy Research in Education (Diane Massell)
Council for Aid to Education (Diana Rigden)
Council for Basic Education (Ruth Mitchell)
Council for Elementary Science International (Eileen Bengston/Charles Barman)
Council of Chief State School Officers (Rolf Blank/Edward Roeber)
Council of State Science Supervisors (Bill Spooner)
Council on Foundations (Mary Leonard)
DC Science Educators Association (Almetta Hall)
Earth Sciences Coalition (Chip Groat)
Education West (Maureen Shiflett)
Florida Department of Education (Dr. Martha Green)

Foundation for Science and the Handicapped (E.C. Keller)
Geological Society of America (Edward E. Geary)
Hispanic Secretariat (Betty Mandel)
International Planetarium Society (William Gutsch)
International Reading Association (Brenda Townsend)
International Technology Education Association (Kendall Starkweather)
Laboratory Safety Workshop (James Kaufman)
Maryland Association of Science Teachers (Donald Lewis)
Massachusetts Association of Science Supervisors (Nick Micozzi)
Mathematical Sciences Education Board (Mary Harley Kruter)
Mississippi Science Teachers Association (Bess Moffatt)
Music Educators National Conference (John J. Mahlmann)
NASA Classroom of the Future Project (Craig Blurton)
National Action Council for Minorities in Engineering (George Campbell)
National Alliance of Black School Educators (to be appointed)
National Association of Biology Teachers (Pat McWethy)
National Association of Geology Teachers (Robert Christman)
National Association for Research in Science Teaching (Emmett Wright)
National Association for Science Technology & Society (Robert Yager)
National Board for Professional Teaching Standards (Judith White)
National Center on Educational Outcomes for Students with Disabilities (Jim Shriner)
National Center for History in the Schools (Linda Symcox)
National Center for the Improvement of Science Education (Ted Britton)
National Center for Science Education (Eugenie Scott)
National Center for Science Teaching and Learning (Arthur White)
National Council for Geography Education (Susan Munroe)
National Council of Teachers of English (Kathy Karle)
National Council of Teachers of Mathematics (James Gates)
National Earth Sciences Teachers Association (Frank Ireton)
National Education Association (Glen Cutlip)
National Governors Association (Jean McDonald)
National Middle Level Science Teachers Association (Linda Maier/John Jaeschke)
National Network of Regional Science and Mathematics Consortia (Robert Larson, Robert Roth, Dena Stoner)
National Research Center on Student Learning (Robert Glaser)
National Science Resources Center (Douglas Lapp)
National Science Supervisors Association (Harold Pratt)
National Science Teachers Association (Bill Aldridge; John Staver, Task Force Chair)
New York Academy of Sciences (Beatrice Klier)
NSF SSI Technical Assistance Project (Brian Lord)
Phi Beta Kappa (Douglas Foard)
Rhode Island Science Teachers Association (Judith Sweeney)
School Science and Math Association (Darrel Fyffe)
Science Association for Persons with Disabilities (Janet Davies)
Science Outreach Program/The Rockefeller University (Bonnie Kaiser)
Sigma Xi (Jackie Langston)
Society for the Advancement of Chicanos and Native Americans in Science (J.V. Martinez)
Society for College Science Teachers (Rebecca Halyard)
Society of Elementary Presidential Awardees (Stephen Blume)
Society of Hispanic Professional Engineers (Melissa Villegas)
Society of Mexican American Engineers and Scientists (Ralph Gonzalez)
Spokane Public Schools (Scott Stowell)
The Evaluation Center (Zoe Barley/Mark Jenness)
Triangle Coalition for Science and Technology Education (Lauren Williams)
U.S. Metric Association (Lorelle Young)