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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. The following chapters are included; (1) "Introduction"; (2) "Taking Up the Challenge"; (3) "A Framework for the Content Standards"; (4) "Fundamental Understandings and Prototype Standards for the Physical Sciences"; (5) "Fundamental Understandings for the Life Sciences"; (6) "Nature of Science"; (7) "Application of Science"; and (8) "Context of Science." (PR)

National Science Education Standards:
An Enhanced Sampler

A Working Paper of the

National Committee on Science Education Standards and Assessment

National Research Council

February, 1993

PREFACE

National Science Education Standards
Background on the Project

It has been just three years since the announcement by the President and the National Governors Association of their unprecedented agreement on national education goals; a little more than two years since the acceptance of the national standards concept by these leaders and the National Education Goals Panel, giving rise to its offspring, the National Council on Education Standards and Testing; and about one year since a full battery of efforts to develop national standards for curricula in various disciplines was launched with the support of the U.S. Department of Education.

National Standards: What Are They?

Given the fact that we talk so freely about such ideas today, it is difficult to appreciate the circumstances in late 1988, only a year before President Bush and the nation's governors, led by Governor Clinton, held their National Education Summit. The finishing touches were being put on the National Council of Teachers of Mathematics' (NCTM's) *Curriculum and Evaluation Standards for School Mathematics* and the National Research Council's (NRC's) *Everybody Counts: A Report to the Nation on the Future of Mathematics Education* and there was great apprehension about whether the open talk of national goals and standards in these documents might set off a sort of educational-political fire storm, raising the specter of national interference with the authority and prerogatives of the states and localities. To appreciate why this didn't happen, and to see why the idea of national standards is now held to be "right", it is important to understand something about what is meant, and what is not meant by "standards" in this context -- what the concept is, as applied to any of several major disciplinary areas:

- National standards for curricula should be goals for young people in different age brackets to strive for -- demanding but attainable learning goals providing a vision of what we want all of our young people to know and be able to do.
- They must not be reducible to a set of minimum competency thresholds.
- The standards should help states, localities, teachers and others who select or develop curricula or frameworks -- allowing for local variation and adaptation but providing sufficient consistency from school to school, town to town, and state to state that a change of schools or household move does not create educational chaos for the student.
- They must not be federally mandated; their use by teachers, schools, districts, or states should be voluntary.
- The standards should be openly accessible and presented in narrative form with illustrative examples, so as to be readable by those whom they affect and those who will effect their use: students, teachers, administrators, parents, school board members, legislators, etc.
- They must not be pronouncements from on high, but should emanate from the teaching profession with strong involvement of disciplinary experts, educators, and key constituencies.
- It is important to develop professional standards for teaching as well as assessment standards, both aligned with the valued learning defined in the curriculum standards -- the goal being to have three interrelated sets of standards, covering curriculum, teaching, and assessment, all backed by nationwide consensus support.

The Movement Toward Science Standards

Science education was also on the move in the last decade. Before *A Nation at Risk* issued its clarion call for general reform, the National Academies of Sciences and Engineering (1982), the National Science Board (1983), and other groups called to the country's attention the urgency of strengthening the science and mathematics education of the nation's young people, emphasizing that science was something needed by the many, not the few. By the middle of the decade, the American Association for the Advancement of Science (AAAS) also had underway its ambitious multiyear undertaking called *Project 2061*, which in 1989 published *Science for All Americans*, describing school learning outcomes appropriate for *all* students. In 1985, the National Academy of Sciences (NAS) and the Smithsonian Institution established the National Science Resources Center (NSRC) to develop and promulgate materials and resources for hands-on science in the elementary schools. The Education Development Center (EDC), the Biological Sciences Curriculum Study (BSCS), the Lawrence Hall of Science, and other organizations continued their active involvement. In the late 1980s, the National Science Teachers Association started its *Scope, Sequence & Coordination Project* in secondary school science, which has recently published its *Content Core* to guide curriculum developers. By the end of the last decade, other projects of significance were underway around the country, including efforts to develop state science frameworks.

As the 1990s began, many science education leaders were asking how to bring all of this work together in support of nationwide systemic reform. The pressure to find a way was increased by the national events described earlier, principally the strong entry of the governors and the President into education. [A 1993 update: With Governor Clinton having become President Clinton and the National Governors' Association led by Governor Roy Romer of Colorado, we can expect continued acceleration of education efforts.]

National Science Standards: A Concerted Effort Begins

In the spring of 1991, the President of the National Science Teachers Association (NSTA), acting on the basis of a unanimous vote of the NSTA Board, wrote to Dr. Frank Press, Chairman of the National Research Council (NRC), asking the NRC to convene and coordinate a process that would lead to national science education standards, K-12. This request was seconded by the presidents of several leading science and science education associations, as well as the U.S. Secretary of Education, the Assistant Director for Education and Human Resources at the National Science Foundation, and the Co-Chairs of the National Education Goals Panel.

The NRC leadership was anxious to help, but initially exercised caution, because they would be entering the rightful domain of the teaching profession, and they were well aware of the complexity of the undertaking needed. This complexity derives from the fact that science in U.S. schools is a considerably more heterogeneous field than is mathematics, in part because several strong disciplines are involved and in part because an organized K-12 curriculum is wanting. Traditionally, science has had a weak presence in elementary school, a stronger presence in higher grades, but with rather sharp separations by the disciplines of biology, chemistry, and physics, typically taught in one-year courses taken by 95%, 45%, and 20% of high school students, respectively. In recent decades, the earth, atmospheric, and space sciences have grown to be a stronger part of this mix. Coordinated action, bringing the secondary school disciplinary faculties together and linking them to elementary teachers, has always seemed a daunting task. Yet in 1991 there was a recognized urgency to doing this, in order to move the science reform effort ahead in parallel with other efforts and to help science gain the full curricular presence that is called for in an increasingly knowledge-based, technology-intensive society. After extensive discussions with leaders in science education and science teaching organizations, the NRC agreed to take the lead.

The Science Standards Effort: Getting Organized

On September 16, 1991, just ten weeks after the NSTA letter had reached Dr. Frank Press, Secretary of Education Lamar Alexander announced the award to the NRC of a grant to support start up activities. Over the fall, the NRC developed a general design and time plan for the project, and Dr. James Ebert, Vice President of the National Academy of Sciences, was designated as Chair of a National Committee on Science Education Standards and Assessment (NCSESA), to oversee both development of science education standards and a nationwide critique and consensus process.

As 1992 began, a Chair's Advisory Committee was formed, consisting of representatives of the National Science Teachers Association, the American Association for the Advancement of Science, American Association of Physics Teachers, American Chemical Society, Council of State Science Supervisors, Earth Science Education Coalition, and the National Association of Biology Teachers, to assist in planning the project and helping steer it throughout its lifetime. This group participated directly in a process lasting through the spring to identify and recruit Co-Directors of the staff and 89 volunteers to serve on the 36-member oversight committee (NCSESA) and its three working groups, dealing with curriculum standards, teaching standards, and assessment standards.

Carrying out the Task

Preparations for work on the intellectual substance of the standards began in the fall of 1991. Staff of the NRC were assigned to produce *Science Framework Summaries*, based on the work of NSTA Scope, Sequence & Coordination, AAAS Project 2061, and other projects, as well as state science frameworks, and science standards from other countries. This compendium was made available to the working groups and the national committee when they started work.

The National Committee on Science Education Standards and Assessment (NCSESA) first met in May, 1992, and -- following organizational meetings that same month -- the three working groups each had intense working sessions in the summer of 1992. The Curriculum Working Group devoted four weeks to sorting out the initial framework for standards. The spring and summer efforts also produced the detailed plan and structure for the National Science Education Standards Project. One of the early decisions was to go for an integrated volume containing curriculum, teaching, and assessment standards displayed in mutually re-enforcing ways. Another committed the working group chairs to functioning as a team throughout the project. A third was to take the critique and consensus process very seriously, issuing frequently both updates on the project and draft materials suitable for intense critique by teachers, subject matter experts, and others. Using feedback from working papers released in October and December of 1992, and February, 1993, plus further intense work over the spring, it is planned to have an overview of the curriculum standards, together with initial work on teaching and assessment standards, available by the summer of 1993, to be very widely critiqued. The first (and still preliminary) integrated draft of curriculum, teaching, and assessment standards will appear late in 1993. The overall goal is to have the final version published before the end of 1994.

Summary Statement of Task

National Science Education Standards, developed through a nationwide development, critique, and consensus-building initiative involving teachers, scientists, and other educators -- together with parents, policy makers, and a broad base of interested citizens -- will provide by the end of 1994 the qualitative criteria and framework for judging science curricula, teaching, and assessment. The standards will:

- define the understanding of science that all students, without regard to background, future aspirations, or prior interest in science, should develop;
- present criteria for judging science education content and programs at the K-4, 5-8, and 9-12 levels including learning goals, design features, instructional approaches, and assessment characteristics;
- include all natural sciences and their interrelationships, as well as the natural science connections with mathematics, technology, social science, and history;
- include standards for the preparation and continuing professional development of teachers, including resources needed to enable teachers to meet the learning goals;
- propose a long-term vision for science education -- some elements of which can be incorporated almost immediately in most places, others of which will require substantial changes in the structure, roles, organization, and context of school learning before they can be implemented;
- provide criteria for judging models, benchmarks, curricula, and learning experiences developed under the guidelines of on-going national projects, or under state frameworks, or local district, school, or teacher-designed initiatives; and
- provide criteria for judging teaching, the provision of opportunities to learn valued science (including such resources as instructional materials and assessment methods) and science education programs at all levels.

Financial Support

The National Science Education Standards project was started with funds from the U.S. Department of Education, which is also supporting development of curriculum standards. Work on teaching and assessment standards plus the extensive critique & consensus process are being supported by a coalition of federal agencies led by the National Science Foundation, the National Aeronautics and Space Administration, the U.S. Department of Energy, the U.S. Department of Agriculture, and the National Institutes of Health.

FOREWORD

This document is a precursor to the volume that will contain the National Science Education Standards. It is one of a series of working papers that started with the Discussion Document issued in October, 1992 and the Sampler issued in November, 1992. Its release is part of the Critique & Consensus process of the National Science Education Standards effort, with the purpose of inviting the education community and other constituencies to suggest and react to particular ideas, especially the proposed substance and form of the standards -- both of which are evolving under constant review. This Enhanced Sampler should not be viewed as a draft of the final standards report. A more complete treatment of the curriculum standards, together with initial work on teaching and assessment standards, will be available by the summer of 1993, to be very widely reviewed. What might be called a first draft, integrating curriculum, teaching, and assessment, will be developed over the fall for release in late 1993.

An Invitation

In Appendix A, you will find a survey that will help us in collecting feedback. Please capitalize on this opportunity to communicate your concerns and advice, noting the deadline of May 1, 1993 for responses.

Like its predecessor the November Sampler, this Enhanced Sampler focuses on: (a) frameworks for science content; and (b) prototype content standards. Two basic kinds of enhancements have been made: (i) expansion and modification of the introduction, making more clear the context for standards development and responding to some reviewer criticisms; and (ii) addition of sets of fundamental understandings in physical sciences and life sciences. We also eliminated what in some early copies of the Sampler were Appendices A and B, dealing with philosophy and psychology, though these topics will be addressed in appropriate ways in later documents.

We have included specific commentary on feedback received by January 15, 1993, indicating how various concerns either have been or will be dealt with. In cases where reviewer comments referred to a particular portion of the text, the commentary has been included in a textbox placed near the relevant new text. In many cases, the comments were of a more general form. For example, numbers of comments were made about readability, redundancy, and organization. This version has been edited to produce a more readable, consistent, and accessible tone and more logical organization.

The most frequent general comments identified areas that reviewers felt had been given insufficient attention. One of these is the amount of detail given concerning the frameworks and sample standards and, as stated above, this has been strengthened. Another is the balance between and among the body of scientific knowledge, the nature of science, and the contexts of science. In the November Sampler, three prototypes were presented, one in each of three major science content categories of fundamental understandings, modes of inquiry, and applications of science. Some reviewers thought that this implied an equal attention to these three categories in the final document, or perhaps inadequate attention to category one. Although the full scope of that document has not been delineated, fundamental understandings will surely be strongly emphasized.

The treatment of issues of equity, in terms of what is said as well as tone and manner of expression, concerned numbers of reviewers. Considerable attention has been paid to this in the editing and rewrite, and clarifications have been made at key points.

What Is Not In This Document

Four major areas to receive more serious attention in later documents are:

1. Teaching and Assessment Standards

The final document on National Science Standards will address teaching and assessment as essential components, along with curriculum. The working group chairs in these areas have been assisting with curriculum standards and are not as far along in their own work, which explains why there is less emphasis on teaching and assessment standards in the present draft.

2. Mathematics

Many people have pointed out the importance of dealing with connections between mathematics and science, and felt that this received too little emphasis in the November Sampler. We agree about the importance. The Mathematical Sciences Education Board (MSEB) has offered to convene mathematicians and mathematics educators to help us.

3. Technology

The treatment of technology continues to need clarification. Our concern at this stage is not instructional technology, but the role of technology in the science curriculum. Reviews thus far indicate several concerns with the working papers and a range of opinions regarding what to do about these concerns. Work on the general issue continues within the three Working Groups.

4. Implementation

Many individuals have expressed concern about the feasibility of implementing the new science education standards. We acknowledge that implementation will require strong support on each tier of the education system, and will address needed resources in the final standards report. We are working with the NRC's Committee on a Nationwide Education Support System for Teachers and Schools (NESSTS) as well as science and science education associations, and many other education and policy organizations to help build the needed implementation structures.

Revisions for this *Enhanced Sampler* were prepared as a team effort by the staff and working group chairs of the National Committee on Science Education Standards and Assessment (NCSESA), with input from working group members. It is a working paper, not a committee-approved draft. Early sections utilize material that also appears in a paper, "Science for All: Getting It Right for the 21st Century", by Kenneth M. Hoffman and Elizabeth K. Stage, in the February, 1993 issue of *Educational Leadership*.

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APPENDICES

I. INTRODUCTION

One hundred years ago, in December 1892, 18 men met at The University of Chicago to advise the "Committee of Ten" on science preparation needed for college admission. They were teachers at a range of high schools and prep schools, faculty at public and private colleges and universities. They agreed that at least one year of biology, followed by one year of chemistry and one year of quantitative physics, would best prepare young people to grow up to be just like them. (National Education Association, 1894)

Recently, in December 1992, 600 men and women -- mathematics and science teachers, supervisors, and faculty; state coalition and systemic initiative directors; assessment reformers, governors' education aides, and others -- gathered in Washington, DC to discuss systemic education reform based on national standards, those that exist in mathematics and ones under development in science education. Using working documents of the National Committee on Science Education Standards and Assessment, the group addressed "Science for All," a challenge that our nation is finally, one hundred years later, ready to embrace.

The Legacy of the Committee of Ten

There is much of value in the 1892 reports to the committee of ten college and university presidents, including a recommendation, "That the laboratory record should form part of the test for admission to college." What is more difficult to accept is that the content recommendations, crafted by a small number of scientists and science teachers for students who were going on to college, set the high school curriculum that -- the Sputnik era not withstanding -- remains in place today for nearly all U.S. students. This has led to the current situation -- *some* science for *some* students.

As the body of scientific knowledge has exploded, high school courses have become cluttered with so much new vocabulary, often exceeding that of foreign language courses, that terms can only be memorized rather than understood.

To prepare students for what most of them perceive as a deluge of disconnected facts in high school, junior high courses have often become imitations of high school courses with levels of abstraction and quantification that go beyond the

Tone and Style

The constructive criticism we received about readability of the November Sampler referred frequently to tone and style. In this Enhanced Sampler we have assumed less background on the part of the reader and, at least in early sections, have used a somewhat more informal style that follows a story line. This should enhance readability and pave the way for making the final standards document understandable to a broad audience. One consequence of such a choice is that some points are made in ways that experts will regard as oversimplifications. For instance, by starting in 1892 and skipping to 1992 we are merely trying to pique interest and focus attention on the marked difference between science for some and science for all, not to suggest that nothing has happened in science education for 100 years. Several other issues are presented in early sections without many of the qualifiers. The style for the final standards document is not set.

intellectual capacities of many young people, who have learned to succeed by memorization. Since memorized work is easily forgotten, many teachers teach as if students' minds were empty. Thus, the learning expectations in science for elementary school children are usually minimal: "Keep their curiosity alive."

The elementary curriculum depends largely on the interests of the teachers, only a quarter of whom feel "well qualified" to teach science (Weiss, 1989). Is it any surprise, then, that although seventy percent of elementary students declare themselves interested in science (Weiss, 1989), by the time they reach high school, science enrollments drop by more than one half each year? Only twenty percent of high school students nationally take the final course in physics recommended in 1892 (Blank, 1990).

Challenges to the Status Quo

Some will ask what is wrong with that. Since only three or four percent of the work force is engaged in science and engineering (U. S. Department of Labor, 1992), why do all of our citizens need to learn science? Concerns regarding economic competitiveness are fueling the renewal of science and mathematics education so that we can keep up with our global competitors. The business community has declared that all entry-level workers need to be able to think -- "the ability to learn, to reason, to think creatively, to make decisions, and to solve problems." (Secretary's Commission, 1992)

Informed citizenship in the year 2000 requires that all people have a substantially greater understanding of science. Recall last Fall's ballot initiatives in several states, or confront the supermarket decision, "Paper or plastic?" and realize that we are increasingly confronted with questions in our public and personal lives for which scientific information and ways of thinking are necessary, though insufficient, for informed decision-making.

Finally, and most important, science is one way that humans have used to seek understanding of their place in the universe. The personal fulfillment and excitement offered by science are benefits to be shared by everyone. For this reason, scientists and science educators are eager to take advantage of the policy opportunity provided by the current attention regarding national education goals to do a better job this time around.

The job has in fact been worked on throughout this century, but efforts have been accelerated since the mid 80s. *Science for All Americans* is not only the name of an influential book issued by Project 2061, the far-reaching effort of the American Association for the Advancement of Science (AAAS); Science for All Americans is also its goal (Rutherford and Ahlgren, 1989). Initiated in 1985, a year in which Halley's Comet came close to the earth, and named for the year in which Halley's Comet will return, Project 2061 delineates the science that people whose lives span those years will need to achieve scientific literacy. Taking the long view, it defines "science" broadly, to include not only natural sciences, but also social sciences, mathematics, and technology.

Using a different approach, the National Science Teachers Association (NSTA) has crafted what its creators see as a more immediate solution. The Committee of Ten recommendation in 1892, "That it is better to study one subject as well as possible during the whole year than to study two or more superficially during the same time," has led to the high school courses we have today. Thus, NSTA's Scope, Sequence & Coordination Project (SS&C) recommends that the subjects of biology, chemistry, physics, and earth science (an omission of the Committee of Ten) should be taught each year, starting in the 6th or 7th grade and continuing through 12th grade (Aldridge, 1992). The SS&C slogan, "Every Student, Every Science, Every Year," is a short-term version of the Project 2061 vision.

Standards in the Science Landscape

Among the questions most frequently asked of us are: Why do we need national standards, given the numbers of other curriculum and curriculum framework projects underway around the country? In particular, what is the relationship of the standards effort to AAAS Project 2061 and the NSTA Scope, Sequence & Coordination project? These questions are partially addressed in this Enhanced Sampler. In this section we discuss at a general level the relationships between and among these major projects. Later on, we note that the nationwide Critique & Consensus process we are running in connection with the standards development effort is one of its distinguishing features and is also our basis for calling the standards national.

Why Standards?

With a far-reaching vision for the future and the potential of short term solutions being implemented in schools today, why do we need national standards for science education? First, standards are criteria by which judgments can be made. They need to be based on a vision, to be sure, and they need to address characteristics of curriculum design so that people can decide if one of Project 2061's models or a particular version of Scope, Sequence & Coordination is the one to select for their students, or if they want to choose something else. A hallmark of American education is local control, where boards of education and teachers make decisions about what their students will learn. What they need from the national level is assistance in making those decisions.

Second, standards are criteria to guide a multitude of other choices. Evidence of this need can be seen by watching a mathematics teacher arguing convincingly for a better system of assessment on the basis of the National Council of Teachers of Mathematics (NCTM) *Curriculum and Evaluation Standards for School Mathematics* (1989). Or, talking with a textbook publisher who would like to make wise selections among the seeming plethora of material in current K-12 science curricula. The banner put forward by the NCTM Standards has allowed everyone to move in the same direction, assured that the risks they take in the name of improving mathematics education will be supported by policies and practices throughout the system. This is needed in science too.

There are outstanding things happening in science classrooms today, even without national standards, but they happen because of the extraordinary teachers who do what needs to be done despite the norms, and despite the risks. Many generous elementary teachers spend their own money on science supplies, knowing that elementary students learn best by investigating. There are middle school science programs that are relevant to students' lives instead of being merely practice for high school courses. Some high school teachers ignore the vocabulary-dense syllabus and encourage student inquiry into their own questions, hoping that their students will not be penalized by high prestige examinations.

We need national standards to shine the light on and promote the best practices of these extraordinary teachers, to put them in the forefront instead of behind closed classroom doors. We need to make their curricula exemplars -- part of the core of teacher preparation programs, the model for instructional materials and assessments, and the basis on which science programs are judged -- to become the rule rather than the exception. We need to recognize and encourage the school principals who find money in their budgets for field trips, parents whose bake sale proceeds purchase science equipment, authors who write materials that cannot possibly satisfy the divergent criteria of twenty two adoption states and thousands of local districts, and publishers who are pioneering in authentic assessments despite the lucrative market for multiple choice tests.

Finally we need national standards to help chart a course into the future. They should build on the best of current practice and yet take us beyond the constraints of present structures of schooling, creating the forward-looking goals -- the shared vision -- toward which we strive.

II. TAKING UP THE CHALLENGE

In an effort to help the science education community meet these challenges, the National Research Council (NRC) agreed in the summer of 1991 to convene and coordinate a three and one-half year process that would lead to national science education standards. Responding to requests received in mid-1991 from teacher associations and other professional societies, as well as government officials, the NRC established a National Committee on Science Education Standards and Assessment to oversee the development of standards and the nationwide consensus-building effort needed to give them validity. (Further details about the project and how it evolved can be found in the Preface.)

While scientists and science teachers are prominent in the process, with teachers a plurality on all committees and working groups, the broader communities of educators, business representatives, and the public at large are also involved in the process. To further rectify the sins of omission of the 1892 committee, women and members of other groups currently underrepresented in the sciences (people of African American, Latino, and Native American origin) are involved directly in the process. To insure that the views of 18, or even 180 people, do not set the agenda for standards intended for all students, there is also a plan for nationwide critique and consensus that has been built into the process from the beginning.

The National Committee on Science Education Standards and Assessment (NCSESA), meeting for the first time in May 1992, approved a plan to produce science education standards by late 1994. Their charge to their working groups on curriculum, teaching, and assessment is:

> ... to develop, in cooperation with the larger science, science education, and education communities, standards for school science.
>
> The standards will provide a vision of excellence to guide the science education system in productive and socially responsible ways. Standards for 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.

What Standards Are Being Developed?

The National Science Education Standards will deal with K-4, 5-8, and 9-12 levels. They will be descriptive, not prescriptive. Narrative form, rather than checklists, will support thoughtful consideration and application.

The curriculum standards will not prescribe particular courses, programs of study, or textbooks; assessment standards will not be a set of examinations; teaching standards will not be certification or licensure specifications. Overarching goals and criteria will be provided, and examples used to illustrate the range of what is possible, not define the one "best" approach. In simplified form, the charges to the working groups are:

Science **curriculum** standards will define:

- the scientific concepts, facts, laws, theories, modes of reasoning, and methods of investigation that all students should understand and be able to use;
- the attitudes, inclinations, and abilities to apply scientific principles and ways of thinking that all students should develop; and
- the nature of experiences that contribute significantly to the acquisition of such understandings, attitudes, and abilities.

Science **teaching** standards will define:

- the skills and knowledge teachers need to provide students with school experiences to achieve the valued learning outcomes of the science curriculum standards;
- the preparation and professional development needed by teachers to carry out their roles; and
- the support systems and resources necessary for effective science teaching.

Science **assessment** standards will define:

- guidelines for development and selection of methods for assessing student achievement of the valued science learning outcomes;
- criteria for assessing whether school science programs provide appropriate opportunities for students to achieve these outcomes; and of valid and reliable science assessment data and methods for collecting them that assure appropriate correspondence between the data and the purposes they are intended to serve.

Didn't You Say That Before?

In doing the revisions that produced this Enhanced Sampler, considerable effort has gone into eliminating redundancy. However, the present organization has left some overlap between references to the National Science Education Standards Project in the first two sections and those in the Preface, which gives the history, structure, schedule, and sponsorship of the effort. For instance, the descriptions on this page of the charges to the Working Groups restate parts of the Summary Statement of Task on page iv. This has occurred because we felt it was important that working papers continue to carry a more or less formal description of the standards project, while at the same time we wanted the early sections to tell a story regarding major aspects of what is going on. We believe that for a general reader a bit of overlap will not be the problem it is for informed readers, and may even be a help. At any rate, in later documents the redundancy will recede as the project description moves to the rear, taking up its rightful place in an appendix.

While working groups in curriculum, teaching, and assessment convened separately in the summer of 1992, they adopted from the outset the working mode of constant review of each other's work. This habit and their overlapping memberships and common goals will lead to a unified document so that the system of science education moves forward in concert. As a result of the work over the summer of 1992, the team of working group chairs -- Audrey Champagne, Karen Worth, and Henry Heikkinen -- and the National Committee have put forth guiding principles for the work that will produce a complete draft by late 1994. These principles delineate the territory of school science -- somewhat broader than Scope, Sequence & Coordination, but narrower than Project 2061. They also determine how ambitious the standards will be. The first and most crucial principle deserves special comment here, because it implies a great deal about the basic goals for school science.

Science for All

The National Science Education Standards project is based on the premise that all students can learn science and that all students should learn science, and puts this premise in the forefront of its work. The basic principle, Science for All, takes an unwavering stand that "The science standards will define the level of understanding that all students, regardless of background, future aspirations, or interest in science, should develop." The October, 1992 working paper set the tone for subsequent documents:

> "We emphatically reject the current situation in science education where members of populations defined by race, ethnicity, economic status, gender, physical or intellectual capacity are discouraged from pursuing science and excluded from opportunities to learn science. By adopting the goal of Science for All, the standards prescribe the inclusion of all students in challenging science learning opportunities and define a level of understanding that all should develop.
>
> "In particular, the commitment to Science for All implies inclusion not only of those who traditionally have received encouragement and opportunity to pursue science, but of women and girls, all racial and ethnic groups, students with disabilities, and those with limited English proficiency. Further, it implies attention to various styles of learning and differing sources of motivation. Every person must be brought into and given access to the ongoing conversation of science.
>
> "Thus, the commitment to Science for All requires curriculum, teaching, and assessment standards that take into account student diversity vis-a-vis interests, motivation, experience, and ways of coming to understand science. The standards must define criteria for high quality science experiences that include the engagement of all students in the full range of science content. These experiences must teach the nature and process of science as well as the subject matter and support the notion that men and women of diverse backgrounds engage and participate in science and that all have a claim on this common human heritage.
>
> "The commitment to Science for All has implications for program design and resource allocation at local, state, and national levels."

Through its emphasis on Science for All, the National Committee on Science Education Standards and Assessment (NCSESA) intends to convey its strong belief that the time has come for U.S. education to make the transition from the 1890s objective of science for some in some grades to the 1990s goal of science for all in all grades, hoping that after 100 years of observation and experimentation, we move closer to getting it right.

Implications for the Standards

One should not underestimate the difficulty of gaining acceptance of such a proposition, with either educators or the public. In the United States, there is a pervasive attitude that science is a difficult, somewhat exotic, and impractical area of study, pursued by an elite with a natural gift for it. Even some very influential people can be heard to say that they got by in life very well without a knowledge of science and almost everyone should be able to. Others seem proud to say that they know nothing about science. It is therefore extremely important in preparing for presentation of the standards to refine and hone both understandings of and convincing arguments for why science is so important in the education of all students today, why all students and eventually all adults should be and can be "scientifically literate". The general lines of argument are familiar:

> The world is changing, has changed, and increasingly citizens must make informed decisions about matters that have scientific elements. We are bombarded every day with news of new fuel economy measures; new information about physiology and health, new technology described in scientific-sounding terms, new environmental problems, from acid rain to holes in the ozone layer to global warming. Computers and other forms of information technology are transforming our lives at a very rapid pace, forcing workers of virtually all kinds to work with -- and to some extent understand -- new machines and tools for carrying out their jobs.

The ability to apply scientific knowledge to such aspects of one's life is part of what is usually called "scientific literacy." It is not a simple matter to pin down exactly what else is to be encompassed by scientific literacy or to understand what the specific implications are of taking it seriously as a national goal. The thesis of the National Committee on Science Education Standards and Assessment (NCSESA) is that, if any such goal is to be achieved for all students, then -- as the brief charge to the curriculum working group implies -- science education must prepare students who understand a significant amount about: (i) the basic concepts of science and the principles, laws, and theories that organize the body of scientific knowledge; (ii) the varied applications of science, ranging from engineering and medicine to the use of science in making informed decisions in

The Broader School Context

The goals of school science must of course be seen against the background of the broader goals of education. Several reviewers of the November Sampler resonated with the brief descriptions of these broader goals that were given there. The reorganization used in the Enhanced Sampler mitigated against going too far into such matters, but we agree that these broader goals and several other contextual matters need to be addressed in the final standards document. These range from the purposes of schools and schooling to a variety of critical problems that teachers, principals, school boards and others must deal with that are inherited from the larger society. Especially important to take note of are societal changes that are radically altering the lives of children and youth -- all the way from drugs to altered family structures to the pervasive effects of information technology. The last issue alone may cause fundamental changes in schooling.

the home, community, and workplace; (iii) the modes of reasoning of scientific inquiry and their varied uses in enriching the dialogues with nature that we individually and collectively conduct; and (iv) the nature and history of the scientific endeavor, including its relationship to technology and other disciplines, including mathematics and the social sciences. To gain acceptance of this thesis and support for a nationwide attempt to have such ambitious learning goals for all students, the standards must do three things. First, they must present clear and readable explanations of just what these four rhetorical-sounding descriptors mean.

Second, they must:

- *Create a Strong, Positive, and Compelling New Image for School Science*

  School science must develop and maintain in students an appreciation of the beauty and order of the natural world, and of the immediate and far-reaching applications of science. Far too many adults 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. The new standards will create a new image for science, portraying the power and excitement of scientific knowledge and reasoning. This new image 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 help guide educators, government officials, policy-makers, concerned citizens and business and industry leaders who are trying to improve science education -- providing consistency of direction. 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 Teaching Methods and Encourage Teacher Professionalism*

  Teachers will no longer be constrained to go "by the book" in class. The standards will provide teachers with authority to use new exemplary methods that meet the standards' spirit and intent.

- *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 public with information to make valid judgments and to hold education systems accountable.

Third, the standards must go beyond content *per se* to address characteristics that school science programs should have if all students are to reach the valued learning outcomes. For example, few would doubt that -- while attending to the knowledge base -- school programs that are aimed at Science for All will need to provide experiences that:

- are personally and socially engaging;
- call for a wide range of knowledge, methods, and approaches to analyze personal and societal issues critically;
- encourage students to reflect on the impact of scientific knowledge on their lives, society, and the world; and
- cultivate students' appreciation of the scientific endeavor and their excitement and pleasure in its pursuit.

Few school science programs offer these experiences now, just as few students today come close to demonstrating the abilities we have associated here with scientific literacy.

The development of such understandings, abilities, and appreciations in all students has two other implications for programs: (i) that schools begin the process the day the students first walk in the door and continue it throughout the school years; and (ii) that both a reorganization of the subject matter of school science and significant modifications in learning environments will be required. The description of a framework for content standards presented in the next section makes a start on addressing these difficult issues. Finally, we should note that a discussion of school science programs raises not only the issue of what programs should be like, but also the question of how needed changes can be brought about. Save for noting here how important it is to have the determination, staying power, and patience that it will take to carry out the many changes in school programs, discussion of implementation will be left for a later working paper.

Revolution or Evolution?

Many reviewers of the November Sampler questioned the use of such words as "revolution" and "non-traditional", saying that what was being described was already taking place in their classrooms, schools, districts, or states. It is true, as it should be, that most elements of these standards can be found somewhere. It is also true that the experiences of many, if not most, American students are not yet meeting the criteria delineated here. Changes are needed in the way students and teachers spend their time, administrators allocate resources, and decisions are made and evaluated, before the full vision can be realized for all students. Yet there are steps that can be taken within existing contexts that may help stimulate the changes that need to take place. The distance between the status quo and the vision is revolutionary; the processes by which the vision will be attained are evolutionary, building in some measure upon current examples of best practice.

Critique & Consensus

The last important component of taking up the challenge is to create and implement a nationwide critique and consensus process, to involve many thousands of people in developing and supporting the standards. This effort has begun and is growing rapidly. The October 1992 discussion document quoted above was debated in a variety of places, beginning with the AAAS Forum for School Science. Both it and the November 1992 Sampler were discussed at numbers of other meetings concerned with science education. At all of these, much valuable criticism and support were received.

By working with the several science and science education communities (biology, chemistry, physics, earth and space sciences) it is hoped to overcome the fragmentation and territoriality that has characterized much of science education in the past.

By involving those who have been left out -- females (e.g., the Association for Women in Science); members of racial and ethnic groups (e.g., the American Indian Science and Engineering Society, the Hispanic Secretariat, the National Association of Black School Educators); and students with disabilities (e.g.,the Foundation for Science and the Handicapped) the NRC will work to enlarge the mainstream of the science and science education communities.

By extending the range of communications to the larger education community (e.g., groups developing standards in other disciplines, Association for Supervision and Curriculum Development, Council of Chief State School Officers, American Association of School Administrators, National Associations of Elementary School Principals, Secondary School Principals, State Boards of Education, etc.); the business community (e.g., Corporate Council for Mathematics and Science Education, National Alliance of Business, Business Roundtable); parent organizations (e.g., the National Parent Teacher Association); and the policy community (e.g., National Governors Association, Education Commission of the States, Council of Chief State School Officers, National School Boards Association, National Association of State Boards of Education), our National Committee hopes to improve the quality of its work and create a context in which science education goals are widely embraced.

Who's Been Involved So Far?

From November, 1991 to November, 1992 -- the year that encompassed project conceptualization, organization, start up, and initial activities -- 120 presentations were made to audiences totalling nearly 8,000 people in 25 states, using whatever materials were available at the time. Starting November 25, 1992, the NRC distributed 1,200 copies of the first standards Sampler and then 6,000 copies of it that excluded the original Appendices A and B. Copies were mailed to nearly 1,000 individuals, including 133 Organizational Liaisons listed in Appendix C. The additional 6,200 copies that the NRC distributed were used for presentation and discussion of the Sampler at 20 meetings in 13 states, plus Puerto Rico and the District of Columbia. We know that some of these recipients made and circulated copies for their colleagues, but do not know the numbers. In the seven weeks between the release and the January 15, 1993 deadline, reviews were received from 525 individuals and 18 group discussion leaders. They are summarized in Appendix C. Given that the time period was short and included the winter holidays, this was a very gratifying response. Critiques from forms, letters, and group discussions were shared with the working group chairs and staff of the project. We regret our inability to acknowledge responses personally, but would like to thank the thousands of people who have contributed to the Critique & Consensus effort thus far.

And by working with public and private funders of education (e.g., the Council on Foundations, National Council of State Legislatures, the U.S. Congress, the National Science Foundation, Department of Education, National Aeronautics and Space Administration, Department of Agriculture, the National Institutes of Health, and other federal agencies), it hopes to help provide the support that teachers and schools will need to meet the standards.

III. A FRAMEWORK FOR CONTENT STANDARDS

The close interconnections among curriculum, teaching, and assessment in school science argue that standards in these three areas should be presented together, mutually reinforcing one another. As noted previously, this will be done in the final standards document. In this working paper, however, the primary focus is on curriculum standards, and even more particularly on content standards, which describe at an appropriate level of specificity what students at various ages and stages should know and be able to do.

The charge to the curriculum standards working group makes clear that the standards will define "content" broadly. An initial decision of the working group was to identify what all students should know and be able to do within four general categories:

- **Science Subject Matter**
- **Nature of Science**
- **Applications of Science**
- **Contexts of Science.**

Science subject matter includes those concepts, principles, facts, laws, and theories that constitute the body of scientific knowledge. Science introduces children and young adults to the natural world as it is investigated and understood by scientists. Thus the intellectual character of the science curriculum is derived in large part from the knowledge base and modes of inquiry of the natural sciences.

But school science content is more than subject matter. It also includes the ability to carry out scientific investigations and understand modes of reasoning involved in scientific inquiry -- things important for understanding the nature of science.

By including applications of science, students will understand something about how things are made and how they work; how science relates to their lives, through such things as the environment, medicine, engineering, and entertainment; and decisions they will make as adults.

Two Cautions

The term "standards" means many things to many people. A general sense of our meaning can be gleaned from the descriptors found near the top of page 6 and on pages i and iv of the Preface. The flavor will be somewhat like that of the NCTM *Curriculum and Evaluation Standards for Mathematics* which display a tone, style, and level of specificity that has proved acceptable in standards at a national level -- but many features of emerging science standards will be quite different.

All of the ideas presented in this and succeeding sections are evolving. Both the frameworks for science content and the form of (prototype) standards that we develop will be significantly affected by the integration of teaching and assessment with the content. We have concentrated our early work on specifications of content -- what students should know and be able to do at K-4, 5-8, and 9-12 levels -- because funding was first available for curriculum standards and we are under a tight overall timeline. This places a burden on our readers, who must imagine that our work will be reshaped in later documents, combining content, teaching strategies, assessment methods, and aspects of program design.

The social and historical contexts in which science evolved are also important for students to know. Insights about the nature of scientific inquiry, the ways in which scientists reason, values underlying the work of scientists, and the historical development of scientific ideas also are an important part of scientific knowledge. These all contribute to a more comprehensive view of the total scientific endeavor and provide a basis for understanding "how we know what we know."

Caveats

The four categories of science content that we have identified are not mutually exclusive. It is difficult to deal with one component without involving one or more of the others. Indeed, they should frequently be interwoven in curricula and teaching.

Another caveat: We are not saying that the four categories should necessarily receive equal emphasis in a school curriculum nor how the relative weights should be assigned, however, specification of the general attainments hoped for in each category will convey something about overall balance.

Finally, it should be said that any brief discussion of the applications of science sounds a bit idealistic. Whether one is talking about engineering, mathematics, or biomedical research, the line between science as a tool and the tools of science is a fine one.

Science Subject Matter Standards

A good deal of the focus in this paper is on science subject matter and understandings of it that should be regarded as fundamental. These understandings are framed here in terms of broad disciplinary areas. Whether these will be the organizers for the subject matter standards eventually to emerge has not yet been decided. What is clear is that:

- *The subject matter of science must be consistent with the body of scientific knowledge from which it is derived.*
  Teaching science to young people requires the presentation of sophisticated ideas in ways that allow them to gradually build scientific understandings that reflect the current state of knowledge.

- *Science must engage students in the study of the natural world in ways that reflect science as it is practiced.*
  Frequently, science content is presented to students in the form of dry conclusions without reference to the empirical evidence upon which the conclusions are based. Often, the chain of reasoning that leads from questions to evidence to conclusions to applications is lost, as is the excitement of exploration. Teachers must model and educational materials must reflect the demand for evidence and reasoning that reflects the spirit of scientific inquiry. The materials must engender in students the habit of meeting new ideas with questions. What is the evidence? What assumptions are made in developing inferences? Is the reasoning leading from evidence to conclusions sound? What applications have been made?

As the body of knowledge and information developed by the scientific community has grown, science textbooks and programs have become increasingly overburdened with vocabulary, facts, and information, remaining generally unresponsive to growing knowledge of how conceptual understanding of science is developed. The quantity of science subject matter is overwhelming, and the complexity of some topics does not allow young people to construct meaningful understanding of science through extended use of inquiry and through opportunities to apply scientific knowledge.

Consequently, *science subject matter standards will identify, from the body of scientific knowledge, a limited number of important concepts, principles, facts, laws, and theories that provide a foundation for understanding and applying science.*

However, *science subject matter standards will not and should not specify the full range of what students in a particular local setting should know and be able to do.* Although the standards will specify fundamental understandings that all students should develop, teachers and school systems must continue to construct thought-provoking, engaging science experiences that build on local resources and environments, reflect their particular interests and expertise, and stimulate their students to go beyond the fundamental understandings.

Charts and Clarifications

In the November Sampler, Section III contained a series of charts that provided an "overview in advance" of several school science domains related to the four basic categories of content. Potential "organizers" were shown within each of these domains. Numbers of readers found these charts very helpful. We apologize for shifting the ground on these readers by removing these particular charts but, as the White House said in an era now passed, they "are no longer operative."

The remainder of this section is devoted to clarifying what is meant by "fundamental understandings" and how we are now going about developing standards. The text of the new Section III and the material now in Sections IV through VIII should make it clear to those who read the November Sampler that things have not really changed all that much -- we have simply reorganized a bit.

Standards to be drafted later this year will include criteria to guide the selection of additional science subject matter and activities. These criteria will address such things as developmental appropriateness, linkages to students' experiences, enhancement of students' understanding of applications, and a weighing of the "benefits" from the increased acquisition of knowledge against the "costs" in time and resources involved in cultivating the additional learning.

Fundamental Understandings

In selecting fundamental understandings, we employ criteria related to both structure and appreciation of scientific knowledge. Our first ground rule is:

Science subject matter is **fundamental** if it

- represents central scientific ideas and organizing principles;
- has rich explanatory and predictive power;
- motivates the formulation of significant questions;
- guides fruitful observation; and
- is applicable in many situations and contexts common to everyday experience.

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What is viewed as fundamental subject matter within particular grade levels also depends, in part, on what is known about how students learn. Direct and extensive student engagement with the natural world is a critical element in the development of an active body of scientific knowledge at all levels, and must be at the heart of learning science. These engagements, however, have a different quality and engender different learning, depending on the developmental level of the students.

For younger children, direct experience with the visible world around them is the foundation. They observe, describe, and manipulate this world as they engage in investigations. Young children collect largely qualitative data from their experiences that they are able to analyze for simple patterns and generalizations.

Science education for older students must also be grounded in direct experience. However, as they mature, students become increasingly able to understand "invisible", conceptual worlds of science, and to build more abstract understandings. They develop manipulative and cognitive skills that allow more complex experimentation and involve collection and analysis of quantitative as well as qualitative data. In addition to their ability to identify patterns within such data, students become increasingly able to formulate explanations for phenomena in terms of models and theories, many of them mathematically grounded. Secondary resources also become more important (and meaningful) sources of scientific information and ideas as students mature.

Thus our second ground rule is:

> In addition to dealing with fundamental subject matter, **fundamental understandings** must be:
>
> - capable of being linked in a meaningful way to direct student observations or to data or evidence that is accessible to students;
> - developmentally appropriate for students at the grade levels specified.

Finally, the selection and use of fundamental understandings depend on clarity regarding acceptable evidence that student understanding has been attained. This clarity is equally essential to future progress within both science teaching and assessment standards, work that will intensify in the coming months.

Knowledge of Learning

Some central ideas from the psychology of learning have helped delineate the structure of science subject matter as reflected in fundamental understandings, as has the wisdom of practice reflected in teachers' knowledge. Future reports from the Teaching Standards Working Group of the National Science Education Standards Project will include a general summary and analysis of the knowledge from cognitive psychology and science education that guide current science standards work.

Organization of Fundamental Understandings

Guided by these two simple ground rules regarding fundamental subject matter and student understanding, sets of K-12 fundamental understandings in science subject matter are being developed in *three general domains of the natural sciences*:

- physical sciences;
- life sciences; and
- earth and space sciences.

Such understandings have been provisionally identified within both the physical sciences and the life sciences. These are presented in the two following sections. Comparable work regarding the earth and space sciences will be released in the summer.

Within the three major areas of the natural sciences, fundamental understandings are grouped within a limited number of subheadings. These subheadings were selected because they were useful in delineating major "clusters" of understandings. They also help highlight central links among understandings within particular grade levels and across grade levels.

The grade levels are dealt with in three blocks: K-4, 5-8, and 9-12. Questions of the developmental appropriateness of these divisions and whether they provide a fine enough gradation are the subjects of ongoing debates, but the three blocks have been adopted for now because: (i) finer subdivisions by grade could lead to a multitude of standards; and (ii) this particular cut has been generally well received in the case of the mathematics standards, and a science/mathematics comparison and alignment could be very useful to teachers in elementary and middle school. *There is no intent to suggest that schools or curricula must be organized K-4, 5-8, 9-12 in order to make use of the standards.*

Likewise, the use of three major domains of the natural sciences as organizers simply reflects the fact that the origins of most fundamental understandings in subject matter arise within the disciplines of science. The choice of these organizers does not imply any preferred organization for a particular science curriculum, individual science courses, or for specific

A Binding Resolution?

Several reviewers of the November Sampler expressed concern over the use of three major disciplinary domains to organize fundamental understandings. Some were worried that curricula would then be bound by such an organization, others that the impact of cross-disciplinary work in science might be lost, and still others that the organization was just too conventional and unexciting. We acknowledge that fundamental understandings could, with equal validity, be organized in alternative ways, including the use of major "themes", "big ideas", or broad scientific issues, such as the problems of health, the environment, or global change. The difficulty our Curriculum Working Group found after trying such approaches is that, when dealing with standards on a nationwide scale, it is difficult to reach any agreement early on about whose favorite themes or big ideas to use. The resolution of the issue for now has been to use the major disciplinary domains as the starting point, planning to build outward through further development work and the Critique & Consensus process, and leaving open the possibility of regrouping a bit farther on.

Will this resolution be binding?

Tell us what you think.

units of study. The things that are being "organized" are the intended attainments of science students, rather than the sequence of instructional experiences by means of which students develop these understandings. In particular, science instruction in support of these fundamental understandings can be organized in a wide variety of ways, depending on locally elected options that range from interdisciplinary courses, issue centered modules, and spaced learning (as implemented, for example, in NSTA's Scope, Sequence & Coordination project), to more traditional formats.

Similarly, the subheadings defining clusters of fundamental understandings should not be regarded as defining particular units of science study. In other words, the process of organizing standards for science content is not necessarily congruent with the process of organizing a particular program of study or science curriculum.

IV. FUNDAMENTAL UNDERSTANDINGS AND PROTOTYPE STANDARDS FOR THE PHYSICAL SCIENCES

Overview of Fundamental Understandings for Physical Sciences

Grades K-4

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

The study of physical science in grades K-4 builds on the need for students to understand important characteristics of objects and materials they encounter daily and to begin seeing the utility of classifying them into various categories, based on their properties. In addition, manipulations of objects by pushing, pulling, throwing, dropping, and rolling also lead students to think about the movement of objects, types of motion, how such motion can be usefully described, and -- to a limited extent -- how various kinds of motion can be controlled.

Presentation

To provoke discussion regarding the scope, level, and specificity of the draft fundamental understandings for the physical sciences, they are presented in this document in relatively stark form. We recognize that more specificity and probably narrative paragraphs will be needed before the understandings are useful in an educational context. In several cases we have used short, all too simple declarative sentences in order to convey quickly the general intent regarding scope of science subject matter. We are especially interested in comments on four things: (i) whether the intent is unclear; (ii) whether the fundamental understandings represent learning expectations in physical science that are appropriate for *all* students; (iii) whether the clusters we have used seem appropriate for creating standards; and (iv) how such expectations can best be presented in the final science standards document.

The dialogue we have been having with physical scientists in different disciplines and subdisciplines suggests that it is important to find a balanced representation of their varying perspectives.

Observing, manipulating, and classifying common objects lead children to reflect, as they move through the early grades, on similarities and differences among the materials that compose these objects, and on similarities and differences in how they can move and be placed in motion. Initial student sketches and single-word descriptions lead to increasingly detailed drawings and richer verbal descriptions.

Experiences with light, heat, electricity, and the motion of objects create an interest in and an intuitive understanding of these phenomena and contribute to introduction and development of the concepts of energy and forces later.

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Physical science fundamental understandings for Grades K-4 are organized under three major categories: (1) Characteristics and Changes of Objects and Materials, (2) Light, Heat, and Electricity, and (3) Motion of Objects: Types and Changes. Students' understandings in these areas should not be cultivated through isolated events or activities. Rather, these should develop within broader explorations of the child's world. For example, fundamental investigations of living things (see Life Sciences) or of rivers and rocks (Earth/Space Sciences) can make important contributions to children's understanding and use of basic ideas concerning objects, materials, and their motion.

Grades 5-8

In the early part of grades 5-8, students continue to investigate the properties of objects and the substances of which they are composed. In the process, their experiments will become more quantitative as they expand their ability to make measurements, design and conduct investigations and come to higher-level conclusions. The attention shifts from properties of objects, to characteristic properties of substances, to the question of what model of matter can be created to explain the properties.

The introduction of the particulate model presents a major and exciting challenge for both teachers and students starting late in this grade span. Students bring the terminology and primitive notions of atomicity to the science class but lack virtually any understanding of the evidence for the model or the logical arguments that lead to the development of one model in preference to others. Although the full line of evidence and argument for particles cannot be introduced at this level, experimental results should be treated as evidence contributing to and consistent with the particulate model.

The energy strand continues from the lower grade levels with more quantitative descriptions and terminology. The idea of energy and its interconversions begins to emerge towards the end of these grades as students observe and measure relationships among light, heat, sound, and electricity. The study of motion and forces causing them anticipates a more comprehensive understanding of energy at the next level.

Grades 9-12

By the end of this period students will have accumulated enough evidence to expand the model for matter to include the electronic and nuclear structure of the atom. These fundamental ideas allow students to investigate, explain, and to a limited extent, predict the structure and reactions of simple compounds, making it possible to make informed decisions about a variety of household and industrial processes.

The examination and description of motion becomes more quantitative at this level. The vector quality can be added to the description of motion as a number of well-defined laws and principles are introduced. The idea that energy exists in many forms is refined and enlarged to include the conservation principle and the notion of entropy.

Figure 4-1 is a simple schematic showing the basic progression of student understandings starting with qualitative descriptions in the early grades, which build to large, encompassing principles by the time students complete high school.

Figure 4-1

Framework for Physical Sciences Fundamental Understandings

<table>
<tr><td rowspan="2">9-12</td><td colspan="2">Conservation of Matter and Energy
Interactions of Matter and Energy</td></tr>
<tr><td>Structure of Matter
Interactions of Substances (Chemical/Physical Changes)</td><td>Energy and Its Transformations
Motion of Objects and Their Changes</td></tr>
<tr><td rowspan="2">5-8</td><td>Particulate Model of Matter</td><td>Energy</td></tr>
<tr><td>Characteristic Properties of Matter and Their Changes</td><td>Motion and Changes in Motion (Forces)</td></tr>
<tr><td>K-4</td><td colspan="2">Characteristics and Changes of Objects and Materials
Light, Heat, and Electricity
Motion of Objects: Types and Changes</td></tr>
</table>

Physical Sciences
Fundamental Understandings
Grades K-4

Characteristics and Changes of Objects and Materials

Organization

Draft fundamental understandings for the Physical Sciences are presented for grades K-4, 5-8, and 9-12 using the clusters of understandings displayed in Figure 4-1. The K-4 and 5-8 listings are each followed by a prototype standard dealing with one cluster for that grade range: Characteristics and Changes of Objects and Materials, in the case of Grades K-4, and Particulate Model of Matter for Grades 5-8. There is no prototype standard for Grades 9-12 in this working paper.

- All objects occupy space and have mass. Objects have properties (size, shape, volume, and mass) that can be compared and measured. Such properties can be used to describe, group, or classify the objects.

- 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, which are independent of the amount of material, are useful in describing, grouping, and classifying materials.

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

- Some properties of a material may change when it experiences some external change; other properties do not. For example, if the temperature of water is decreased, it may change from one state to another (liquid to solid). However, the mass of an object remains unchanged when it is broken into smaller parts.

Light, Heat, and Electricity

- The Sun supplies heat and light to the Earth.

- When placed in a beam of light, some objects cast shadows, while others bend or transmit the light.

- Light, sound, heat, and sparks can all be produced in electrical circuits with batteries as an energy source.

Motion of Objects: Types and Changes

- Motion of an object can be described as change in position with time, and can be represented on grids or graphs. The varieties of such motion include straight line, zigzag, vibrational, or circular.
- An object's motion can be at a constant speed or it can be changed so as to move faster or slower, through the action of a push or pull on the object.
- Sound can be produced by an object that moves (vibrates). Properties of sound such as pitch and loudness can be altered by changing the properties of its source.

Physical Sciences
Prototype Standard for Grades K-4:
Characteristics and Changes of Objects and Materials

A. Comments on This Standard

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

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 substances can be built starting in grades 5-8.

Why No Change in Prototypes?

Although feedback forms in the November Sampler explicitly asked for comments on the prototypes, few reviewers made specific remarks. In the comments that were made, there were no consistent patterns. Some asked for more student-centered examples -- "these activities stem largely from the teacher". Others said that there was too much emphasis on experimentation, which is only one basic paradigm for science and science learning. Some asked for more emphasis on quantitative reasoning and connections with other disciplines. A few said that the expectations for K-4 and 5-8 grade spans were too low, and some said they were too high. Similarly, some said the activities were boring or routine; others expressed concern about the feasibility of implementation. There was virtually no comment on format. We agree with some of the comments, but would like to hear more.

B. In grades K-4, activities such as the following, supplemented by experiences in daily life, 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 near the school, 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 planned to take the class for a walk near the school, 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 map of the vicinity on a clipboard and a bag, the children completed the walk, 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, 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. Students were then 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 be included in extended studies and can enable students to understand objects, materials, and their properties include:

- observing, comparing, and describing the sizes, shapes, and masses of common objects (such as rocks, liquids, fossils, 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);
- 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);
- comparing the mass 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-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:**

- **All objects occupy space and have mass. Objects have observable properties (size, shape, volume, and mass) that can be compared and measured. Such properties can be used to describe, group, or classify the 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 mass 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.
- **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, which are independent of the amount of material, 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.
- **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. For example, if the temperature of water is decreased, it may change from one state to another (liquid to solid). However, the mass 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 mass of a sample of material remains the same even though its shape, location, or appearance may change.

Physical Sciences
Fundamental Understandings
Grades 5-8

Particulate Model of Matter

- It is possible to devise a particulate model for matter that accounts for the observed properties of substances.

- Experimental evidence supports the idea that matter can be viewed as composed of very small particles. Particles in solids are close together and not moved about easily. Particles in liquids are close together, tend to stick to each other, but are moved about easily. Particles in gases are quite far apart and move about freely.

- The conservation of mass is consistent with the particulate model that describes changes in substances as the rearrangement of the component particles. Since the number of these particles remains the same, the total mass of the sample remains unchanged.

Characteristics Properties of Matter and Their Changes

- Different materials have characteristic properties that can be compared and measured. These properties allow materials to be distinguished from one another and often make them well suited to specific purposes.

- A chemical change involves the transformation of one or more substances into new substances with different characteristic properties.

- The total mass of materials involved in any observed change remains the same. For example, mass is conserved during a change in state (such as solid to liquid or liquid to gas) or a chemical reaction.

- A change in either the pressure, temperature, or volume of a gas sample results in measurable, predictable changes in either of the other two properties.

Energy

- Energy comes in different forms, such as light, thermal, electrical, kinetic (motion), and sound, which can be changed from one form to another.

- Temperature changes in a sample of matter are related to the loss or gain of thermal energy by the sample.

- Energy comes to Earth from the Sun both as visible light and as invisible electromagnetic radiation, such as ultraviolet, infrared, and radio waves. The amount of each type of radiation reaching Earth's surface depends on the absorption properties of the atmosphere.

- Light, which has color, brightness, and direction associated with it, can be absorbed, scattered, reflected, or transmitted by intervening matter. An opaque object's color is due to interaction of visible light with the object's surface. Light's direction can be changed by passing from one medium to another in a process called refraction, which is the basis for the operation of lenses and prisms.

- Energy changes involved in physical or chemical changes can be measured in the form of heat.

- The principles of electrical circuits can be demonstrated using wires, batteries, and bulbs to analyze electrical energy, resistance, current, and power. Electric currents can also be used to produce electromagnetic coils of wire, and, conversely, a moving magnet can generate a current in a circuit.

Motion and Changes in Motion (Forces)

- Several forces acting on objects can be regarded as pushes or pulls that can either reinforce or cancel each other. Forces are quantities that have both magnitude and direction.

- Changes in motion of an object, which also have magnitude and direction, are caused by forces.

- An object's motion can be described and represented graphically in terms of direction, speed, velocity, and position versus time.

Physical Sciences
Prototype Standard for Grades 5-8:
Particulate Model of Matter

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-4. However, during their years in grades 5-8, 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 5-8 can be regarded as a transition period in school science from the experiential focus of grades K-4 to the more serious emphasis on principles and theories in grades 9-12. Students' work toward a particle model for matter in grades 5-8 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 substances, 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 5-8, 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.

- **It is possible to devise a particulate model for matter that accounts for the observed properties of substances. Experimental evidence supports the idea that matter can be viewed as composed of very small particles. Particles in solids are close together and not moved about easily. Particles in liquids are close together, tend to stick to each other, but are moved about easily and they tend to stick together. Particles in gases 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 substances, 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 substances described above.

- **The conservation of mass is consistent with the particulate model that describes changes in substances as the rearrangement among the component particles. Since the number of these particles remains the same, the total mass of the substance remains unchanged.**

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 reaction or change of state. Students also should also 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 one class session allows. (Ideally, this video should be developed by the students.)

The groups discuss their observations, then are invited to describe things that changed and 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 team 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 eventually offered as a useful way to account for this important generality, as an extension of these model-building efforts

Examples of activities that help 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.

Physical Sciences
Fundamental Understandings
Grades 9-12

Conservation of Matter and Energy

- The total mass of matter remains constant in any chemical or physical change.
- The total quantity of energy in a closed system remains constant in any chemical or physical change, although its usefulness to prompt further change is reduced through each process, as randomness increases.

Interactions of Matter and Energy

- Waves, such as electromagnetic waves or sound waves, have wavelength, amplitude, frequency, and characteristic speed. Waves can be used to transmit signals or energy without the transport of matter. Electromagnetic waves can be transmitted through a vacuum, such as in space.
- Interactions of matter with electromagnetic radiation, electricity, or heat can produce useful evidence regarding the structure and composition of matter.
- The loss or gain of thermal energy by a sample of matter is related to a temperature change, which depends on the sample's mass and the nature of the material.
- Characteristic and predictable quantities of energy are associated with each chemical and physical change.
- The same concepts of energy, matter, and their interactions apply both to biological and physical systems on Earth and in the observable Universe.
- Energy can be harnessed to do work, which is represented by the quantity of force applied to an object times the distance the object moves in the direction of the force.

Structure of Matter

- The model of the atom consists of a positively-charged nucleus (composed of protons and neutrons) surrounded by one or more negatively-charged electrons, held together by electrical forces described by Coulomb's Law.
- The observed properties of elements, which are each made from a single type of atom, result from the number and arrangement of electrons in their atoms. The properties of a compound can often be predicted from the structure of its smallest units (either molecules or crystals).

- Compounds form when atoms of two or more elements combine (bond). Chemical bonds form when atoms share or transfer electrons.

- Substances can be represented by formulas or three-dimensional models showing the number, types, and/or relative positions of the atoms that make up the substance.

- Matter is made up of elements, compounds, and numerous mixtures of these two kinds of substances.

- Elements and compounds can be grouped into classes, based on similarities in their structures and resulting properties.

- Forces among particles in a nucleus are extremely strong and act at very small distances; large quantities of energy are associated with nuclear changes.

- Some nuclei are radioactive. The atoms undergo radioactive decay at their own characteristic rate.

- Radiation emitted during nuclear changes can affect living materials, i.e., it can damage cells.

- Energy released in certain nuclear reactions can be harnessed in controlled ways within a nuclear power plant or released suddenly and destructively in atomic or hydrogen bombs.

Interactions of Substances (Chemical/Physical Changes)

- All observed changes involve either a net decrease in potential energy or a net increase in disorder (entropy), or both.

- Some changes do not proceed to completion, but reach a state of equilibrium with the rate of change in one direction being equal to the rate of change back in the other direction.

- Electrical forces between the charges of the protons and electrons are responsible for the stability of substances. Chemical interactions and physical changes occur when these forces are altered.

- Chemical change can be explained in terms of rearrangements of atoms, which is made possible by the breaking and forming of chemical bonds.

- Chemical reactions can be represented by symbolic or word equations that specify all reactants and products involved.

- Chemical reactions can be classified into general types based on the nature of the changes involved (such as acid-base, oxidation-reduction, precipitation, polymerization).

- The rate of a reaction can be increased by adding a suitable catalyst. The rate is also affected by changes in temperature or concentration of the reactants.

- The relatively weak attractive forces among molecules that account for the physical state of molecular liquids and solids also account for the energy involved in changes of state.

Motion of Objects and Their Changes

- The position and motion of an object are judged relative to a particular frame of reference. An object at rest tends to stay at rest unless acted upon by some outside force. An object in uniform motion remains in this state of motion with constant momentum, unless acted upon by some outside force, which changes the momentum. No experiment can distinguish "rest" from "uniform motion."

- Motion can take place in two or three dimensions. An object's motion can be can be described in terms of velocity or acceleration, and can be represented in various ways, including distance-time and speed-time graphs, as well as through mathematical equations and vectors.

- All forces have both magnitude and direction. Forces acting in the same direction reinforce each other. Forces acting in different directions may detract or cancel each other.

- If an object exerts a force on a second object, then the second exerts an equal and opposite force on the first.

- All changes in motion or momentum are caused by forces. Examples: gravitational forces act between masses and are responsible for objects falling on Earth and for the motions of objects in the Solar System. Magnetic forces act on moving charged particles. Electrical forces act between charged particles. Friction depends on contact between masses.

- Constant motion in a circle requires a force to maintain it.

- Acceleration is the rate of change of velocity, where the change may be in magnitude or direction. Force and acceleration are related by the relationship $F = ma$.

V. FUNDAMENTAL UNDERSTANDINGS FOR THE LIFE SCIENCES

Overview of Fundamental Understandings for the Life Sciences

Grades K-4

During the primary school years, students are introduced to basic biological concepts including life cycle, diversity and variability of familiar organisms. Children learn about the ways in which organisms maintain and continue life, and the ways in which they interact with and depend on other living organisms and the nonliving parts of the environments in which they live. Children build understanding through direct experience with the living world and in the process are introduced to the scientific way of knowing. Young children are naturally curious and continuously engaged in interacting with the living world and trying to structure and understand it. The scientific way of knowing implies (1) more focused observations of plants and animals of the child's world, those that can be studied directly in the school, home and immediate environment, and (2) more guided drawing of inferences or making meaning from those observations. For children in the primary grades, scientific observations are those that have been made carefully, using their senses and simple magnifiers and measuring tools, recorded using words or pictures, and communicated to their classmates. At this stage in children's development, scientific terms are not critical. This does not mean that children should be discouraged from using scientific terms, only that the words should be used when students have first understood something or described an object or event using their own words.

Finding patterns involves a community of young learners in first sharing, discussing, and coming to agreement about what is observed, and then drawing conclusions about predictable events, relationships, and interactions. This may take time and the revisiting of what was observed, as children's observations are often strongly influenced by their beliefs and prior experiences.

As children explore a diversity of organisms in their environment, categorizing and assigning labels to groups of organisms arises quite naturally. Classification is a useful tool for children to use in organizing and understanding the natural world. However, at this age it need not lead to the classification systems of the scientific community. Two important categories are living/non-living and plant/animal. While the latter does not provide for all organisms, it is an important understanding that allows children to sort familiar organisms. The following dialogue actually occurred with a second grader studying animals and suggests the nature and complexity of children's thinking (in this case about categories), and the need for time for many related experiences with familiar organisms.

Adult:	What are you learning about in science?
Child:	Dogs, cats, squirrels, and mice and how they are alike.
Adult:	How are they alike?
Child:	They have fur.

Adult: Are people like dogs, cats, squirrels, and mice?
Child: No, because they are animals and people are not animals.
Adult: But people have hair, isn't that like fur?
Child: No, hair is not fur.
Adult: If people are not animals, are they plants?
Child: No, because they are not green. But they do make their own food so that makes them like plants.

Grades 5-8

The basic understandings of the K-4 years are elaborated and become more sophisticated in grades 5-8 as students study the human organism, encounter organisms outside their immediate environment, and engage in experimentation and field study. Students at this age also have the fine motor skills to work with a light microscope and can interpret accurately what they see. With this tool they can be introduced to the world of microorganisms. With this range of experiences and greater abilities to analyze data and think abstractly, students will look at the classification of organisms, variation, and diversity in more sophisticated ways. With greater experience, more refined observational tools, and a greater understanding of reproduction, students will begin to build an understanding of heredity, the continuity of life and evolution.

At this level students study ecosystems (environments that are conceptually bounded for the purpose of studying the living things within them) in greater depth and how living things interact with each other and with non-living parts of the system. These studies of ecosystems and also of populations and their change support the development of an understanding of interdependence of all organisms and of long- and short-term change, ideas which, in turn, are essential to beginning their study of evolution.

Organisms are also important in grades 5-8. At this level, the microscope allows students to see the cell and to build an understanding of the cell as the basic building block of life. A central focus of study becomes life processes and the relationship of the life processes of cells with those of organisms. A related theme is that of living systems. Students explore cells as subsystems of multicellular organisms, and single-celled and multicellular organisms as living systems composed of interacting subsystems.

Grades 9-12

Students come to grades 9-12 with the fundamental understanding of organisms, ecosystems, and the interdependence of living things necessary to engage four of the big ideas of the life sciences:

- the chemical nature of life processes;
- the molecular basis of heredity;
- evolution; and
- the flow of matter and energy in biological systems.

These big ideas are fundamental to the life sciences and they are also fundamental for the understanding of many of the scientifically related issues of our times.

Molecular biology will continue into the twenty-first century as a major area of science. Already, applications of research in this area have provided humans with powerful tools to modify the living environment to their own ends. Students need an understanding of the chemical basis of life not only for its own sake, but because of the need to take informed positions on some of the practical and ethical implications of humankind's capacity to tinker with the fundamental nature of life.

Likewise in the arena of environmental issues, students' understanding of the chemical basis of life, the molecular basis of heredity, and the nature of the flow of matter and energy in biological systems all provide some of the scientific understanding and knowledge that students will need to help make informed decisions about their environment.

Figure 5-1 outlines the general relationships among the Life Science Fundamental Understandings presented in the next section for grades K-12.

Figure 5-1

Framework for Life Sciences Fundamental Understandings

9-12	Matter and Energy in Biological Systems Variation, Diversity, and the Evolution of Species		
	The Chemical Nature of Life Processes		The Molecular Basis of Heredity
5-8	Life Processes of Cells and Multicellular Organisms		Interaction of Populations, and Their Environment
	Characteristics of Cells Subsystems of Multicellular Organisms	Variation and Diversity of Organisms	Ecosystems, Populations, Interdependence, and Change
K-4	Organisms and Their Characteristics Organisms in Their Environments		

Life Sciences
Fundamental Understandings
Grades K-4

Organisms and Their Characteristics

- Plants and animals are alive and go through predictable life cycles. These cycles differ from species to species but all include growth, development, reproduction, and death. Offspring grow up to be similar to their parents.
- Animals familiar to children must eat, drink water, breathe and get rid of waste products.
- Plants and animals are composed of different parts, serving different purposes and contributing to the well-being of the whole organism.
- Most plants and animals need air, food, water, light, and suitable environments. Green plants make their own food. Animals consume plants or other animals for food.
- Many different kinds of plants and animals (species) live on Earth today (diversity). Living organisms can be sorted (classified) into groups (species) on the basis of similarity in appearance and behavior.
- Within every species individuals vary.

Presentation

To provoke discussion regarding the scope, level, and specificity of the draft fundamental understandings for the life sciences, they are presented in this document in relatively stark form. We recognize that more specificity and probably narrative paragraphs will be needed before the understandings are useful in an educational context. In several cases we have used short, all too simple declarative sentences in order to convey quickly the general intent regarding scope of science subject matter. We are especially interested in comments on four things: (i) whether the intent is unclear; (ii) whether the fundamental understandings represent learning expectations in science that are appropriate for *all* students; (iii) whether the clusters we have used seem appropriate for creating standards; and (iv) how such expectations can best be presented in the final science standards document.

The dialogue we have been having with life scientists in different subdisciplines suggests that it is important to find a balanced representation of their varying perspectives.

Organisms in Their Environments

- Environments have living and nonliving parts. Plant and animal species depend on each other to maintain life. They meet their needs through interactions with living and nonliving parts of their environments. Each species has features that enable it to live and reproduce in a particular environment or habitat.

- Living organisms change the living and nonliving parts of environments in which they live. The activities of humans can be very important in this regard.
- Natural forces affect the environments in which plants and other animals live. Natural events, such as volcanic eruptions, affect individual organisms as well as groups of organisms.

Life Sciences
Fundamental Understandings
Grades 5-8

Variation and Diversity of Organisms

- Plants, animals, and microorganisms are major categories of living organisms. Each category includes many different species.

- Reproduction is the key characteristic of living organisms. In some instances a single organism is involved such as when a single yeast cell divides to form two cells (asexual). In other instances two parents are involved, typically one parent produces eggs and the other produces sperm that unite to form a new organism (sexual).

- Differences passed on to an organism's offspring are the result of changes in genetic material in the parent organism's reproductive cells. Organisms that have two parents receive a full set of genetic instructions specifying individual traits from each parent. Offspring exhibit traits from each parent.

- Sorting and recombining of the genetic material of parents during reproduction produce the potential for variation among offspring.

- There are minor differences among individuals from the same population or among individuals of the same kind (species). Some differences are acquired by the individual and affect only that individual while other differences can be passed on to the individual's offspring.

Ecosystems, Populations, Interdependence, and Change

- All species ultimately depend on one another. Interactions of organisms with each other and nonliving parts of their environments result in the flow of energy and matter throughout the system.

- Energy is supplied to an ecosystem primarily via sunlight. Plants convert light energy into stored (chemical) energy which the plant, in turn uses to carry out its life processes. Animals use plants for food.

- Plants, animals, and microorganisms have a balanced relationship that makes life possible. The waste products of animals (CO_2, nitrogen compounds and salts) are used by plants. Animals use the bodies of plants for food and the oxygen that plants produce to oxidize food. Microorganisms decompose bodies of dead animals and plants liberating chemical substances that can be used by plants (and animals to a limited degree). Thus, matter is recycled in an ecosystem.

- Organisms can be classified according to the function they serve in a food chain (Any single organism can serve each of these functions.):
  - production of food
  - consumption of food
  - decomposition of organic matter

- The quantity of light and water, the range of normal temperatures, and the soil makeup vary in ecosystems. This variation is largely responsible for the existence of different kinds of organisms and population densities in an ecosystem.

- Short-term changes in available food, moisture, or temperature of an ecosystem may result in a change in the number of organisms in a population or in the average size of individual organisms. Long-term changes may result in the elimination of a population.

- In the long term (millions of years), changes in the environment have resulted in qualitative changes in the kinds (species) of plants and animals that inhabit Earth (biological evolution). Fossils provide evidence of species that lived long ago but have become extinct.

Characteristics of Cells

- Cells are the basic units of life. They are the smallest unit of life that can reproduce themselves.

- Cells contain a common set of observable structures (organelles) that carry out the various functions of the cell. For instance, the nucleus stores information.

- Cell replication results not only in the multiplication of individual cells, but also in the growth and repair of multicellular organisms.

- Some organisms consist of only one cell.

- In multicellular organisms, cells can differ in many ways, assuming different appearances and carrying out specialized functions. Examples include:
  - cells containing chloroplasts that have the capacity to store energy from the sun as high energy chemical substances
  - sperm cells that carry a copy of the male's genetic information and transport themselves in the female reproductive system toward the egg cell.

Subsystems of Multicellular Organisms

- All organisms, whether single or multicellular, exhibit the same life processes, including growth, reproduction, and the exchange of materials and energy with their environments.

- Complex multicellular organisms are interacting systems of cells, tissues, or organs that fulfill life processes through mechanical and chemical means including:

  - procuring or manufacturing food
  - breathing and respiration
  - excreting waste products of metabolism
  - reproducing
  - protecting against disease
  - supporting structures and movement
  - controlling body functions (nervous and endocrine systems)
  - providing information about events within the body and in the organisms surroundings (sensory).

Life Sciences
Fundamental Understandings
Grades 9-12

The Chemical Nature of Life Processes

- Many molecular aspects of life processes of multicellular organisms occur in cells.
- Cells are highly organized collections of chemical substances. The fundamental chemical substances of life are long chains of carbon atoms with differing functional groups. Important among these are:
  - * carbohydrates
  - * lipids
  - * proteins
  - * nucleic acids
- Cells are the sites of chemical syntheses and energy conversions essential to life. Each metabolic event consists of many chemical reactions each catalyzed by a specific enzyme. Information about the nature of substances synthesized is carried to the site of the synthesis by a form of RNA.
- The complexity of the processes of energy conversions in cells is an adaptation of living organisms to the violent nature of energy conversions in vitro which are incompatible with living cells.
- In complex multicellular organisms, cells have specialized functions, communicate with each other, and are mutually dependent.
- Biological systems -- cells, multicellular organisms, and ecosystems -- obey the same conservation laws as do physical systems.

Matter and Energy in Biological Systems

- The conservation of energy law is a powerful tool for the analysis of metabolic processes in cells and organisms and for the analysis of energy flow in ecosystems.
- Energy is supplied to ecosystems by sunlight and dissipates as heat.
- Plants convert light energy into chemical energy. High energy chemical substances produced by plants, carbohydrates, and fats are the primary source of energy for all animal life.
- Energy flows through an ecosystem from prey to predator in the form of high energy chemical substances.
- Energy conversions that take place when animals metabolize carbohydrates and fats from plant or other animal sources are inefficient.
- Matter is recycled in ecological systems (water cycle, carbon cycle, nitrogen cycle).

The Molecular Basis of Heredity

- Cells are repositories of biological information.
- Chromosomes are the components of cells which convey hereditary information from one cell to its daughter cells, and from a parent to its offspring.
- Chromosomes are composed of sub-units called genes; each gene encodes the information directing the synthesis of a cell product, usually a protein, and can often be identified with a trait observed in the organism. Each chromosome contains a molecule of DNA, a long polymer that encodes information using four different sub-units. The structure of DNA, a double helix, insures that the cell can replicate the coded information.
- Many (50,000 - 100,000) bits of information, or genes, are encoded in human DNA. The expression of a given trait will depend to some degree on the genetic background made up of all other traits.
- In reproductive processes involving two parents (sexual reproduction), two specialized reproductive cells (gametes), one from each parent, fuse. One set of chromosomes from each parent is present in the resulting cell (zygote) which directs the formation of a new organism that has attributes of both parents.
- In some cases it is possible for a new organism to grow from a single cell or a cluster of cells from a parent organism (asexual reproduction). In the case of asexual reproduction, the offspring is exactly like the parent.
- Changes in DNA (mutations) occur when a cell is exposed to certain kinds of radiation or chemical substances. If this change occurs in the germ cells, it is passed on to the offspring; if it occurs in other (somatic) cells, it is passed on only to the products (daughters) of that cell.
- In a multicellular organism, the use of genetic information is controlled by a complex process; the use of different information results in different cell types, specialized in different ways to contribute to the well-being of the organism as a whole.
- DNA is a chemical substance that can be separated from cells and altered mechanically and chemically in test tubes. When altered DNA (from the same species) or DNA from another species is introduced into a cell, a new trait may be introduced into the cell's genetic material.
- Fragments of DNA can be analyzed to identify the individual from which the sample of DNA came, diagnose human genetic abnormalities, and to study populations.

Variation, Diversity, and the Evolution of Species

- Through mutation and natural selection, species change.
- Species may respond to changing conditions, by modifying their behavior.
- The human brain represents the highest level of evolution that has occurred.
- The diversity of a population of organisms improves the chances that the species will survive under new environmental conditions.

VI. NATURE OF SCIENCE

Introduction and Overview

The second category of science content, which we call the Nature of Science, includes knowledge of the inquiry process, the ability to design and carry out an investigation, perspectives associated with critical thinking or "habits of mind", and other positive attitudes usually associated with learning. We think it is important to distinguish between understanding the nature of inquiry and exhibiting the associated behaviors and to include both dimensions. Figure 6-1 displays the three clusters of content presently included in the Nature of Science framework.

Following this is a prototype standard for the first cluster, Modes of Inquiry. It is for Grades 9-12. This standard has implications for teaching standards, since it describes the ways in which teachers model, through their behaviors and the environment and teaching materials they create, values of the scientific community. The assessment of both teachers and students should also be consistent with this standard.

Standards for Modes of Inquiry for Grades K-4 and 5-8, not drafted yet, will reflect the same general perspectives, but will address the relevant skills and understandings at developmentally appropriate levels. Standards will also be developed for the other two clusters under the Nature of Science framework.

Figure 6-1

Topics to Be Included in the Nature of Science Framework

NATURE OF SCIENCE	
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

Nature of Science
Prototype Standard for Grades 9-12:
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;
- to develop the skills--and the disposition to use them--necessary to become independent inquirers about the natural world;
- 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:**
    - generating a number of possible questions;
    - recognizing which questions are in the domain of scientific inquiry; and
    - being aware of the complexity of the questions being generated.

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

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

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

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

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

7. **Coordinate and implement a full investigation by:**
   - formulating questions;
   - planning experiments;
   - conducting systematic observations;
   - interpreting and analyzing data; and
   - 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 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:

- 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.
- 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, evaluate examples of work using the skills, and 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 providing 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 class is responsible for evaluating each group's work. Students discuss with the presenting team their systematic observations, (including the organization and interpretation of data) and their drawing of conclusions (including the synthesis of ideas) and offer suggestions for improvement.

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.

Querying Inquiry

Most reviewers of the November Sampler responded favorably to inclusion of an inquiry prototype, although the range of opinion was very large. The example we chose accentuates the process of science rather than scientific content. Some urged that we modify the example to illustrate stronger science as well, and many offered suggestions for improvement:

"Emphasize that modes of inquiry cannot be separated from content... Students should be asked to generate and interpret models and theories. This is implicit in the activity but not clearly stated in the standard."

Others remarked on the necessity of including mathematical analysis, the need for the standards to address level of expectation and individual accountability, the importance of the connections between Modes of Inquiry and Decision Making, and the need to include observation as a skill of inquiry. -- exuding skepticism to extreme optimism:

"Your emphasis on Modes of Inquiry is not only inconsistent with Habits of Mind in Project 2061, but you support emphasizing process skills that were never justifiable."

"I applaud the emphasis upon inquiry learning in which students, on some level or another, formulate questions about the world and attempt to answer the questions themselves in a systematic and scientific way."

There was general support for the approach taken. Since there was insufficient time to incorporate suggestions for improvement, the example will be refined at a later date.

VII. APPLICATIONS OF SCIENCE

Introduction and Overview

The ability to use appropriate scientific knowledge to clarify and address issues and problems is vital to informed decision-making in our society. We have not dealt with the full scope of Applications of Science in this working paper. Rather, we have focused on one aspect, the application of scientific knowledge to personal and societal decision-making. Other aspects will be dealt with in future papers.

We consider Decision-Making as a set of interrelated skills, together with an understanding of how these skills are used in making sound decisions. Decision-Making includes the ability to:

- Formulate problem statements
- Identify dimensions of an issue
- Gather information
- Generate and evaluate alternative solutions
- Recommend a preferred solution
- Participate in decision-making
- Understand decision-making.

A prototype standard for Grades 9-12 is presented. Standards for Decision-Making for Grades K-4 and 5-8, not drafted yet, will reflect the same general perspectives, but will address the skills and understandings at developmentally appropriate levels.

Applications of Science
Prototype Standard for Grades 9-12:
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. For example, a proposed solution can be evaluated for scientific feasibility 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:

- 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?"
- identify important dimensions of the issue such as the scientific, political, ethical, cultural, technological, and economic impacts.
- gather information about the scientific and technological aspects of the issue, including relevant principles, concepts, and data.
- generate a set of alternative solutions that address all dimensions of the issue.
- 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.
- 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.
- 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:

- 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.

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

- 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.

- 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.

- 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.

- In complex, real-life situations, there seldom is

Decisions, Decisions

The Decision-Making prototype in the November Sampler provoked some of the liveliest written comments and letters that we received. The majority of comments on decision-making as an application of science were favorable (83% rated it "excellent" or "very good"). Most of the criticism was directed at the science content, or lack thereof, rather than the concept of decision-making. About "decision-making" as an application of science, compare these comments:

"It almost seems a waste of time to encourage young people to apply science to such decision-making. With so little time available for science, it is a travesty to devote time provided to learn natural science to decision-making involving personal health (health class), economics (home ec class), societal problems (social science class), or technology (technology class). Your charge is natural science, not social science, not civics, not ..."

"The Decision-Making prototype is the key to 21st century science. The emphasis in this section is exactly what all students need to be successful in life. It's about time it became a required part of science education."

A marginal comment on part A: "Superb", while another reviewer took exception to the way in which decision-making was portrayed: "Decision-making process as presented is a myth. Decision-making is not a straightforward, rational process. Decisions reached within and outside science are often based on irrational considerations and then worded back to rational justification."

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:

- The problem should have a large science component, for which information is readily available.
- The problem should have relevance to students.
- The science ideas associated with the problem should depend upon and reinforce other science content and the students' experience.
- 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.

The Comments Continue

The specific example used in Decision-Making came in for the harshest criticism. For example, "This is not a science question! It is a sociological-political question. Hydrologic and precipitation data are needed for the groups to discuss this particular question, but these data are NOT scientific data coming from the hard sciences of biology, chemistry, and physics -- nor are they data from the science side of meteorology or geology. I have no problem with students considering application of science questions, but please pick a set of questions for which real science has something to say (e.g., ozone layer depletion, acid rain). However, applications of science questions should be developed in a civics curriculum rather than a science curriculum, because the resolution of these applications questions, as important as they are, most often turns much more on political and sociological factors than on hard scientific data."

One small group discussing this prototype was asked directly if it should be eliminated. One person gave an emphatic, "Yes!" and two others immediately responded, "No!" One of the latter argued that our effort to engage all students would be substantially aided by having Decision-Making in the standards. Another small group who heard about the negative feedback quoted above was concerned that their favorite part of the November Sampler might be in jeopardy. They agreed to submit examples that addressed expressed concerns for "good science" -- an invitation we extend to others who have had successful experiences with decision-making activities in science classrooms.

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 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 (that again may be addressed in non-science classes). They will conduct investigations at the river; for example, measuring dis-charge, 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,

What About Decision-Making?

The National Committee on Science Education Standards and Assessment (NCSESA) will make the final judgements about what will and will not be in the science standards when the development and Critique & Consensus processes are far enough along. Things look about like this for Decision-Making, based on the thinking of the Curriculum, Teaching, and Assessment Working Groups and the diverse feedback received thus far: Granted that all decisions are not reached through straightforward, rational processes, Decision-Making can help to develop cognitive skills that can be carried with an individual throughout life and motivate more young people to study science -- and we think these purposes support the goals of the science standards as described in Section I. We also think the relationship to science needs to be clear. The discussion continues.

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.

VIII. CONTEXTS OF SCIENCE

Introduction and Overview

Knowing about the historical and social contexts of science and its relationships with other disciplines is part of the content of school science.

Studying the history of science -- its people and events -- shows students how science has evolved, and that the drive to understand the natural environment and to predict the course of natural events is universal. Such study should also highlight the interactions between science and technology. New technological devices have allowed 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 microscope technologies open new fields of scientific endeavor, providing useful views of individual atoms in matter.

The social contexts of science -- political, economic, and cultural -- allow students to understand that science is embedded in and interacts with other forms of human activity, and to sense how science fits in their lives.

Standards for school science will also take into account the close relationships between and among natural sciences, mathematics, social sciences, and technology. They will reflect the fact that the boundaries between and among these formerly distinct fields are blurring and that new partnerships among the fields are emerging. 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.

Prototype standards have not been developed in Contexts of Science.

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APPENDIX A

CRITIQUE AND CONSENSUS: A CALL FOR FEEDBACK

CRITIQUE & CONSENSUS FEEDBACK FORM

Please take this time to provide us with input and comments on the science education standards document. In order to ensure that we consider your comments before we compile our next document, please return this survey to us as soon as possible, but no later than **MAY 1, 1993**. Letters outlining your feedback are also helpful and welcome if you do not wish to adhere to the questions and format provided. While we appreciate all of the input we receive, we are unable to acknowledge the responses personally. **THANK YOU!**

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 review the *November Sampler* ? yes ☐ no ☐
If so, did you provide us with feedback? yes ☐ no ☐
Did the revisions reflect your input? yes ☐ no ☐
Please elaborate:

Name______________________________

Address______________________________
____

Would you like to be added to our mailing list? _______

Occupation______________________________

How are you involved with the Standards development effort? National Committee or Working Group member ________Organizational Liaison ________ State Science Supervisor ________ Interested Reviewer________

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 that I feel **needs further clarification**:

THE FUNDAMENTAL UNDERSTANDINGS: LIFE SCIENCES

What is your reaction to the substance of the Fundamental Understandings in the Life Sciences? Do they represent learning expectations in science that are appropriate for *all* students?

If you think that there are too many, what would you leave out or consolidate? (Please be specific!)

If you think that there are too few, what would you add and why (keeping in mind criteria found in Section III)? Again, please be specific, including the rationale for additions.

THE FUNDAMENTAL UNDERSTANDINGS: PHYSICAL SCIENCES

What is your reaction to the substance of the Fundamental Understandings in the Physical Sciences? Do they represent learning expectations in science that are appropriate for *all* students?

If you think that there are too many, what would you leave out or consolidate? (Please be specific!)

If you think that there are too few, what would you add and why (keeping in mind criteria found in Section III)? Again, please be specific, including the rationale for additions.

THE FUNDAMENTAL UNDERSTANDINGS: GENERAL QUESTIONS

The Fundamental Understandings are presented in this document in a list so that they can be viewed easily for purposes of critique to provoke discussion regarding scope, level, and specificity. What advice do you have for the presentation of Fundamental Understandings in subsequent documents? Do you prefer a narrative form or have other suggestions?

We intend to use physical, life, and earth & space sciences as major organizers for the Fundamental Understandings. Do you favor this approach, or would you prefer to have the Fundamental Understandings grouped in some other way? Please explain.

Are the frameworks found in Figures 4.1 and 5.1 helpful in organizing the Fundamental Understandings? Do we clearly explain their purpose?

Are the clusters utilized in organizing the Fundamental Understandings useful groupings?

PROTOTYPES

Do you have specific comments on the content or format of any of the prototype standards?

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

APPENDIX B

COMMITTEES, STAFF, AND ORGANIZATIONAL LIAISONS

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.

FRYE, Shirley M., Independent Mathematics Consultant, Scottsdale, Arizona.

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

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

GOODLAD, John I., Director, Center for Educational Renewal; and Professor of Education, University of Washington, Seattle.

GOULD, Stephen Jay, Professor of Earth Sciences, Harvard University, Cambridge, Massachusetts.

HERNANDEZ, Sonia C., Director, Education Policy, Office of the Governor of Texas, Austin, Texas.

LANG, Michael, Science Superintendent, Arizona Department of Education, Phoenix, Arizona.

LINDER-SCHOLER, William, Director, Community Affairs, Cray Research, Inc., Mendota Heights, Minnesota.

LONGREED, William, Adjunct Instructor, Biology and Chemistry, Navajo Community College; Teacher, Biology and Biological Sciences, Tuba City High School, Tuba City, Arizona.

MALCOM, Shirley M., Director, Education and Human Resources, American Association for the Advancement of Science, Washington, D.C.

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APPENDIX C

SUMMARY OF FEEDBACK FORMS FROM THE NOVEMBER SAMPLER

Summary of Feedback Forms from the November Sampler

THANK YOU FOR PROVIDING US WITH FEEDBACK TO THE ***NOVEMBER SAMPLER***. Below is a summary of the responses from the approximately 600 individuals and groups that returned a feedback survey or letter. The summary follows the format of the long form, which was used by over 78% of the respondents.

Did you see the *October Discussion Document*? yes: 130 no: 482
If so, did you give us feedback? yes: 79 no: 61
If so, do you see any progress in the direction you hoped? yes: 78 no: 8

Please describe:

- **"more specifics and detail than in October document"**
- **"progress on technology issue and better section describing 'science for all'"**
- **"proposed content on the Standards is still very narrowly defined in terms of the disciplines included"**

Occupation: 48% from teachers; 17% from science education administration; 17% from scientists, 8% education professors, 10% other

State of Residence?: 47 states (all except HI, ID, ND); Puerto Rico and Canada

How did you hear about the national science education standards effort? (e.g. conference, publication, word of mouth)? all of the above

Italics **are used for summary paraphrases;** normal type **for direct quotes.**

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

- *an effort is underway that integrates curriculum, teaching and assessment*
- *activities are hands-on and group-oriented*
- *emphasis on science process*
- *basic principles and concepts underlying document, including principle of "more depth, less breadth"*
- *broad and flexible*
- *the commitment to all students*
- "I value statement on social commitment because it is very important that this be a guiding philosophy at national level."

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

- *writing and organization*
- *need more emphasis on role of curiosity and creativity*
- *social and cultural aspects overemphasized*
- *calls for decrease in amount of knowledge taught (what about AP classes and future scientists?)*
- *lack of detail regarding body of scientific knowledge and level of depth to be covered*
- *layer cake boundaries still apparent*
- *unrealistic in scope and goals*
- "absence of math and technology"

An area which I feel **needs clarification**:

- *relationship of science, technology and society in the science curriculum*
- *commitment to "science for all"*
- *implementation and teacher preparation*
- *effect on university and college community (preparation for, and teaching)*
- *integration of various disciplines*
- *more explicit identification of laws and principles to be mastered*
- *student accountability*
- "What is role of quantitative and analytic studying and the link between math and science?"

SECTION I: Introduction

		How well did you read?		
		carefully	fairly	skim
How well did we address?	well	145	49	21
	adequately	56	39	8
	poor	8	7	0

Additional comments:

- *comments primarily concerned with readability and redundancy*
- *do not specify full science program, allow flexibility*
- *address time allotment and order for science courses*
- *emphasize connections between disciplines*
- "define 'level of understanding that all should develop' in a way distinguishable from minimum competency."
- "I am wary of phrase 'teachers create learning environments' because the structure of the department or the policies of the school as a whole may thwart an individual teacher's efforts to create a situation that optimizes student learning."

SECTION II: The Goals of School Science Education

		How well did you read?		
		carefully	fairly	skim
How well did we address?	well	163	27	21
	adequately	62	36	6
	poor	6	1	0

Additional comments:

- *be more specific with goals*
- *elaborate on equity*
- *in general, favorable response to broader definition of "scientific literacy"*
- "very inspirational. I hope it is possible"
- "It seems to be too optimistic when it is stated 'all students can be expected to know, understand, and use this knowledge and use this knowledge , if they are given appropriate educational opportunities.' You are setting unrealistic mastery type goals which contradicts the main aim of the standards, improved science education."

SECTION III: The Character of School Science

		How carefully did you read?		
		carefully	fairly	skim
How well did we address?	well	116	34	13
	adequately	70	37	12
	poor	24	4	1

Additional comments:

- *figures do not match text*
- *more explanation needed what the* "fundamental concepts, laws and theories" *are, how they are being identified, and how they will be defined as to what students should know and do*
- *elaborate on* "the amount of information and the body of knowledge to be learned must be reduced substantially"
- *give rationale for inclusion of the historical, cultural, social contexts of science*
- *range of comments on statement that* "science education must reflect science as it is practiced"*--some praised concept while others found it problematic citing, for one, that a science classroom is not a science lab*
- "Technology is a very loaded word, as you indicate, and is worthy of clarification: why is it a footnote rather than part of the body of the text?"
- "I welcome focus on reducing the body of information and developing deeper understanding of central ideas. However, the Framework expands the science curriculum to include attitudes, dispositions, and the contexts of science."

SECTION IV: The Standards for School Science

		How well did you read?		
		carefully	fairly	skim
How well did we address?	well	141	28	14
	adequately	57	29	8
	poor	11	4	1

Additional comments:

- *be consistent with format among prototypes*
- *be more specific regarding* "Body of Scientific Knowledge"*, and level of depth of understanding that will be recommended*
- *emphasize science in activities*
- *too much stress on experimentation and group learning (not only ways to learn)*
- *create student-centered activities--these activities till largely stem from teacher*
- *allow for cross-disciplinary references and activities*
- "...we will finish up with much stronger and more age-appropriate standards if we use narrower grade groupings to define curriculum expectations. The current document jumps from K-4 section that to me is more appropriate for K-2 to a 5-8 section where the focus appears more towards the 7-8 students, and it leaves some gaping holes in the middle."
- "These are not creative activities! Please save the word 'creative' for divergent, activities that haven't appeared in science education before."
- "I am concerned with selecting concepts to be learned without some defined criteria for that selection process."

THE INTELLECTUAL TERRITORY OF SCHOOL SCIENCE

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 among different kinds of technology--applied science, principles of engineering, and design. Do you see the distinctions? Why or why not?

As indicated in the front of the document, the role of technology in the science curriculum (as opposed to instructional technology) needs further clarification. Few individuals expressed views differing from the belief that technology had to be addressed to some extent in the science education standards. However, divergence appeared with individual's thoughts concerning the attention and integration that technology warranted in the science curriculum, as will as how the draft of the standards addressed the issue. Below are some of the comments that we received. The working groups, especially the curriculum group, will continue to work on clarifying the issue.

- *technology is the application of science; therefore, it must be included in science education*
- *appropriate degree of the integration of technology depends on grade level*
- *technology serves as a motivator to learn science: shows relevance and practicality of science*
- "Science and technology must be viewed holistically."
- "Science does not require application to human activities."
- "Science and technology are blended in the real world and should also be blended in the curriculum."

PLEASE RATE THE FOLLOWING PROTOTYPE STANDARDS:

	excellent	very good	fair	poor
Prototype Standard for Modes of Inquiry	143	157	28	1
Prototype Standard for Matter and Its Interactions	121	142	55	13
Prototype Standard for Decision-Making	127	143	50	7

Additional Comments:

Inquiry:

- *Need to connect the generalities of process and the content of science*
- *Add numerical analysis, include mathematics, math modeling, and math insights which can be tested by experiment & can be used to pose questions & test theories;*
- *Explain that this activity focuses on inquiry aspect, not content aspect of the standards*
- *Processes of science need deeper level inquiry then presented in prototypes*

Matter & Its Interaction:

- *Make Matter & Interaction and other activities more creative. Move away from cook-book type of labs*
- *Matter Activity for 5-8 Boring*
- *Middle school activity makes no allusions to applications*
- *Matter Activity for K-4 good*
- *Use of Hammers in elementary schools unrealistic and unsafe*
- *K-4 Matter Activity not appropriate for urban settings or classes with more than 15 students*

Decision-Making:

- *In Decision-Making prototype, more emphasis should be placed on quantifying data (math & statistics) as support for reporting data to make decisions & to build consensus*
- *Emphasize that decision-making need not involve a global issue*
- *In general, comments were favorable toward concept of Decision Making, criticism involved the activity/example*