Science Framework for the 2009 National Assessment of Educational Progress

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EXECUTIVE SUMMARY

Introduction

In the rapidly changing world of the 21st century, science literacy is an essential goal for all of our nation's youth. Through science education, children come to understand the world in which they live and learn to apply scientific principles in many facets of their lives. In addition, our country has an obligation to provide young people who choose to pursue careers in science and technology with a strong foundation for their post-secondary study and work experience. The nation's future depends on scientifically literate citizens who can participate as informed members of society and a highly skilled scientific work force, well prepared to address challenging issues at the local, national, and global level. Recent studies, including national and international assessments, indicate that our schools still do not adequately educate all students in science.

Science seeks to increase our understanding of the natural world through empirical evidence. Such evidence gathered through observation and measurement allows explanation and prediction of natural phenomena. Hence, a scientifically literate person is familiar with the natural world and understands key facts, concepts, principles, laws, and theories of science, such as the motion of objects, the function of cells in living organisms, and the properties of Earth materials. Further, a scientifically literate person can connect ideas across disciplines, for example, the conservation of energy in physical, life, Earth, and space systems. Scientific literacy also encompasses understanding the use of scientific principles and ways of thinking to advance our knowledge of the natural world, as well as the use of science to solve problems in real-world contexts, which this document refers to as "Using Technological Design."

The National Assessment of Educational Progress (NAEP) and its reports are a key measure in informing the nation on how well the goal of scientific literacy for all students is being met. The *Science Framework for the 2009 National Assessment of Educational Progress* (the *Framework*) sets forth recommendations for the design of a new science assessment. The assessment resulting from this *Framework* will start a new NAEP "science trend" (i.e., measure of student progress in science) beginning in 2009. This *Framework* represents a unique opportunity to build upon previous NAEP science work as well as key developments in science standards, assessments, and research. This document is intended to inform the general public, educators, policymakers, and others about what students are expected to know and be able to do in science as part of "The Nation's Report Card," a program of the U.S. Department of Education (ED) that reports on NAEP findings.

In 1988, Congress created the National Assessment Governing Board (NAGB) to set policy for NAEP. The National Center for Education Statistics (NCES, a division of ED) carries out NAEP. As the ongoing national indicator of the academic achievement of U.S. students, NAEP regularly collects information on representative samples of students in grades 4, 8, and 12 and periodically reports on student achievement in reading,

mathematics, writing, science, and other subject areas. NAEP scores are always reported at the aggregate level, not for individual students or schools. (By law, NAEP cannot report results for individual students.) For science, NAEP results are reported at the national, state, and select district levels. The district reports are provided for urban school systems that volunteer for the Trial Urban District component of NAEP.

NAEP produces comparative student achievement results according to demographic factors such as gender, race/ethnicity, and geographic region. Results are also provided in terms of student, teacher, and school background variables related to science achievement. Taken together, this information from NAEP helps the general public, educators, and policymakers make informed decisions about education. Interested individuals can access performance results and released questions through NAEP reports and Web sites.

A new framework to guide the science assessment in 2009 is necessary for several reasons: publication of national standards for science literacy, advances in both science and cognitive research, growth in national and international science assessments, and increases in innovative assessment approaches. This 2009 *Framework* presents the content to be assessed, as well as the conceptual base for the assessment. It is intended for a general audience. A more detailed, technical document, the *Science Assessment and Item Specifications for the 2009 NAEP* (the *Specifications*), is a companion piece. The *Specifications* document provides detailed information on the content to be assessed, item development, and other aspects of assessment development and administration. The audience for the science *Specifications* is NCES and the NAEP assessment development contractor.

Key Features

This *Framework* is the result of extraordinary effort and commitment by hundreds of individuals across the country, including some of the nation's leading scientists, science educators, policymakers, and assessment experts. Under contract to the National Assessment Governing Board, WestEd and the Council of Chief State School Officers conducted an 18-month process to develop the *Framework* involving committees, regional hearings, and other public forums. The Governing Board also engaged an external review panel to evaluate the draft *Framework* and convened a public hearing to gather additional input during the development process.

The new *Framework* incorporates the following key features:

- Its design is based on widely accepted national science standards and assessments, in addition to state curriculum standards. However, the *Framework* is intended to inform development of an assessment, not to advocate for a particular approach to instruction or to represent the entire range of science content and skills.

- In view of the need to keep the United States and our nation's youth internationally competitive in science and technology, the *Framework* development process gave special consideration to international assessment frameworks, such as those for *Trends in International Mathematics and Science Study* (TIMSS) and *Programme for International Student Assessment* (PISA).
- The breadth of the science principles represented in the source materials necessitated focusing on the foundational and pervasive knowledge within each discipline and paring down the science content to be assessed.
- The *Framework* is based on scientific knowledge and processes derived from tested explanations and supported by accumulated empirical evidence. Explanations of natural phenomena that rely on non-scientific views are not reflected in the *Framework.*
- Science content is presented in detailed, grade-specific charts that also allow the reader to see the progression in complexity of ideas across grades.
- Every attempt has been made to be free of error in the description of the science content. The language used strives to be accurate but not technical so as to make the *Framework* accessible to a wide audience.
- There is a focus on students' conceptual understanding, that is, their knowledge and use of science facts, concepts, principles, laws, and theories. Students' abilities to engage in some components of scientific inquiry and technological design are also reflected in the *Framework.*
- New types of items are recommended, including the use of interactive computer tasks.

Content of the Framework

The *Framework* describes the science content and the science practices that form the basis for the 2009 NAEP Science Assessment. It also discusses item distribution and types of items, as well as draft achievement levels. Finally, it recommends several small-scale, special studies to be considered in conjunction with the 2009 or future science assessments.

Science Content

The science content for the 2009 NAEP is defined by a series of statements that describes key facts, concepts, principles, laws, and theories in three broad areas:

- Physical Science
- Life Science
- Earth and Space Science

Physical Science deals with matter, energy, and motion; Life Science with structures and functions of living systems and changes in living systems; and Earth and Space Science with Earth in space and time, Earth structures, and Earth systems. Details about the

science content and the science content statements themselves can be found in Chapter Two.

Science Practices

The second dimension of the *Framework* is defined by four science practices:

- Identifying Science Principles
- Using Science Principles
- Using Scientific Inquiry
- Using Technological Design

These practices can be combined with any science content statement to generate student performance expectations, and assessment items can then be developed based on these performance expectations. The cognitive demands placed on students as they engage in assessment tasks are also described. The science practices and cognitive demands are more fully detailed in Chapter Three.

Distribution of Items

As measured by student response time, the distribution of items by content area should be as follows: approximately equal across Physical Science, Life Science, and Earth and Space Science at grade 4; more emphasis on Earth and Space Science at grade 8; and a shift to more emphasis on Physical Science and Life Science at grade 12. With respect to science practices, at all grades, the greatest emphasis should be on Identifying and Using Science Principles; and slightly less than a third of the time should be spent on items related to Using Scientific Inquiry. Specific recommended percentages are discussed in Chapter Four.

Types of Items

Item types for the 2009 NAEP Science Assessment fall into two broad categories: selected-response items such as multiple-choice items and constructed-response items such as short answer items. As measured by student response time, 50% of the assessment items at each grade level should be selected-response items and 50% should be constructed-response items. In order to further probe students' abilities to combine their understandings with the investigative skills reflective of practices, a subset of the students sampled should receive an additional 30 minutes to complete hands-on performance or interactive computer tasks. At each grade, there should be at least a total of four of these tasks. Of these four tasks, there should be at least one hands-on performance *and* one interactive computer task; the number of interactive computer tasks should not exceed the number of hands-on performance tasks. More on types of items can be found in Chapter Four.

Hands-on Performance Tasks

In hands-on performance tasks, students manipulate selected physical objects and try to solve a scientific problem involving the objects. NAEP hands-on performance tasks should provide students with a concrete task (problem) along with equipment and materials. Students should be given the opportunity to determine scientifically justifiable procedures for arriving at a solution. Students' scores should be based on both the solution and the procedures created for carrying out the investigation. Further discussion about hands-on performance tasks can be found in Chapter Four.

Interactive Computer Tasks

Interactive computer tasks may be of four types: (1) information search and analysis, (2) empirical investigation, (3) simulation, and (4) concept maps. Information search and analysis items pose a scientific problem and ask students to query an information database and analyze relevant data to address the problem. Empirical investigation items put hands-on performance tasks on the computer and invite students to design and conduct a study to draw conclusions about a problem. Simulation items model systems (e.g., food webs) and ask students to manipulate variables, and predict and explain resulting changes in the system. Concept map items probe aspects of the structure or organization of students' scientific knowledge by providing concept terms and having students create a logical graphic organizer. More on interactive computer tasks can be found in Chapter Four.

Special Studies

On occasion, NAEP carries out special studies to inform future assessments. Three special study proposals ranked as top priority for NAEP Science:

- "Exchangeability" of Hands-on Performance and Interactive Computer Investigations
- Impact of Variation in Item Format and Language Demand on the Performance of English Language Learners and Students with Disabilities
- Computer Adaptive Testing to Assess the Development of Student Understanding of Earth Systems

Details of these proposed studies are found in Chapter Four.

Achievement Levels

Results of the NAEP Science Assessment are reported as average scores for groups of students and as percentages of students who attain the Basic, Proficient, or Advanced achievement levels. Preliminary descriptions of these achievement levels may be found in Appendix C.

2009 SCIENCE FRAMEWORK PROJECT PARTICIPANTS

The *Science Framework for the 2009 National Assessment of Educational Progress* is the result of extraordinary effort and commitment by hundreds of individuals across the country, including some of the nation's leading scientists, science educators, policymakers, and assessment experts. See Appendix A for more detailed lists of Steering Committee members, Planning Committee members, and other individuals and organizations that contributed to the development of this *Framework*. Every attempt has been made to be accurate in the description and representation of the science content. Existing framework development policies and procedures ensure periodic reviews and revisions, if necessary, to reflect advancements in scientific knowledge. As this is a public endeavor, the National Assessment Governing Board (www.nagb.org) welcomes suggestions for future versions of the *Framework*.

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CHAPTER ONE: OVERVIEW

Introduction

The National Assessment of Educational Progress (NAEP) measures student science achievement nationally, state-by-state, and most recently across selected urban school districts. Periodically, the framework underlying the science assessment is revised or updated. This document, the *Science Framework for the 2009 NAEP* (herein called the *Framework*), contains a new set of recommendations for the NAEP Science Assessment to be administered in 2009 and beyond. The *Framework* provides guidance on the science content to be assessed, the types of assessment questions, and the administration of the assessment.

For more than 35 years, NAEP has gathered information on student achievement in selected academic subjects. Originally, assessments were age-based samples of students 9-, 13-, and 17-years old. Beginning in 1983, the assessment also has included grade-based samples of students in grades 4, 8, and 12. Currently, long-term trend NAEP continues to assess 9-, 13-, and 17-year-olds in mathematics and reading, while main NAEP assesses students in grades 4, 8, and 12. For more information about differences between long-term trend and main NAEP, see the following website: http://nces.ed.gov/nationsreportcard/about/ltt_main_diff.asp (National Center for Education Statistics [NCES], 2005b).

NAEP has become an important source of information on what U.S. students know and are able to do in reading, mathematics, science, U.S. history, writing, and other subjects. In addition, NAEP provides information on how student performance has changed over time. Since the 1990s, in addition to the national-level assessments, NAEP has conducted and reported state-level assessments at grades 4 and 8 in reading, mathematics, writing, and science. State-level, as well as national, science assessments were conducted in 1996, 2000, and 2005. The resulting data on student knowledge and performance have been accompanied by background information that allows analyses of a number of student demographic and instructional factors related to achievement. The assessments have been designed to allow comparisons of student performance over time and among subgroups of students according to region, parental education, gender, and race/ethnicity. In 2002, NAEP began a Trial Urban District Assessment (TUDA) in districts that volunteered to participate. The TUDA has continued through 2005 when ten districts took part in NAEP assessments that produced district-level results.

Need for a New Framework

The framework that guided the last three NAEP Science Assessments (administered in 1996, 2000, and 2005) was developed some 15 years ago. Since then, the following developments have taken place, making it necessary to create a new framework for assessing science in 2009 and beyond:

- Publication, for the first time, of national standards for science literacy in *National Science Education Standards* (National Research Council [NRC], 1996) (herein called *National Standards*) and *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science [AAAS], 1993) (herein called *Benchmarks*). Since their publication, these two national documents have informed state science standards.
- Advances in science research (e.g., on the relationship between human activity and the natural world) that have increased knowledge and as a consequence influenced the school curriculum in the fields of physical, life, and Earth and space sciences.
- Advances in cognitive research (e.g., on how students learn increasingly complex material over time) that have yielded new insights into how and what students learn about science (NRC, 1999c).
- Growth in the prevalence of science assessments nationally and internationally, including the requirements in the current federal education legislation, *No Child Left Behind*, for science assessment starting in 2007; the ongoing international assessment, *Trends in International Mathematics and Science Study* (TIMSS) (see http://timss.bc.edu); and *Programme for International Student Assessment* (PISA) (see www.pisa.oecd.org).
- Growth in innovative assessment approaches that probe students' understanding of science in greater depth than before (e.g., clusters of items tapping students' conceptions of the natural world), sometimes with the use of computer technology (NRC, 2001).
- Increased inclusion of formerly excluded groups in science assessments (e.g., students with disabilities and English language learners), requiring a new assessment to be as accessible as possible and also to incorporate accommodations so that the widest possible range of students can be fairly assessed. Accommodations should not alter the science constructs being measured.

Context for Planning the Framework

Any NAEP framework must be guided by NAEP purposes as well as the policies and procedures of the National Assessment Governing Board (NAGB), which oversees NAEP. For the NAEP Science Assessment, the main purpose of the *Framework* is to establish what students should know and be able to do in science for the 2009 and future assessments. Meeting this purpose requires a framework built around what communities involved in science and science education consider as a rigorous body of science knowledge and skills that are most important for NAEP to assess.

In prioritizing the content, the *Framework* developers used the guidance from the NAEP Science Assessment Steering Committee (presented later in this chapter), which recommended the two national documents, *National Standards* and *Benchmarks*, as representative of the leading science communities and their expectations for what students should know and be able to do in science. As curriculum frameworks, however, these documents cover a very wide range of science content and performance. The

inclusive nature of both these documents demonstrates the difficulty of identifying a key body of knowledge for students to learn in science and, therefore, what should be assessed. Neither document limits or prioritizes content as is necessary for developing an assessment, posing a considerable challenge to the *Framework* developers. The development of the *Framework* also was informed by research in science and science education, best practices, international assessment frameworks, and state standards.

The Framework Development Process

In September 2004, NAGB awarded a contract to WestEd and the Council of Chief State School Officers (CCSSO) to develop a recommended *Framework* and *Science Assessment and Item Specifications for the 2009 NAEP* (herein called the *Specifications*). WestEd and CCSSO, in collaboration with the American Association for the Advancement of Science (AAAS), the Council of State Science Supervisors (CSSS), and the National Science Teachers Association (NSTA), used a process designed to accomplish the purposes of this project with special attention given to the assessment issues that are specific to K-12 science achievement. The process for developing the *Framework* and related products was inclusive and deliberate, designed to achieve as much broad-based input as possible.

A two-tiered committee structure, consisting of a Steering Committee and a Planning Committee, provided the expertise to develop the *Framework* as specified by NAGB. (See Appendix A for lists of committee members.) The two committees were composed of members who were diverse in terms of role, gender, race/ethnicity, region of the country, perspective, and expertise regarding the content of the assessment to be developed.

Comprised of leaders in science, science education, general education, assessment, and various public constituencies, the Science Assessment Steering Committee set the course for the project. Functioning as a policy and oversight body, this group developed a charge that outlined what the Planning Committee should attend to in the development of the *Framework.* The committee also reviewed and provided feedback on drafts of the *Framework* and related materials.

The Science Assessment Planning Committee, supported by the project staff, was the development and production group responsible for drafting the *Framework*, the *Specifications*, recommendations for background variables, designs for one or more small-scale studies, and preliminary science achievement level descriptions. This committee was made up of science teachers, district and state science personnel, science educators in higher education, scientists, and assessment experts. The Planning Committee's work was guided by policies, goals, and principles identified by the Steering Committee. In addition, the Planning Committee used a number of resources to facilitate their work. These included an *Issues and Recommendations* paper (Champagne, Bergin, Bybee, Duschl, & Gallagher, 2004) developed specifically for this NAEP project; the frameworks and specifications for the 2005 NAEP Mathematics Assessment and 1996-2005 NAEP Science Assessments; other NAEP reports and documents produced by

NAGB and NCES; international assessment frameworks; syntheses of state and national curriculum standards; and research papers and resources provided by Steering and Planning Committee members and project staff.

The structure for conducting the work consisted of a series of meetings. From December 2004 through September 2005, the Steering Committee met three times and the Planning Committee met six times; two of the Steering Committee meetings overlapped with Planning Committee meetings. NAGB staff supported and participated in the work of the committees during the meetings. Additionally, between formal work sessions, NAGB members and staff provided ongoing feedback and guidance on project documents and processes.

During spring 2005, CCSSO led a series of outreach efforts to solicit feedback on draft versions of the *Framework*. Formal activities included the following:

- A series of 13 regional meetings held across the country and hosted by CCSSO and members of the Council of State Science Supervisors (CSSS)
- A national meeting of CSSS representatives
- A web-based survey of science teachers distributed through the National Science Teachers Association (NSTA)
- An invitational science and industry feedback forum held in Atlanta in conjunction with a NAGB meeting

These activities are discussed in *A Summary of National Feedback Provided on Preliminary Drafts Gathered from Surveys and Regional and National Feedback Meetings* (CCSSO, 2005). Feedback from these sessions has been incorporated into the *Framework*. Examples include reduction of the number of statements of science content to be assessed; a comparison of the old and new Science Frameworks; and ensuring a high level of consistency in scope, specificity, language, and format across the science content areas.

Other related outreach activities included but were not limited to presentations and sessions held with the American Association for the Advancement of Science (AAAS); the CSSS annual conference; the NSTA national and regional conventions; meetings of the National Research Council (NRC)'s Board on Science Education and Committee on Science Learning K-8; and CCSSO's Mega-SCASS (State Collaborative on Assessment and Student Standards) conference, Large-Scale Assessment conference, and Education Information Management Advisory Consortium (EIMAC). NAGB engaged an external review panel to evaluate the draft *Framework* and convened a public hearing to gather additional input during the development process. (See Appendix A for more complete lists of individuals and organizations that contributed to the development of this *Framework*.) The Planning Committee reviewed feedback from these groups as well as that from the Steering Committee and made changes as it deemed appropriate. After final approval from the Steering Committee, the *Framework*, the *Specifications*, and related products were submitted to NAGB for action. The Governing Board unanimously

approved the 2009 Science Framework on November 18, 2005. Final copies of the *Specifications* and related products were submitted to NAGB in March of 2006.

Steering Committee Guidelines

Because of the importance of the Steering Committee Guidelines to the Planning Committee in developing the *Framework*, the major points of the Guidelines are summarized in the following bulleted text. (The complete document may be found in Appendix B.) The Guidelines consist of a set of criteria that the *Framework* and *Specifications* must meet:

- The *Framework* is informed by the *National Standards* and *Benchmarks*. The *Framework* should reflect the nation's best thinking about the importance and age-appropriateness of science principles and thus be informed by two national documents that were subject to extensive internal and external reviews during their development.
- The *Framework* reflects the nature and practice of science. The *National Standards* and *Benchmarks* include standards addressing science as inquiry, nature of science, history of science, and the human-made world. The *Framework* should emphasize the importance of these aspects of science education and should include the expectation that students will understand the nature and practice of science. Because the scientific disciplines are no longer practiced in isolation and research that cuts across discipline boundaries is common, the *Framework* should identify some of the science concepts and skills that cut across the assessed content areas. The *Framework* should address science in both the natural and human-made world, as well as social and historical contexts.
- The *Framework* uses assessment content, formats, and accommodations consistent with the objectives being assessed. It should be guided by the best available research on assessment item design and delivery. The *Framework* should be inclusive of student diversity as reflected in gender, geographic location, language proficiency, race/ethnicity, socio-economic status, and disability. The assessment should be designed and written to be accessible by the majority of students, minimizing the need for special accommodations for both students with disabilities and English language learners. However, those students with special needs should be provided appropriate accommodations to allow them to participate in the assessment. The *Framework* should reflect knowledge about the acquisition of key science concepts over time, based on research about how students learn. Critical content and skills should be articulated and assessed across grades 4, 8, and 12 (vertically), as well as across the fields of science (horizontally) by creating items that are deliberately layered to achieve these goals.
- The *Framework* uses a variety of assessment formats. This includes well-constructed multiple-choice and open-ended items as well as performance tasks. In addition, multiple methods of assessment delivery should be considered, including the appropriate uses of computer technology.

- Each achievement level—Basic, Proficient, and Advanced—includes a range of items assessing various levels of cognitive knowledge that is broad enough to ensure each knowledge level is measured with the same degree of accuracy. Descriptions of Basic, Proficient, and Advanced must be as clear as possible.
- Connections among the *Framework*, the *Specifications*, and the assessment items themselves are transparent, coherent, and have a consistent level of specificity. The *Specifications* should be written with detail consistent with the *Framework*. The content addressed in the *Specifications* should reflect the standards and focus on the significant information and knowledge that students should retain over time (e.g., big ideas, fundamental understandings). The verbs used in the *Specifications* should describe the expected target for assessment (e.g., identify, describe, evaluate, relate, analyze, and demonstrate). The content expectations should match in level of specificity and scope across the disciplines. The *Specifications* should follow the idea of learning progressions. To assess overarching concepts or themes, the *Specifications* should reflect a scaffolded or layered understanding of growth in knowledge of the concepts.
- The *Framework* addresses the use of assessment data to conduct research on science learning and to improve science achievement. Data (background variables) from the assessment should be collected in such a way as to provide information that supplies details of the characteristics of the students being assessed (e.g., race/ethnicity and gender), the academic preparation of their teachers, and the nature of their schools. Such data provide feedback to educators for improving science instruction and learning.

Uses of NAEP Data

For more than four decades, NAEP has provided information integral to reporting on the condition and progress of education at grades 4, 8, and 12 for the nation, and more recently, for the states and for a set of large, urban school districts. Legislation concerning NAEP states that its purpose is to provide, in a timely manner, a fair and accurate measurement of student academic achievement and reporting of trends in such achievement in reading, mathematics, and other subject matter (Public Law 107-279).

Because of its rigorous design and methodology, NAEP reports are increasingly used for monitoring the state of education in the subjects that are assessed, as models for designing other large-scale assessments, and for secondary research purposes.

Monitoring

As the nation's only ongoing survey of students' educational progress, NAEP has become an increasingly important resource for obtaining information on what students know and can do. Because the information it generates is available to policymakers, educators, and the public, NAEP can be used as a tool for monitoring student achievement in reading, mathematics, science, and other subjects at the national, state, and selected district levels. For example, NAEP reports, known as "The Nation's Report Card," compare student performance in a given subject across states, within the subject

over time, or among groups of students within the same grade. NAEP also reports long-term achievement trends for 9-, 13-, and 17-year-olds in reading and mathematics (e.g., Perie, Moran, & Lutkus, 2005). To the extent that individual state standards reflect the common core of knowledge and skills specified in the *Framework*, state comparisons can legitimately be made. If a state has unique standards, any comparison is limited by the degree of mismatch between NAEP content and state content. Even with this caveat, NAEP still stands as a key indicator of what students know and can do in science at grades 4, 8, and 12.

Model of Assessment Development and Methods

NAEP assessment frameworks and specifications documents are themselves used as resources for international, state, and local curriculum and assessment. The broad-based process used in the development of the frameworks and specifications means that current thinking and research is reflected in these descriptions of what students should know and be able to do in a given subject. In addition, NAEP uses a rigorous and carefully designed process in developing the assessment instruments themselves. Pilot tests and internal and external reviews ensure that NAEP assessments are reliable and valid with respect to what they attempt to accomplish. This sophisticated methodology serves as a model for other assessment developers. Given the requirements contained in *No Child Left Behind* to assess students in science, states may wish to use NAEP as one model to guide their own assessment development.

Research and Policy

The data NAEP provides include subject-matter achievement results (reported as both scale scores and achievement levels) for various subgroups; background information about schools, teachers, and students at the subgroup level (e.g., course-taking patterns of Hispanic male 12th graders); state-level results; reports for a set of large urban districts; history of state and district participation; and publicly released assessment questions, student responses, and scoring guides. The NAEP Web site, http://nces.ed.gov/nationsreportcard, contains user-friendly data analysis software to enable policymakers, researchers, and others to examine all aspects of NAEP data, perform significance tests, and create customized graphic displays of NAEP results. These data and software tools can be used to inform policymaking and for secondary analyses and other research purposes.

Challenges of Developing a NAEP Assessment

There are three major challenges in developing a NAEP framework, and, in particular, this *Framework*. One such challenge arises from measurement constraints and the nature of the items included on the assessment; the next relates to time and resource constraints and how much can be assessed in NAEP; and the last comes from the time horizon for the *Framework* and the difficulty of developing a ten-year framework with the rapid explosion of knowledge in the Information Age. Each of these is discussed in detail below.

Measurement Constraints

NAEP, like any large-scale assessment in education, the workplace, or clinical practice, is constrained in what it can measure. This has implications for the proper interpretation of NAEP Science Assessment results. The *Framework* is an assessment framework, not a curriculum framework. Although the two are clearly interrelated, each has a different purpose and a different set of underlying assumptions. A curriculum framework is designed to inform instruction, to guide what is taught, and often, to guide how it is taught. It represents a very wide universe of learning outcomes from which teachers pick and choose what and how they teach. An assessment framework is a subset of the achievement universe from which assessment developers must choose to develop sets of items that can be assessed within time and resource constraints. Hence, the science content to be assessed by NAEP has been identified as that considered central to the Physical, Life, and Earth and Space Sciences. As a result, some important outcomes of science education that are difficult and time-consuming to measure—such as habits of mind, sustained inquiry, collaborative research—but valued by scientists, science educators, and the business community, will be only partially represented in the *Framework* and on the NAEP Science Assessment. Moreover, the wide range of science standards in the guiding national documents that could be incorporated into the *Framework* had to be reduced in number so as to allow some in-depth probing of fundamental science content. As a result, the *Framework* and the *Specifications* represent a careful distillation that is not a complete representation of the original universe of achievement outcomes desirable for science education.

Time and Resource Constraints

What NAEP can assess is limited by time and resources. Like most standardized assessments, NAEP is an "on demand" assessment. It ascertains what students know and can do in a limited amount of time (50 minutes for paper-and-pencil questions and, for a subset of students sampled, an additional 30 minutes for hands-on performance or interactive computer tasks), with limited access to resources (e.g., reference materials, feedback from peers and teachers, opportunities for reflection and revision). The national and state standards, however, contain goals that require extended time (days, weeks, or months). To assess the achievement of students in the kinds of extended activities that are a central feature of the national and state standards and many science curricula, then, it would be necessary to know, for example, the quality of students'

- reasoning while framing their research questions;
- planning for data collection and the execution of that plan;
- abilities to meet unpredictable challenges that arise during an actual, ongoing scientific investigation;
- lines of argument in deciding how to alter their experimental approach in the light of new evidence;
- engagement with fellow students and/or the teacher in interpreting an observation or result and deciding what to do about it; and

- deliberations and reasoning when settling on the defensible conclusions that might be drawn from their work.

NAEP, like other "on demand" assessments, then, cannot be used to draw conclusions about student achievement with respect to the full range of goals of science education. States, districts, schools, and teachers can supplement NAEP and other standardized assessments to assess the full range of science education standards. In addition to describing the content and format of an examination, assessment frameworks, like this one, signal to the public and to teachers what elements of a subject are important. The absence of extended inquiry in NAEP, however, is not intended to signal its relative importance in the curriculum. Indeed, because of the significance of inquiry in science education, the *Framework* promotes as much consideration of inquiry as can be accomplished within the time and resources available for assessment.

Balancing Current and Future Curricula

The *Framework* attempts to strike a balance between what can reasonably be predicted about future school science and what students are likely to encounter in their curriculum and instruction now and in the near future. It is a significant challenge to write a framework for the future. Cutting-edge science research creates new knowledge at the intersection of disciplinary boundaries. For example, research on human and natural systems has generated new understandings about environmental science that are closely linked to knowledge generated in the physical, life, and Earth and space sciences. Although the *Framework* is organized into the more traditional Physical, Life, and Earth and Space Sciences, features of current science research are woven throughout.

Another example of burgeoning knowledge relates to technology and technological design and the role of both in the NAEP Science Assessment. Technology and technological design are closely interrelated with science, yet the focus of this assessment is science. Hence, technology and technological design are included in the *Framework* but are limited to that which has a direct bearing on the assessment of students' science achievement. (See Chapter Three.)

The *Framework* is intended to be both forward-looking (in terms of what science content will be of central importance in the future) and reflective (in terms of current school science). Because it is impossible to predict with certainty the shape of school science in 2009 and beyond, the choices made for 2009 should be revisited in response to future developments in school science.

Achievement Levels

Public Law 107-279 specifies NAGB's responsibilities regarding NAEP, including the identification of appropriate achievement goals for each age and grade in the subject areas assessed by NAEP.

To carry out its mandated responsibility to set appropriate achievement goals for NAEP, NAGB adopted an achievement levels policy in 1989 (modified in 1993). This policy establishes three levels of achievement—Basic, Proficient, and Advanced. **Basic** denotes partial mastery of prerequisite knowledge and skills that are fundamental for proficient work at each grade. **Proficient** represents solid academic performance for each grade assessed. Students reaching this level have demonstrated competency over challenging subject matter, including subject-matter knowledge, application of such knowledge to real world situations, and analytical skills appropriate to the subject matter. **Advanced** signifies superior performance. These levels are the primary means of reporting NAEP results to the general public and policymakers regarding what students should know and be able to do on NAEP assessments. (See Appendix C for the NAEP Science Preliminary Achievement Level Descriptions and additional information about their development and use.)

Introduction to the Assessment Framework

Science comprises both content and practices. The NAEP Science Assessment provides a snapshot view of what the nation's 4th, 8th, and 12th graders know and can do in science. One expects students, as a result of their education and life experiences, to have learned about the principles (along with the facts, concepts, laws, and theories) that have been verified by the community of scientists, as well as how scientists discover regularities in the natural world.[1] NAEP will assess students' abilities to identify and use science principles, as well as use scientific inquiry and technological design. (See Chapter Three.) While the *Framework* distinguishes content from practice, the two are closely linked in assessment as in science itself.

The *Framework* addresses scientific knowledge and processes. Science is a way of knowing about the natural world based on tested explanations supported by accumulated empirical evidence. Explanations of natural phenomena that rely on non-scientific views are not reflected in the *Framework*. The committees responsible for the *Framework* development relied on *National Standards*, *Benchmarks*, international frameworks, and state standards for content about the nature and practice of science. As stated in the *National Standards*,

> Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public (p. 201).

[1] "Science principles" is used throughout this *Framework* to denote not only the principles but also the facts, concepts, theories, and laws of science.

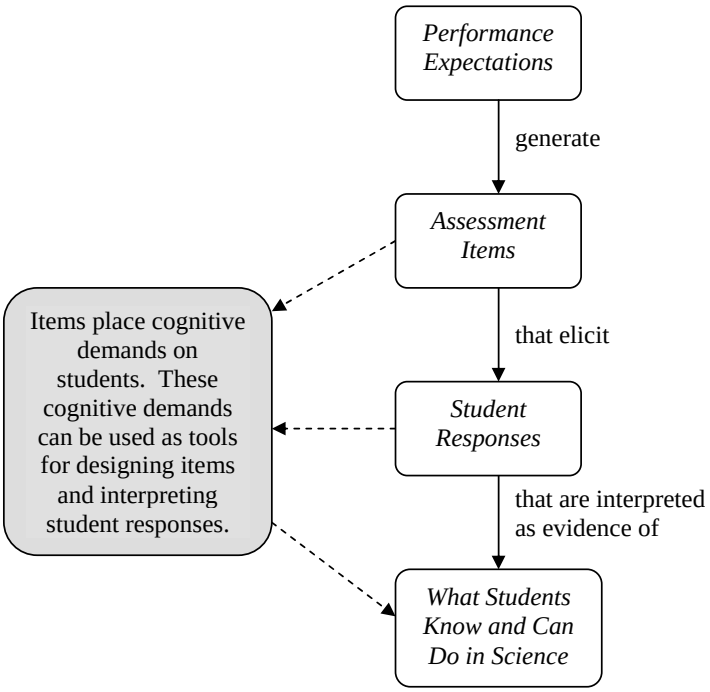
The design of the NAEP Science Assessment is guided by the *Framework*'s descriptions of the science content and practices to be assessed. Figure 1 illustrates how content and practices are combined ("crossed") to generate performance expectations. The columns contain the science content (defined by content statements—propositions that express science principles—in three broad areas), and the rows contain the four science practices. A double dashed line distinguishes Identifying Science Principles and Using Science Principles from Using Scientific Inquiry and Using Technological Design. The former two practices can be generally considered as "knowing science," and the latter two practices can be considered as the application of that knowledge to "doing science" and "using science to solve real-world problems." The cells at the intersection of content (columns) and practices (rows) contain student performance expectations. Since content and practice categories are not entirely distinct, some overlap in the resultant performance expectations is to be expected, as denoted by dashed lines.

Figure 1. Crossing Content and Practices to Generate Performance Expectations

		Science Content		
		Physical Science content statements	**Life Science** content statements	**Earth and Space Science** content statements
Science Practices	**Identifying Science Principles**	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Using Science Principles	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Using Scientific Inquiry	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Using Technological Design	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*

Figure 2 illustrates the fuller process of generating assessment items and interpreting student responses. An item is an individual question or exercise on the NAEP Science Assessment and is used to gather information about students' knowledge and abilities. Figure 2 begins with student performance expectations, which describe in observable terms what students are expected to know and do on the assessment. These performance expectations guide the development of assessment items. The cognitive demands (see Chapter Three) of the items can then be used to interpret students' responses as evidence of what students know and can do in science (see Ruiz-Primo, Shavelson, Li, and Schultz [2001] for more on cognitive interpretations of performances on assessment tasks). Figure 2 suggests a linear process, but the development of an assessment is iterative (e.g., assessment items are modified based on student responses provided on trials of pilot versions).

Figure 2. Generating Items and Interpreting Responses



Overview of Framework Chapters

This section provides an overview of the succeeding chapters of the *Framework*. For ease of understanding, three types of textboxes are used throughout the *Framework*: Clarification, Crosscutting Content, and Illustrative Item. *Clarification* textboxes provide details on potentially confusing topics, such as the distinction between mass and weight. *Crosscutting Content* textboxes provide descriptions of science content that cuts across

the three broad content areas, such as biogeochemical cycles. *Illustrative Item* textboxes provide assessment items that exemplify recommendations discussed in the text.

Chapter Two: Science Content

Key principles as well as facts, concepts, laws, and theories that describe regularities in the natural world are presented in Chapter Two as a series of content statements to be assessed at grades 4, 8, and 12. Taken together, these statements comprise the NAEP science content. They define only what is to be assessed by NAEP and are not intended to serve as a science curriculum framework. The content statements should be revisited periodically in response to new developments in science research and school curriculum.

The content statements are organized according to the three broad content areas that generally comprise the K-12 school curriculum:

- Physical Science
- Life Science
- Earth and Space Science

Classifying content statements into one content area is not always clear-cut, but doing so helps ensure the areas of science are assessed in a balanced way. Some common content is found to be significant in each of the three content areas (e.g., energy conservation and its associated principles are applicable to the living and non-living systems studied by physical, life, and Earth scientists). This crosscutting content is further described in Chapter Two.

The content statements are derived from *National Standards* and *Benchmarks*, as well as informed by international frameworks and state standards. Content statements have been added where warranted by advances in science since the development of the standards documents. The selection of science content statements to be assessed at each grade level focuses on principles central to each discipline, tracks related ideas across grade levels, and limits the breadth of science knowledge to be assessed. The selection of content statements used an iterative approach and took into account the many perspectives of various stakeholders.

Chapter Three: Science Practices

The following science practices are found in most or all of the major sources used to develop the *Framework* (see standards documents listed above). The practices to be assessed at grades 4, 8, and 12 are organized into four categories:

- Identifying Science Principles
- Using Science Principles
- Using Scientific Inquiry
- Using Technological Design

As shown in Figure 1, the Physical Science, Life Science, and Earth and Space Science content statements listed in Chapter Two can be deliberately combined ("crossed") with each of the above four practices to generate specific performance expectations. These performance expectations are written in observable terms and guide the development of assessment items. Performance expectations thus provide an outline of what the NAEP Science Assessment will expect as evidence of what students know and can do. At the end of Chapter Three, examples of performance expectations, items, and interpretations of student responses are provided. (See also the *Specifications* for more examples.)

Students' understanding increases over time as they learn more and more, moving from initially naïve to increasingly more sophisticated knowledge about the natural world. These learning progressions are further described in Chapter Three.

Chapter Four: Overview of the Assessment Design

Chapter Four provides an overview of the design of the assessment. Assessment item contexts, types of items, distribution of items, accessibility concerns for English language learners and students with disabilities, and recommendations for small-scale special studies are all discussed in this chapter.

Beyond the science content statements and practices, there are other valuable components of science that will not be directly assessed by NAEP. These components—the history and nature of science and the relationship between science and technology—are treated in Chapter Four as providing possible contexts in which assessment items may be presented.

The types of items to be used on the assessment include selected-response (multiple-choice) items and constructed-response items (which include short and extended constructed-response items as well as concept-mapping tasks). Some "combination items" may require more than one response. Such combination items include item clusters, Predict-Observe-Explain (POE) item sets, hands-on performance tasks, and interactive computer tasks. The responses requested may be all selected-response, all constructed-response, or a mixture. (See Chapter Four for a fuller explanation of types of items, including examples.)

Chapter Four recommends three types of percentages for item distribution (as measured by student response time) at each grade level:

- Items by content area (Physical, Life, and Earth and Space Sciences)
- Items by science practice (Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, and Using Technological Design)
- Items by type (Selected-response and Constructed-response items)

Additional specifications about the number of hands-on performance tasks and interactive computer tasks are also provided.

Chapter Four also describes considerations for English language learners and students with disabilities. In particular, NAEP assessments need to be responsive to growing demands of increased inclusion of all types of students in the general curriculum, and increased emphasis and commitment to serve and be accountable for all students. A number of small-scale special studies also are recommended at the end of Chapter Four.

Comparing the NAEP Science Frameworks: 1996-2005 → 2009

The chapter overviews provided above reflect the differences between the NAEP 1996-2005 science framework and this new *Framework* to be used for 2009 and future NAEP science assessments. The assessment resulting from this 2009 *Framework* will start a new NAEP "science trend" (i.e., measure of student progress in science). One difference between the two frameworks is that the 2009 Steering and Planning Committees drew upon a variety of new standards and assessments. They also were able to extract findings from research in science, science education, and cognition, as well as consider the use of technology to increase the options for assessment administration. Table 1 lists the major differences between the 1996-2005 and 2009 NAEP science frameworks.

Table 1. NAEP Science Framework: 1996-2005 → 2009

	1996-2005 Framework	2009 Framework
Science Content	Few science standards available on which to base the content to be assessed	Content drawn from existing standards and assessment frameworks: *National Standards*, *Benchmarks*, TIMSS, PISA, and state standards
	Content areas organized into Physical Science, Life Science, and Earth Science	Content areas organized into Physical Science, Life Science, and Earth and Space Science
	Recommendations on distribution of questions by fields of science and grade: approximately equal distribution in grades 4 and 12; a somewhat heavier emphasis on Life Science in grade 8	Recommendations on distribution of questions by science content area and grade: equal weight for all three sciences in grade 4; emphasis on Earth and Space Science in grade 8; emphasis on Physical Science and Life Science at grade 12
	Content presented as bullets and short phrases	Content presented as statements in tables organized by science content subtopics (e.g., "Forces Affecting Motion" from Physical Science) and by grade level
	Framework employed three abstract themes: Systems, Models, and Patterns of Change	
		Framework employs crosscutting content among Life, Physical, and Earth and Space Sciences
	Assessment asked questions about the nature of science	

	1996-2005 Framework	2009 Framework
Science Practices	Knowing and Doing dimension organized into Conceptual Understanding, Scientific Investigation, and Practical Reasoning	Science Practices dimension organized into Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, and Using Technological Design
		Nature of science treated within science practices, particularly Using Science Principles and Using Scientific Inquiry
	Science practices assessed were largely experience-based	Science practices assessed take into account extant research and the cognitive complexity of the items
	Assessment included items on practical reasoning (i.e., applying science to suggest effective solutions to everyday problems)	
		Assessment includes questions on technological design (i.e., the systematic process of applying science knowledge and skills to solve problems in a real-world context)
	Forty-five percent of the assessment focused on conceptual understanding	Sixty percent of the assessment focuses on conceptual understanding (Identifying and Using Science Principles)
		Learning progressions (i.e., connected sequences of science performances across grade spans) are included
Assessment Items		Assessment uses the history of science and the relationship between science and technology as contexts for questions
	Assessment included both paper-and-pencil and hands-on performance tasks	Assessment includes paper-and-pencil questions, hands-on performance tasks, and interactive computer tasks
	No illustrative items to convey science knowledge or practices in the *Framework*; only a few suggested ideas for items provided in the *Specifications*	Illustrative items that convey science knowledge and practices are included in both the *Framework* and the *Specifications*
		Framework and *Specifications* include guidelines for assessing students with disabilities and English language learners
		Framework includes examples showing how questions are generated and interpreted
		Students' naïve conceptions about science principles are explicitly assessed

CHAPTER TWO: SCIENCE CONTENT

Introduction

This chapter presents a series of statements that describe the science content of the 2009 NAEP Science Assessment. The content statements contain key science principles for NAEP assessment. Note that, in the *Framework*, the phrase "science principles" is broadly conceived and encompasses not only the key principles but also the facts, concepts, laws, and theories of science. In order to specify the science that should be assessed at each grade level, the *Framework* organizes the science content into the three broad content areas that generally make up the K-12 school curriculum to which students are exposed:

- Physical Science
- Life Science
- Earth and Space Science

Classifying statements into one primary content area is not always clear-cut and is artificial to some extent. For example, Ernest Rutherford's discovery of the nucleus earned this physicist the Nobel Prize in Chemistry, and Rosalyn Yalow's work on radioimmunoassay earned this physicist the Nobel Prize in Medicine. However, using three broad content areas as an organizer helps ensure that key science content is assessed in a balanced way.

In the interest of clarity, tables are used to depict the content statements at each grade level. The content statements are based on the assumption that a person literate in science is one who understands key science ideas, is aware that science and technology are interdependent human enterprises with strengths and limitations, is familiar with the natural world and recognizes both its diversity and unity, and uses scientific knowledge and ways of thinking for individual and social purposes (see AAAS, 1994, p. xvii).

Two types of textboxes are used throughout this chapter. *Clarification* textboxes provide details on potentially confusing content, such as the distinction between mass and weight. *Crosscutting Content* textboxes provide descriptions of science content that cuts across the three broad content areas, such as biogeochemical cycles.

Development of the Content Statements

The selection and generation of specific content statements at each grade level followed a similar approach across the three broad content areas:

- The *National Standards* and *Benchmarks* were used as key documents for identifying the science content to be assessed, pursuant to the charge from the Steering Committee. Various tools, primarily crosswalks between *National Standards* and *Benchmarks* (AAAS, 1997; Kendall & Marzano, 2004), were used

to crosscheck the documents' content standards and benchmark statements, and those that were common to both documents were generally given priority. On a case-by-case basis, content not represented in both documents was discussed and decisions made about inclusion or exclusion. Additions were made where warranted by scientific advances in the decade or more since the development of the *National Standards* and *Benchmarks*, or as a consequence of international assessment results from TIMSS and PISA. Some of this *Framework*'s content statements are verbatim reproductions of statements from *National Standards* and *Benchmarks*.[2]

- The focus in the selection process was on the central principles of each discipline. The content statements in the *Framework* represent foundational and pervasive knowledge, key points of scientific theories, and underpinnings upon which complex understandings are built; and/or they demonstrate connectivity to other central content.
- A primary consideration was the grade-level appropriateness and accuracy within grade level of content statements.
- Once key content was identified within subtopics, the progression of ideas and performances, informed by available research, was tracked through grades 4, 8, and 12.
- A deliberate attempt was made to limit the breadth of science content to be assessed so that some important topics could be measured in-depth. Once core content was identified in each science area, additional content statements could be added only if others previously included were eliminated.

The selection and generation of content statements for inclusion in the *Framework* was not a linear process. While the Planning Committee attempted to use clear and concise language, the complexities associated with the task of defining what students should know and be able to do in science at particular points in their development necessitated an iterative approach that included many perspectives. In addition to internal review by the project Committees and staff, outreach activities gathered external feedback on the content statements from a variety of stakeholders (e.g., teachers, school and district administrators, state science education personnel, policymakers, scientists, and members of business, industry, and post-secondary communities). The *Framework* should be revisited in the future as new research becomes available and as the influence of new developments in science takes shape in the K-12 curriculum.

Organization of Science Content

As described above, this *Framework* organizes science content into three broad *content areas* (Physical Science, Life Science, and Earth and Space Science). The content is further organized into *topics* (such as Motion), *subtopics* (such as Forces Affecting

[2] Statements are reprinted from *National Science Education Standards* (NRC, 1996) with permission from the National Academy of Sciences, courtesy of the National Academies Press, Washington, DC. Statements are reprinted from *Benchmarks for Science Literacy* (AAAS, 1993) with permission from Project 2061, on behalf of the American Association for the Advancement of Science, Washington, DC.

Motion), and, finally, grade-specific *content statements*. The description of each broad content area follows this structure of increasing specificity and is presented in two ways: narrative introductions and content statements presented in tables (see Tables 6, 8, and 10 in the sections for Physical Science, Life Science, and Earth and Space Science, respectively). The following table summarizes the 2009 NAEP Science content topics and subtopics.

Table 2. 2009 NAEP Science Content Topics and Subtopics

Physical Science	Life Science	Earth and Space Science
Matter • Properties of Matter • Changes in Matter **Energy** • Forms of Energy • Energy Transfer and Conservation **Motion** • Motion at the Macroscopic Level • Forces Affecting Motion	**Structures and Functions of Living Systems** • Organization and Development • Matter and Energy Transformations • Interdependence **Changes in Living Systems** • Heredity and Reproduction • Evolution and Diversity	**Earth in Space and Time** • Objects in the Universe • History of Earth **Earth Structures** • Properties of Earth Materials • Tectonics **Earth Systems** • Energy in Earth Systems • Climate and Weather • Biogeochemical Cycles

As an organizational tool in Tables 6, 8, and 10, each content statement is preceded by a specific code in bold (e.g., "**L12.10:** Sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents."). Within a code, the letter denotes broad content area ("P" for Physical Science, "L" for Life Science, and "E" for Earth and Space Science); the number before the period denotes grade level (grade 4, 8, or 12); the number following the period denotes the content statement's order of appearance within a given content area and grade. Thus, **L12.10** denotes that this is the tenth content statement to appear in the grade 12 section of the Life Science content statements table. Since the numbering within each content area and grade is strictly sequential, code numbers do *not* necessarily indicate any relationships *across* grades (see, for example, P4.13, P8.13, and P12.13).

Interpretation of the Content Statements

In the *Framework*, the content statements generally follow a form that is consistent with the *National Standards*, *Benchmarks*, and the practice of the scientific community. The content statements are phrased as propositions that express science principles. Based on evidence, these principles have been verified by the scientific community and are under constant review. An example of how one grade 8 physical science principle is represented in the *Framework*, *National Standards*, and *Benchmarks* appears below in Table 3.

Table 3. One Grade 8 Physical Science Principle Represented in the *Framework*, *National Standards*, and *Benchmarks*

Framework	***National Standards***	***Benchmarks***
P8.16: Forces have magnitude and direction. Forces can be added. The net force on an object is the sum of all the forces acting on the object. A non-zero net force on an object changes the object's motion; that is, the object's speed and/or direction of motion changes. A net force of zero on an object does not change the object's motion; that is, the object remains at rest or continues to move at a constant speed in a straight line (p. 35).[3]	If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their directions and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion (p. 154).	An unbalanced force acting on an object changes its speed or direction of motion, or both. If the force acts toward a single center, the object's path may curve into an orbit around the center (p. 90).

The content statements form the basis for explaining or predicting naturally occurring phenomena. For example, the above content statement about objects in motion can be used to explain and predict the motions of many different specific objects: an ice skater, an automobile, an electron, or a planet.

The content statements do not include observations of phenomena. As the content statements are written, the empirical foundations of the science principles they represent are not detailed. Instead, knowledge is presented in general terms, such as patterns in observations or theoretical models that account for these patterns. The NAEP assessment will require students to apply content statements to specific observations and examples of phenomena. Therefore, the *Specifications* provide boundaries on the range of phenomena and examples that are appropriate for inclusion on the NAEP Science Assessment. The boundaries also describe the appropriate instrumentation, representations, and technical vocabulary to be included in the assessment.

[3] This content statement is longer in the *Framework* than in *Benchmarks* or *National Standards*, not because it introduces additional science principles, but because it has adopted more detailed language.

The process of item development and making inferences about students' knowledge and abilities (see Figures 1 and 2, Chapter One) may necessitate further clarification of the content statements themselves. For example, this may involve "detailing" the meanings of individual content statements (e.g., "boiling point" assumes standard atmospheric pressure) or *further* defining the boundaries of the content to be assessed (e.g., grade 12 students are expected to know that DNA provides instructions for assembling proteins but not the details of DNA transcription and translation). See Table 4 for an example of commentary on a grade 8 Physical Science content statement. Although the commentary describes key ideas about waves relevant through grade 12, note that only three of these key ideas are recommended for assessment at grade 8. Whenever possible, commentary on content statements was informed by available research on learning and cognition. Commentary is intended as helpful notes to item writers and is provided for a number of content statements in the *Specifications.* Commentary is not always of the same kind, and the examples provided do not exhaustively cover the content statements. Assessment developers should continue the process of "detailing" the grade-appropriate principles to be assessed for all content statements sampled for a particular NAEP Science Assessment.

Table 4. Commentary on a Physical Science Content Statement

Grade 8: Energy—Forms of Energy
Content Statement **P8.10:** Energy is transferred from place to place. Light energy from the sun travels through space to Earth (radiation). Thermal energy travels from a flame through the metal of a cooking pan to the water in the pan (conduction). Air warmed by a fireplace moves around a room (convection). Waves—including sound and seismic waves, waves on water, and light waves—have energy and transfer energy when they interact with matter.
Commentary Wave principles recommended for assessment at grade 8: • Waves involve transfer of energy without a transfer of matter. • Waves are caused by disturbances and are also themselves disturbances. Some of the energy of these disturbances is transmitted by the wave. • Water, sound, and seismic waves transfer energy through a material. Wave principles that are related but not recommended for assessment at grade 8: • Some waves are transverse (water, seismic), and other waves are longitudinal (sound, seismic). • In transverse waves, the direction of the motion is perpendicular to the disturbance. • In longitudinal waves, the direction of motion is parallel to the disturbance. • Waves (e.g., light waves) traveling from one material to another undergo transmission, reflection, and/or changes in speed. • Waves can be described by their wavelength, amplitude, frequency, and speed (speed is frequency multiplied by wavelength; energy is a function of the amplitude for non-electromagnetic waves). • Light has dual wave-particle properties. Energy and refraction calculations are also not recommended for assessment at grade 8. Note that a quantitative understanding of electromagnetic waves is expected at grade 12. See P12.10.

In order to fully understand the content statements and their intent, readers of the *Framework* should be cognizant of the following:

- While all content statements have been assigned a primary classification, some are likely to fall into more than one content area.
- Some assessment items may draw on more than one content statement at a time.
- Empty cells in the content statement tables denote that a particular subtopic is not recommended for assessment at that grade level.
- Retention of foundational knowledge from one grade to the next is assumed; however, if the relevant content statement does not appear in a succeeding grade level, it should not be assessed.
- The content statements listed in the *Framework* describe the whole of what is to be assessed on the 2009 NAEP. The content statements should not be interpreted as a complete description of the school science curriculum that should be taught.

Crosscutting Content

Scientists define their specializations narrowly (e.g., astronomy, molecular biology, organic chemistry) to organize their research communities; and the categories of Physical Science, Life Science, and Earth and Space Science are helpful for organizing school science. These categorizations mask the fact that some science principles cut across the content areas. In this *Framework*, crosscutting content is not represented by abstractions such as “models,” “constancy and change,” or “form and function,” but is anchored in the content statements themselves. Some examples of crosscutting content are described in textboxes that appear throughout the content area introductions: “Energy Sources and Transfer” in Physical Science; “Uses, Transformations, and Conservation of Energy” in Life Science; and “Biogeochemical Cycles” in Earth and Space Science. Additional examples are suggested in the *Specifications*. For instance, the theory of plate tectonics and the evolution of Earth’s surface are inextricably linked with environmental pressures (such as geographic barriers), speciation, and the evolution of life. Such examples illustrate opportunities for assessing specific content in greater depth.

Physical Science

Physical science principles, including fundamental ideas about matter, energy, and motion, are powerful conceptual tools for making sense of phenomena in physical, living, Earth, and space systems. Familiar changes—an ice cube melting, a baseball changing direction after being struck by a bat, the appearance of a bolt of lightning, the formation and erosion of mountains, and the growth of a plant—can be explained using these fundamental ideas.[4]

Energy is the constant in an ever-changing world. Energy from the sun fuels electrical storms, hurricanes, tornados, and photosynthesis. In turn, the products of photosynthesis (carbohydrates and oxygen) react during respiration to fuel life processes, such as growth and reproduction of plants and animals. Consequently, it is important for students to develop an understanding of physical science principles early and to appreciate their usefulness across Physical Science, Life Science, and Earth and Space Science.

The physical science principles to be assessed are sorted into three topics—Matter, Energy, and Motion. Matter is the "stuff" of the natural world. Energy is involved in all changes in matter. Motion of the heavenly bodies, of objects found in daily experiences (e.g., balls, birds, cars), and of the tiny particles (atoms, molecules, and their component parts) composing all objects and substances is the result of interactions of matter and energy. The content statements have been divided into topics and subtopics as summarized in Table 5.

Table 5. Physical Science Content Topics and Subtopics

Matter
Properties of Matter Changes in Matter
Energy
Forms of Energy Energy Transfer and Conservation
Motion
Motion at the Macroscopic Level Forces Affecting Motion

[4] The importance of developing understanding early and making connections among the physical, life, Earth, and space sciences has motivated increased attention on physical science in elementary school and prompted consideration of rearranging the usual Earth–life–chemistry–physics curriculum sequence.

Matter

The topic, Matter, is divided into two subtopics: Properties of Matter and Changes in Matter. Conservation of mass, the particulate model of matter, and the Periodic Table of the Elements are the conceptual glue tying together these two subtopics and their related principles.

Properties of Matter

Matter has physical and chemical properties. Physical properties common to all matter as well as those physical properties unique to solids, liquids, and gases are included in the *Framework*, as are chemical properties. All objects and substances in the natural world are composed of matter. Matter has two fundamental properties: matter takes up space, and matter has inertia—it changes motion only when under the influence of a non-zero net force (grade 4). See the following textbox, "A Matter of Mass," for more on mass versus weight and the *Framework's* treatment of this distinction.

Clarification: A Matter of Mass

Mass is a property common to all objects. It is the amount of matter (or "stuff") in an object. The more mass an object has, the more inertia (or "sluggishness") it displays when attempts are made to change its speed or direction. Mass is measured in grams (g) or kilograms (kg) (1 kg=1000 g) using a beam or electronic balance.[5]

Weight, on the other hand, is a measure of the force of attraction (gravitational force) between an object and Earth. Every object exerts gravitational force on every other object. The force depends on how much mass the objects have and on how far apart they are. Force and weight are measured in newtons (N) using a spring scale.

Changing an object's position (say from Earth to the moon) will change its weight, but not its mass. For example, on the surface of Earth, a cannon ball has a mass of 10 kg and a weight of 98 N. On the surface of the moon, that same cannon ball still has a mass of 10 kg, but its weight is only 16 N. So, the cannon ball weighs less on the moon than on Earth, even though nothing has been taken away. Why? Because of the moon's lesser mass and smaller radius, the force of attraction between the moon and the cannon ball is less than the force of attraction between Earth and the cannon ball. Hence, it is said that an object on the moon weighs less than the same object weighs on Earth.

These concepts of mass and weight are complicated and potentially confusing to 4th grade students. Hence, this *Framework* uses the more familiar term "weight" in grade 4 to stand for both weight and mass, and this usage is denoted as "weight (mass)." By grades 8 and 12, students are expected to understand the distinction between mass and weight, and thus, both terms will be used as appropriate.

[5] As found in current NAEP practice, metric units of measure are used for grades 4, 8, and 12.

Matter exists in several different physical states, each of which has unique properties (grade 4). Three of the most commonly encountered are solids, liquids, and gases. Shape and compressibility are examples of properties that distinguish solids, liquids, and gases (grade 4).

The particulate model of matter can be used to explain and predict the properties of states of matter, such as why ice is harder than liquid water and why ice (once formed) has a shape independent of its container while liquid water takes the shape of whatever container it is in (grade 4). In the particulate model of matter, the molecules or atoms of which matter is composed are assumed to be tiny particles in motion (grade 8). The motion is translational, rotational, and vibrational (grade 12). This model can be used to explain the properties of solids, liquids, and gases, as well as changes of state. The particulate model can be used to explain the unique properties of water, as described in the following textbox.

Clarification: Unique Properties of Water

Grade 12: Matter—Changes in Matter
P12.5: Changes of state require a transfer of energy. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.

The unique properties of water have important consequences for Earth Systems and Life Science, including the origin and existence of life on Earth. Understanding the substance of water requires knowledge across the Physical Science categories of Matter, Energy, and Motion.

As with all kinds of matter, water's unique properties can be explained by the shape of its molecule, the forces between its molecules in solid (ice) and liquid states, and the resulting arrangement of molecules in solid and liquid states. In particular, in the solid state, the molecular bonds are such that they separate the molecules more than in the liquid state, resulting in ice being less dense than liquid water. The strong intermolecular forces of liquid water account for its high specific heat. (The specific heat of a substance is the amount of energy required to change 1g of the substance by 1^0C.)

The detailed structures of molecules and atoms that compose them serve as models that explain the forces of attraction between molecules. The structure of atoms, especially the outermost electrons, explains the chemical properties of the elements and the formation of the chemical bonds made and broken during chemical reactions (grade 12). The Periodic Table of the Elements (introduced at grade 8) is another way in which order can be made out of the complexity of the variety of types of matter. (In grade 8, the emphasis is on observed periodicity of properties.) The Periodic Table demonstrates the relationship between the atomic number of the elements and their chemical and physical properties and provides a structure for inquiry into the characteristics of the chemical elements (grade 12).

Two classes of chemical substances serve as exemplars of chemical properties. One class is metals (elements), and the other class is acids (compounds). A chemical property of metals is to react with non-metals to form salts. Included among the properties of acids is the formation of characteristic colors when interacting with acid/base indicators and the interaction with bases to produce salts and water (i.e., neutralization) (grade 8).

Changes in Matter

Matter can undergo a variety of changes. Changes are physical if the relations between the molecules of the material are changed such as changing from a solid to a liquid or from a liquid to a gas (grade 4). When matter undergoes physical change, generally no changes occur in the structure of the molecules or atoms composing the matter (grade 8), though there are exceptions (e.g., sulfur). Changes are chemical if they involve the rearrangement of how atoms are bound to one another, thereby changing the molecules of the material. These are changes in the configuration of the outermost electron shell surrounding the nuclei of the interacting atoms (grade 12). Changes are nuclear if the particles are emitted from or absorbed into the nucleus of the atom, changing the atoms themselves into isotopes or different elements (grade 12).

That mass is conserved when matter undergoes physical and chemical changes is a powerful principle for understanding the natural world and was influential in the development of chemical theory. Adherence to the principle discourages the conclusion that something “disappears” (as water seems to disappear from a puddle) and encourages the search for the “missing” matter.

Most nuclear reactions, involving changes in the nuclei of atoms, are very high-energy and result in the formation of elements or nuclei different from those that began the process. In nuclear reactions, a measurable amount of mass is converted into energy (grade 12).

Energy[6]

The topic, energy, is divided into two subtopics, one addressing the forms of energy and the other energy transfer and conservation.

Forms of Energy

Knowing the characteristics of familiar forms of energy (grade 4) and the scientific categories of potential and kinetic energy (grade 8) are useful in coming to the understanding that, for the most part, the natural world can be explained and is predictable. The most basic characteristics of thermal, light, sound, electrical, and mechanical energy and the relationship between changes in the natural world and energy

[6] There are different approaches to helping students understand the concept of energy and related observable phenomena, such as light, heat, and sound. These differences are reflected in this *Framework*'s reference documents and have therefore influenced the framing of the Physical Science, Life Science, and Earth and Space Science content statements.

are included in the *Framework*.[7] For example, that two objects, one at a higher temperature than the other, come to the same temperature when placed in contact with each other is a familiar experience. Heat as a concept can be used to explain this experience (grade 8).

Energy Transfer and Conservation

That energy is conserved can be demonstrated by keeping track of the familiar forms of energy as they are transferred from one object to another. The chemical potential energy in a battery is transferred by electric current to a light bulb, which in turn transfers the energy in the form of heat (thermal energy) and light to its surroundings (grade 4). The energy stored in the battery decreases as its surroundings are heated. The loss in chemical potential energy equals the light and heat (thermal energy) transferred by the bulb and the wires to their surroundings. Quantitative accounting is complex; however, on a qualitative basis, both the ability to trace energy transfer and the understanding that energy is conserved (grade 8) are of great explanatory and predictive value. Chemical reactions either release energy to the surroundings or cause energy to flow from the surroundings into the system (grade 12). The sun as the main energy source for the Earth provides opportunity at all grade levels to make important connections between the science disciplines (see following textbox).

[7] The term "heat" in Physical Science is used in grade 4 to stand for thermal energy; this usage is denoted as follows: "heat (thermal energy)." "Thermal energy" is used in grades 8 and 12.

Crosscutting Content: Energy Sources and Transfer

When a sufficiently high temperature due to gravitational attraction occurs in the sun, nuclear reactions take place. These reactions result in the transfer of energy from nuclei to their surroundings. At the same time, those high temperatures cause the sun to radiate visible light and many other forms of electromagnetic waves. A small fraction of this light energy reaches Earth, heating the land, air, and water. Some of this energy causes some water to evaporate. The water vapor travels high into the atmosphere, thus increasing its gravitational potential energy. There it cools and condenses, some of it falling into reservoirs behind dams. At many dams, some of this water is directed downhill through tubes, resulting in the transfer of gravitational potential energy to the descending water as kinetic energy. This water is then used to turn turbines, and energy is thus transferred from the moving water to electrical appliances through circuits and power lines. Accordingly, the energy used to power something as commonplace as a light bulb, TV, radio, or stereo can be traced back to nuclear reactions deep inside the sun.

Consider also the transfer of energy that occurs as a diver falls through air into water. When the diver is initially poised on a cliff high above a lake's surface, one says that the diver has potential energy with respect to the air and water below. As the diver falls, her speed (kinetic energy) increases as her potential energy decreases. Her body transfers energy to the medium through which she falls, that is, the diver's body rubs against the air and water (heating them) and exerts force on the air and water (moving them aside). When the diver finally comes to rest in the lake, some or most of her potential energy has been transferred to heating and setting into motion the air and water through which she fell.

The following grade 12 content statements illustrate the crosscutting nature of energy sources and transfer. They are not intended to represent an exhaustive catalog of all statements related to this crosscutting content.

Physical Science	Earth and Space Science
P12.11: Fission and fusion are reactions involving changes in the nuclei of atoms. Fission is the splitting of a large nucleus into smaller nuclei and particles. Fusion involves joining of two relatively light nuclei at extremely high temperature and pressure. <u>Fusion is the process responsible for the energy of the sun and other stars.</u>[8]	**E12.9:** Earth systems have internal and external sources of energy, both of which create heat. <u>The sun is the major external source of energy.</u> Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from Earth's original formation.

[8] Underlining is used here and on pp. 39 and 53 to link segments of the content statements across content areas.

Motion

The topic, motion, is divided into two subtopics. The first addresses motion at the macroscopic level, and the second addresses the forces that affect motion.

Motion at the Macroscopic Level

Objects observed in daily life undergo different kinds of motion (grade 4). The *Framework* distinguishes three kinds of motion (translational, rotational, vibrational) with emphasis on the translational motion of objects in the natural environment (grade 12). Translational motion is more difficult to describe than it appears because descriptions depend on the position of the observer and the frame of reference used. Speed (grades 4 and 8), velocity (grade 12), and acceleration (grade 12) of objects in translational motion are described in terms of change in direction and position in a time interval.

Forces Affecting Motion

It takes energy to change the motion of objects. The energy change is understood in terms of forces. For example, it takes energy for a baseball pitcher to set the ball in motion toward the batter. Also, pushes and pulls applied to objects often result in changes in motion (grade 4). Principles germane to the relationship of forces and motion serve to motivate the search for forces when objects change their motion or when an object remains at rest even though it seems that the forces acting on it should result in setting it in motion (grade 8).

Some forces act through physical contact of objects while others act at a distance. The force of a bat on a ball and the downward push of a lead block resting on a tabletop are contact forces. Gravitational and magnetic forces act at a distance (grade 8). Magnets do not need to be in contact to attract or repel each other. The Earth and an airplane do not need to be in contact for a force of attraction to exist between them. Qualitative relationships (grade 8) and quantitative relationships (grade 12) between the mass of an object, the magnitude and direction of the net force on the object, and its acceleration are powerful ideas to explain and predict changes in the natural world.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Matter		
Properties of Matter: From physical properties common to all objects and substances and physical properties common to solids, liquids and gases (4) to chemical properties, particulate nature of matter, and the Periodic Table of Elements (8) to characteristics of sub-atomic particles and atomic structure (12).		
P4.1: Objects and substances have properties. Weight (mass) and volume are properties that can be measured using appropriate tools.[9] **P4.2:** Objects vary in the extent to which they absorb and reflect light and conduct heat (thermal energy) and electricity. **P4.3:** Matter exists in several different states; the most commonly encountered are solid, liquid, and gas. Each state of matter has unique properties. For instance, gases are easily compressed while solids and liquids are not. The shape of a solid is independent of its container; liquids and gases take the shape of their containers. **P4.4:** Some objects are composed of a single substance; others are composed of more than one substance. **P4.5:** Magnets can repel or attract other magnets. They can also attract certain non-magnetic objects at a distance.	**P8.1:** Properties of solids, liquids, and gases are explained by a model of matter that is composed of tiny particles in motion. **P8.2:** Chemical properties of substances are explained by the arrangement of atoms and molecules. **P8.3**: All substances are composed of one or more of approximately one hundred elements. The Periodic Table organizes the elements into families of elements with similar properties. **P8.4:** Elements are a class of substances composed of a single kind of atom. Compounds are composed of two or more different elements. Each element and compound has physical and chemical properties, such as boiling point, density, color, and conductivity, which are independent of the amount of the sample.[10] **P8.5:** Substances are classified according to their physical and chemical properties. Metals and acids are examples of such classes. Metals are a class of elements that exhibit common physical properties such as conductivity and common chemical properties such as reacting with non-metals to produce salts. Acids are a class of compounds that exhibit common chemical properties including a sour taste, characteristic color changes with litmus and other acid/base indicators, and the tendency to react with bases to produce a salt and water.	**P12.1:** Differences in the physical properties of solids, liquids, and gases are explained by the ways in which the atoms, ions, or molecules of the substances are arranged and the strength of the forces of attraction between the atoms, ions, or molecules. **P12.2:** Electrons, protons, and neutrons are parts of the atom and have measurable properties including mass and, in the case of protons and electrons, charge. The nuclei of atoms are composed of protons and neutrons. A kind of force that is only evident at nuclear distances holds the particles of the nucleus together against the electrical repulsion between the protons. **P12.3:** In the Periodic Table, elements are arranged according to the number of protons (called the atomic number). This organization illustrates commonality and patterns of physical and chemical properties among the elements. **P12.4:** In a neutral atom, the positively charged nucleus is surrounded by the same number of negatively charged electrons. Atoms of an element whose nuclei have different numbers of neutrons are called isotopes.

[9] See textbox on p. 24 for more detail on the distinction between weight and mass.
[10] While this content statement generally holds, there are some compounds that decompose before boiling.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Matter		
Changes in Matter: From changes of state (4) to physical and chemical changes and conservation of mass (8) to particulate nature of matter, unique physical characteristics of water, and changes at the atomic and molecular level during chemical changes (12).		
P4.6: One way to change matter from one state to another and back again is by heating and cooling.	**P8.6:** Changes of state are explained by a model of matter composed of tiny particles that are in motion. When substances undergo changes of state, neither atoms nor molecules themselves are changed in structure. Mass is conserved when substances undergo changes of state. **P8.7:** Chemical changes can occur when two substances, elements, or compounds react and produce one or more different substances, whose physical and chemical properties are different from the reacting substances. When substances undergo chemical change, the number and kinds of atoms in the reactants are the same as the number and kinds of atoms in the products. Mass is conserved when substances undergo chemical change. The mass of the reactants is the same as the mass of the products.	**P12.5:** Changes of state require a transfer of energy. Water has a very high specific heat, meaning it can absorb a large amount of energy while producing only small changes in temperature.[11] **P12.6:** An atom's electron configuration, particularly of the outermost electrons, determines how the atom can interact with other atoms. The interactions between atoms that hold them together in molecules or between oppositely charged ions are called chemical bonds. **P12.7:** A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other chemical reactions, atoms interact with one another by sharing electrons to create a bond. An important example is carbon atoms, which can bond to one another in chains, rings, and branching networks to form, along with other kinds of atoms—hydrogen, oxygen, nitrogen, and sulfur—a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

[11] See textbox on p. 25 for more detail on the unique properties of water.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Energy		
Forms of Energy: From examples of forms of energy (4) to kinetic energy, potential energy, and light energy from the sun (8) to nuclear energy and waves (12).		
P4.7: Heat (thermal energy), electricity, light, and sound are forms of energy.[12] **P4.8:** Heat (thermal energy) results when substances burn, when certain kinds of materials rub against each other, and when electricity flows though wires. Metals are good conductors of heat (thermal energy) and electricity. Increasing the temperature of any substance requires the addition of energy. **P4.9:** Light travels in straight lines. When light strikes substances and objects through which it cannot pass, shadows result. When light travels obliquely from one substance to another (air and water), it changes direction. **P4.10:** Vibrating objects produce sound. The pitch of sound can be varied by changing the rate of vibration.	**P8.8:** Objects and substances in motion have kinetic energy. For example, a moving baseball can break a window; water flowing down a stream moves pebbles and floating objects along with it. **P8.9:** Three forms of potential energy are gravitational, elastic, and chemical. Gravitational potential energy changes in a system as the relative positions of objects are changed. Objects can have elastic potential energy due to their compression, or chemical potential energy due to the nature and arrangement of the atoms. **P8.10:** Energy is transferred from place to place. Light energy from the sun travels through space to Earth (radiation). Thermal energy travels from a flame through the metal of a cooking pan to the water in the pan (conduction). Air warmed by a fireplace moves around a room (convection). Waves—including sound and seismic waves, waves on water, and light waves—have energy and transfer energy when they interact with matter. **P8.11:** A tiny fraction of the light energy from the sun reaches Earth. Light energy from the sun is Earth's primary source of energy, heating Earth surfaces and providing the energy that results in wind, ocean currents, and storms.	**P12.8:** Atoms and molecules that compose matter are in constant motion (translational, rotational, or vibrational). **P12.9:** Energy may be transferred from one object to another during collisions. **P12.10:** Electromagnetic waves are produced by changing the motion of charges or by changing magnetic fields. The energy of electromagnetic waves is transferred to matter in packets. The energy content of the packets is directly proportional to the frequency of the electromagnetic waves. **P12.11:** Fission and fusion are reactions involving changes in the nuclei of atoms. Fission is the splitting of a large nucleus into smaller nuclei and particles. Fusion involves joining of two relatively light nuclei at extremely high temperature and pressure. Fusion is the process responsible for the energy of the sun and other stars.

[12] See footnote on p. 27 for more detail on the *Framework*'s use of the terms "heat" and "thermal energy."

Table 6. Physical Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Energy		
Energy Transfer and Conservation: From electrical circuits (4) to energy transfer and conservation of energy (8) to translational, rotational, and vibrational energy of atoms and molecules, and chemical and nuclear reactions (12).		
P4.11: Electricity flowing through an electrical circuit produces magnetic effects in the wires. In an electrical circuit containing a battery, a bulb, and a bell, energy from the battery is transferred to the bulb and the bell, which in turn transfer the energy to their surroundings as light, sound, and heat (thermal energy).	**P8.12:** When energy is transferred from one system to another, the quantity of energy before transfer equals the quantity of energy after transfer. For example, as an object falls, its potential energy decreases as its speed, and consequently, its kinetic energy increases. While an object is falling, some of the object's kinetic energy is transferred to the medium through which it falls, setting the medium into motion and heating it. **P8.13:** Nuclear reactions take place in the sun. In plants, light from the sun is transferred to oxygen and carbon compounds, which, in combination, have chemical potential energy (photosynthesis).	**P12.12:** Heating increases the translational, rotational, and vibrational energy of the atoms composing elements and the molecules or ions composing compounds. As the translational energy of the atoms, molecules, or ions increases, the temperature of the matter increases. Heating a sample of a crystalline solid increases the vibrational energy of the atoms, molecules, or ions. When the vibrational energy becomes great enough, the crystalline structure breaks down and the solid melts. **P12.13:** The potential energy of an object on Earth's surface is increased when the object's position is changed from one closer to Earth's surface to one farther from Earth's surface. **P12.14:** Chemical reactions either release energy to the environment (exothermic) or absorb energy from the environment (endothermic). **P12.15:** Nuclear reactions—fission and fusion—convert very small amounts of matter into appreciable amounts of energy. **P12.16:** Total energy is conserved in a closed system.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Motion		
Motion at the Macroscopic Level: From descriptions of position and motion (4) to speed as a quantitative description of motion and graphical representations of speed (8) to velocity and acceleration as quantitative descriptions of motion and the representation of linear velocity and acceleration in tables and graphs (12).		
P4.12: An object's position can be described by locating the object relative to other objects or a background. The description of an object's motion from one observer's view may be different from that reported from a different observer's view. **P4.13:** An object is in motion when its position is changing. The speed of an object is defined by how far it travels divided by the amount of time it took to travel that far.	**P8.14:** An object's motion can be described by its speed and the direction in which it is moving. An object's position can be measured and graphed as a function of time. An object's speed can be measured and graphed as a function of time.	**P12.17:** The motion of an object can be described by its position and velocity as functions of time and by its average speed and average acceleration during intervals of time. **P12.18:** Objects undergo different kinds of motion—translational, rotational, and vibrational.

Table 6. Physical Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Motion		
Forces Affecting Motion: From the association of changes in motion with forces and the association of objects falling toward Earth with gravitational force (4) to qualitative descriptions of magnitude and direction as characteristics of forces, addition of forces, contact forces, forces that act at a distance, and net force on an object and its relationship to the object's motion (8) to quantitative descriptions of universal gravitational and electric forces, and relationships among force, mass, and acceleration (12).		
P4.14: The motion of objects can be changed by pushing or pulling. The size of the change is related to the size of the force (push or pull) and the weight (mass) of the object on which the force is exerted. When an object does not move in response to a push or a pull, it is because another push or pull (friction) is being applied by the environment. **P4.15:** Earth pulls down on all objects with a force called gravity. With a few exceptions (helium filled balloons), objects fall to the ground no matter where the object is on Earth.	**P8.15:** Some forces between objects act when the objects are in direct contact or when they are not touching. Magnetic, electrical, and gravitational forces can act at a distance. **P8.16:** Forces have magnitude and direction. Forces can be added. The net force on an object is the sum of all the forces acting on the object. A non-zero net force on an object changes the object's motion; that is, the object's speed and/or direction of motion changes. A net force of zero on an object does not change the object's motion; that is, the object remains at rest or continues to move at a constant speed in a straight line.	**P12.19:** The motion of an object changes only when a net force is applied. **P12.20:** The magnitude of acceleration of an object depends directly on the strength of the net force and inversely on the mass of the object. This relationship ($a=F_{net}/m$) is independent of the nature of the force. **P12.21:** Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted by the second object back on the first object. In closed systems, momentum is the quantity of motion that is conserved. Conservation of momentum can be used to help validate the relationship $a=F_{net}/m$. **P12.22:** Gravitation is a universal attractive force that each mass exerts on any other mass. The strength of the gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them. **P12.23:** Electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the electric force is proportional to the magnitudes of the charges and inversely proportional to the square of the distance between them. Between any two charged particles, the electric force is vastly greater than the gravitational force.

Life Science

Life science principles are essential for understanding the functioning of living organisms and their interactions with their environment. In addition, life science principles are crucial for understanding advances in science and technology and appreciating their implications for social and personal decisions. Take, for instance, the following discoveries of the past 25 years, all of which rely on understanding basic ideas in life science: the publication of the human genome and genomes of other organisms, the ability to monitor the oxygen level of specific regions of the brain, and the depletion of the ozone layer by human activities. The media regularly ask questions related to health and disease, such as what constitutes a healthy lifestyle and how to deal with the mutability of bacteria, viruses, and parasites that thwart efforts to develop antibiotics and vaccines. While science does not currently provide complete answers to questions like these, it provides the tools for understanding and addressing them.

Understanding principles in Life Science is inextricably linked with understanding principles in Physical Science and Earth and Space Science. "Living organisms are made of the same components as all other matter, involve the same kind of transformations of energy, and move using the same basic kinds of forces" (AAAS, 1994, p. 59).

Understanding living systems and their interactions with their environment requires not only understanding various levels of biological organization—molecules, cells, tissues/organs, organisms, populations, ecosystems—but also understanding interactions (including the transfer of information) within and across these levels and how they can change over time. For example, understanding how populations of organisms change over time is greatly facilitated by understanding the changes that occur in DNA molecules. These changes are manifest in an organism's traits and may affect its ability to survive and reproduce, which can lead to changing proportions of traits in populations over time.

As summarized in Table 7, the Life Science content statements are sorted into topics and subtopics that, collectively, address structure, function, and patterns of change in living systems. However, any attempt to organize Life Science by a linear set of topics and subtopics, such as those listed below, is somewhat arbitrary. The overlap is evident in Table 8, Life Science Content Statements for Grades 4, 8, and 12.

Table 7. Life Science Content Topics and Subtopics

Structures and Functions of Living Systems
Organization and Development Matter and Energy Transformations Interdependence
Changes in Living Systems
Heredity and Reproduction Evolution and Diversity

Structures and Functions of Living Systems

This topic comprises the ways that living systems are organized and how living systems carry out their life functions. Reasoning about living systems often involves relating different levels of organization, from the molecule to the biosphere, and understanding how living systems are structured at each level. The functions of living systems at these levels, particularly how they transform matter and energy, are included, as are the interactions among living systems and how they depend on one another to carry out their functions.

Organization and Development

As was pointed out early in the 20th century, "Long ago it became evident that the key to every biological problem must finally be sought in the cell; for every living organism is, or at some time has been, a cell" (Wilson, 1928, p. 1). All living things are made up of cells whose work is carried out by many different types of molecules. Cellular and molecular biology has the power to explain a wide variety of phenomena related to the organization and development of living systems, such as synthesis and reproduction, the extraction of energy from food, and regulation. Living organisms have a variety of observable features that enable them to obtain food and reproduce (grade 4). The functions of living organisms are carried out at different levels of organization. In multicellular organisms, cells form organs and organ systems (grade 8). Organisms are subsystems of populations, communities, ecosystems, and the biosphere. Cellular processes are carried out by molecules, particularly proteins. These processes are regulated, both internally and externally, by the environments in which cells exist, including local environments that lead to cell differentiation during the development of multicellular organisms (grade 12).

Matter and Energy Transformations

Matter and energy transformations are involved in all life processes, such as photosynthesis, growth and repair, cellular respiration, and the need of living systems for continual input of energy.

All single-celled and multicellular organisms have the same basic needs: water, air, a source of energy and materials for growth and repair, waste disposal, and conditions for growth and reproduction (grade 4). In terms of matter and energy transformations, the source of food is the distinguishing difference between plants and animals (see textbox below).

Clarification: "Food"

Both plants and animals require a source of energy and materials for growth and repair, and both plants and animals use high-energy compounds as a source of fuel and building material. Plants are distinguished from animals by the fact that plants have the capability (through photosynthesis) to take energy from light to form higher energy molecules containing carbon, hydrogen, and oxygen (carbohydrates) from lower energy molecules.

Plants are similar to animals in that, to make other molecules for their growth and reproduction, they use the energy that is released as carbohydrates react with oxygen. In making these other molecules, plants use breakdown products of carbohydrates, along with minerals from the soil and from fertilizers (known colloquially as "plant foods"), as building blocks. Plants also synthesize substances (carbohydrates, fats, proteins, vitamins) that are components of foods eaten by animals.

So, while synthesis and breakdown are common to both plants and animals, photosynthesis (the conversion of light energy into stored chemical energy) is unique to plants, making them the primary source of energy for all animals.

Basic needs are connected with the processes of growth and metabolism. Organisms are made up of carbon-containing molecules; these molecules originate in molecules that plants assemble from carbon dioxide and water. In converting carbon-containing molecules back to water and carbon dioxide, organisms release energy, making some of it available to support life functions (grade 8). Matter and energy transformations in cells, organisms, and ecosystems have a chemical basis (grade 12). The following textbox on the flow of energy through an ecosystem illustrates principles that cut across the content areas.

Crosscutting Content: Uses, Transformations, and Conservation of Energy

The principles of energy uses, transformations, and conservation hold true across different types of systems. These systems include biological organisms, Earth systems, ecosystems (combining both life forms and their physical environment), the solar system, other systems in the universe, and human-designed systems.

From *Science for All Americans* (AAAS, 1994, p. 66):

> However complex the workings of living organisms, they share with all other natural systems the same physical principles of the conservation and transformation of matter and energy. Over long spans of time, matter and energy are transformed among living things, and between them and the physical environment. In these grand-scale cycles, the total amount of matter and energy remains constant, even though their form and location undergo continual change.
>
> Almost all life on earth is ultimately maintained by transformations of energy from the sun. Plants capture the sun's energy and use it to synthesize complex, energy-rich molecules (chiefly sugars) from molecules of carbon dioxide and water. These synthesized molecules then serve, directly or indirectly, as the source of energy for the plants themselves and ultimately for all animals and decomposer organisms (such as bacteria and fungi). This is the food web: The organisms that consume the plants derive energy and materials from breaking down the plant molecules, use them to synthesize their own structures, and then are themselves consumed by other organisms. At each stage in the food web, some energy is stored in newly synthesized structures and some is dissipated into the environment as heat produced by the energy-releasing chemical processes in cells. A similar energy cycle begins in the oceans with the capture of the sun's energy by tiny, plant-like organisms. Each successive stage in a food web captures only a small fraction of the energy content of organisms it feeds on.

The flow of energy in an ecosystem (such as that described above) can be compared to the flow of energy illustrated earlier (see "Crosscutting Content: Energy Sources and Transfer" textbox on p. 28). They are both identical (the principle) and different (the context). In each case, energy is transformed from one form to another; and while some is no longer available for human use, it is not lost to the system.

The following grade 4 content statements illustrate the crosscutting nature of uses, transformations, and conservation of energy. They are not intended to represent an exhaustive catalog of all statements related to this crosscutting content.

Physical Science	Life Science	Earth and Space Science
P4.7: Heat (thermal energy), electricity, light, and sound are forms of energy.	**L4.2:** Organisms have basic needs. Animals require air, water, and a source of energy and building material for growth and repair. Plants also require light.	**E4.7:** The sun warms the land, air, and water and helps plants grow.

Interdependence

The species interaction in an ecosystem, the dynamics of population growth and decline, the use of resources by multiple species, their impact on their environment, and the complex interactions among all of these have enormous consequences to the survival of all species, including humans.

All animals and most plants depend on both other organisms and their environments for their basic needs (grade 4). Organisms interact with one another in a variety of ways, such as producer/consumer, predator/prey, and parasite/host. In addition to competition among organisms, the size of populations depends on environmental conditions, such as the availability of water, light, and other suitable conditions (grade 8). Ecosystems are characterized by both stability and change, on which human populations can have an impact (grade 12).

Changes in Living Systems

This topic comprises how organisms reproduce, how they pass genetic information to their offspring, and how genetic information can change as it passes from one generation to the next. Over time, these changes can affect the size, diversity, and genetic composition of populations (i.e., the process of biological evolution).

Heredity and Reproduction

Organisms closely resemble their parents; their slight variations can accumulate over many generations and result in more obvious differences between organisms and their ancestors. Recent advances in biochemistry and cell biology have increased understanding of the mechanisms of inheritance and enabled the detection of disease-related genes. Such knowledge is making it possible to design and produce large quantities of substances to treat disease and, in years to come, may lead to cures.

All plants and animals (and one-celled organisms) develop and have the capacity to reproduce (grade 4). Reproduction, whether sexual or asexual, is a requirement for the survival of species. Characteristics of organisms are influenced by heredity and environment (grade 8). Genetic differences among individuals and species are fundamentally chemical. Different organisms are made up of somewhat different proteins. Reproduction involves passing the DNA with instructions for making these proteins from one generation to the next with occasional modifications (grade 12).

Evolution and Diversity

Earth's present-day life forms have evolved from common ancestors reaching back to the simplest one-celled organisms almost four billion years ago. Modern ideas about evolution provide a scientific explanation for three main sets of observable facts about life on Earth: the enormous number of different life forms that exist; the systematic

similarities in anatomy and molecular chemistry seen within that diversity; and the sequences of changes in fossils found in successive layers of rock that have been formed over more than a billion years. The modern concept of evolution, including natural selection and common descent, provides a unifying principle for understanding the history of life on Earth, relationships among all living things, and the dependence of life on the physical environment. The concept is so well established that it provides a framework for organizing most of biological knowledge into a coherent picture.

All organisms are similar to and different from other organisms, and some kinds of organisms and individuals have advantages in particular environments (grade 4). Preferential survival means that differences among individuals in a population affect their ability to survive and reproduce. Classification reflects degrees of relatedness among species (grade 8). Evolution is the consequence of natural selection and differential reproduction. Natural selection and common descent provide the scientific explanation for the history of life on Earth as depicted in the fossil record and as indicated by anatomical and chemical similarities evident within the diversity of existing organisms (grade 12).

Table 8. Life Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Organization and Development: From basic needs of organisms (4) to the levels of organization of living systems (8) to the chemical basis of living systems (12).		
L4.1: Organisms need food, water, and air; a way to dispose of waste; and an environment in which they can live.[13]	**L8.1:** All organisms are composed of cells, from just one cell to many cells. About two-thirds of the weight of cells is accounted for by water, which gives cells many of their properties. In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells and function to serve the needs of cells for food, air, and waste removal. The way in which cells function is similar in all living organisms.[14] **L8.2:** Following fertilization, cell division produces a small cluster of cells that then differentiate by appearance and function to form the basic tissues of an embryo.	**L12.1:** Living systems are made of complex molecules (including carbohydrates, fats, proteins, and nucleic acids) that consist mostly of a few elements, especially carbon, hydrogen, oxygen, nitrogen, and phosphorous. **L12.2:** Cellular processes are carried out by many different types of molecules, mostly proteins. Protein molecules are long, usually folded chains made from combinations of amino-acid molecules. Protein molecules assemble fats and carbohydrates and carry out other cellular functions. The function of each protein molecule depends on its specific sequence of amino acids and the shape of the molecule. **L12.3:** Cellular processes are regulated both internally and externally by environments in which cells exist, including local environments that lead to cell differentiation during the development of multicellular organisms. During the development of complex multicellular organisms, cell differentiation is regulated through the expression of different genes.

[13] See p. 38 for a textbox on "Food."
[14] Human organs and organ systems are subsumed under this content statement. See *Specifications* for details.

Table 8. Life Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Matter and Energy Transformations: From the basic needs of organisms for growth (4) to the role of carbon compounds in growth and metabolism (8) to the chemical basis of matter and energy transformation in living systems (12).		
L4.2: Organisms have basic needs. Animals require air, water, and a source of energy and building material for growth and repair. Plants also require light.	**L8.3:** Cells carry out the many functions needed to sustain life. They grow and divide, thereby producing more cells. Food is used to provide energy for the work that cells do and is a source of the molecular building blocks from which needed materials are assembled. **L8.4:** Plants are producers—they use the energy from light to make sugar molecules from the atoms of carbon dioxide and water.[15] Plants use these sugars along with minerals from the soil to form fats, proteins, and carbohydrates. These products can be used immediately, incorporated into the plant's cells as the plant grows, or stored for later use. **L8.5:** All animals, including humans, are consumers that meet their energy needs by eating other organisms or their products. Consumers break down the structures of the organisms they eat to make the materials they need to grow and function. Decomposers, including bacteria and fungi, use dead organisms or their products to meet their energy needs.	**L12.4:** Plants have the capability (through photosynthesis) to take energy from light to form higher energy sugar molecules containing carbon, hydrogen, and oxygen from lower energy molecules. These sugar molecules can be used to make amino acids and other carbon-containing (organic) molecules and assembled into larger molecules with biological activity (including proteins, DNA, carbohydrates, and fats). **L12.5:** The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in an ecosystem, some energy is stored in newly made structures, but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going. **L12.6:** As matter cycles and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

[15] The statement "they use the energy from light" does not imply that energy is converted into matter or that energy is lost. See p. 39 for textbox on Crosscutting Content.

Table 8. Life Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Structures and Functions of Living Systems		
Interdependence: From the interdependence of organisms (4) to specific types of interdependence (8) to consequences of interdependence (12).		
L4.3: Organisms interact and are interdependent in various ways including providing food and shelter to one another. Organisms can survive only in environments in which their needs are met. Some interactions are beneficial; others are detrimental to the organism and other organisms. **L4.4:** When the environment changes, some plants and animals survive and reproduce; others die or move to new locations.	**L8.6:** Two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship. Or, one organism may scavenge or decompose another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other. **L8.7:** The number of organisms and populations an ecosystem can support depends on the biotic resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. **L8.8:** All organisms cause changes in the environment where they live. Some of these changes are detrimental to the organisms or other organisms, whereas others are beneficial.	**L12.7:** Although the interrelationships and interdependence of organisms may generate biological communities in ecosystems that are stable for hundreds or thousands of years, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution. The impact of the human species has major consequences for other species.

Table 8. Life Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Changes in Living Systems		
Heredity and Reproduction: From life cycles (4) to reproduction and the influence of heredity and the environment on an offspring's characteristics (8) to the molecular basis of heredity (12).		
L4.5: Plants and animals have life cycles. Both plants and animals begin life and develop into adults, reproduce, and eventually die. The details of this life cycle are different for different organisms. **L4.6:** Plants and animals closely resemble their parents.	**L8.9:** Reproduction is a characteristic of all living systems**;** because no individual organism lives forever, reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually. **L8.10:** The characteristics of organisms are influenced by heredity and environment. For some characteristics, inheritance is more important; for other characteristics, interactions with the environment are more important.	**L12.8:** Hereditary information is contained in genes, located in the chromosomes of each cell. A human cell contains many thousands of different genes. One or many genes can determine an inherited trait of an individual, and a single gene can influence more than one trait. **L12.9:** The genetic information encoded in DNA molecules provides instructions for assembling protein molecules. Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features may help, harm, or have little or no effect on the offspring's success in its environment. **L12.10:** Sorting and recombination of genes in sexual reproduction results in a great variety of possible gene combinations from the offspring of any two parents.

Table 8. Life Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Changes in Living Systems		
Evolution and Diversity: From differences and adaptations of organisms (4) to preferential survival and relatedness of organisms (8) to the mechanisms of evolutionary change and the history of life on Earth (12).		
L4.7: Different kinds of organisms have characteristics that enable them to survive in different environments. Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.	**L8.11:** Individual organisms with certain traits in particular environments are more likely than others to survive and have offspring. When an environment changes, the advantage or disadvantage of characteristics can change. Extinction of a species occurs when the environment changes and the characteristics of a species are insufficient to allow survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on the Earth no longer exist. **L8.12:** Similarities among organisms are found in anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance.	**L12.11:** Modern ideas about evolution (including natural selection and common descent) provide a scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms. **L12.12:** Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descent branched. **L12.13:** Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection from environmental pressure of those organisms better able to survive and leave offspring.

Earth and Space Science

The past few decades have brought rapid changes in the character of Earth and Space Science. The study of Earth has shifted from surface geology and mining toward global change and Earth systems; and research methods have changed from human observations and mapping to remote sensing and computer modeling.[16] This concept of Earth as a complex and dynamic entity of interrelated subsystems implies that there is no process or phenomenon within the Earth system that occurs in complete isolation from other elements of the system. There has also been a shift in goals, as advances in theory have made it possible to more accurately predict changes in weather and climate, to provide life-saving warnings of floods, hurricanes, earthquakes, and volcanic eruptions, and to understand how human activities influence ecosystem and climate changes across the globe.

In Space Science, similar changes have taken place as a result of new technologies. Successful probes to Mars, Jupiter, and Saturn have vastly expanded knowledge of the solar neighborhood. The discovery of more than 100 planets outside the solar system has raised new questions about the origin of life. Furthermore, advances in ground and space-based telescopes capable of observing many different parts of the electromagnetic spectrum with unprecedented detail have revolutionized understanding of the structure and evolution of the universe itself. In brief, descriptive methods of Earth and Space Science have given way to theory-based inquiry and problem-solving approaches that have far-reaching consequences with regard to understanding the universe and stewardship of Planet Earth.

Changes in Earth and Space Science education are beginning to catch up with advances in research. The *National Standards* emphasizes a systems approach to studying Earth, especially at the high school level. Some of today's textbooks pay less attention to describing Earth features and focus instead on a systems perspective in which Earth is viewed as a physical system of interrelated phenomena, processes, and cycles. Some high school curricula have integrated the traditional Earth science disciplines of geology, meteorology, and oceanography with aspects of biology, chemistry, and physics to introduce students to a more holistic study of Earth.

The tools available to students for learning about Earth and space have changed as well, although not all of these resources are available to all students. Visualization tools, such as Geographical Information System (GIS) software, have made it possible for Earth Science students to have direct access to the raw data and models used by scientists. Other web-based programs allow students to view and process satellite images of Earth, to direct a camera on board the Space Shuttle, and to access professional telescopes around the world to carry out science projects. In other words, the core concepts, subject matter, and tools used by students have undergone profound changes in recent decades that mirror many of the advances in Earth and Space Science. The data and images

[16] "Earth" is capitalized, rather than referred to as "the earth," in order to recognize it as one of the planets in the solar system.

gathered by these tools could be used as source materials for assessment items. For example, students could examine data on sea surface temperatures and upper atmospheric winds, derived from satellite observations, to predict the intensity and track of a hurricane.

To reflect the importance of this content area, NAEP will include questions about Earth and Space Science at the 4th, 8th, and 12th grade levels. The content statements have been divided into topics and subtopics as summarized in Table 9.

Table 9. Earth and Space Science Content Topics and Subtopics

Earth in Space and Time
Objects in the Universe History of Earth
Earth Structures
Properties of Earth Materials Tectonics
Earth Systems
Energy in Earth Systems Climate and Weather Biogeochemical Cycles

Earth in Space and Time

Earth in Space and Time is divided into two subtopics: Objects in the Universe and History of Earth. The idea that "the universe is large and ancient, on scales staggering to the human mind" (AAAS, 1994, p. 40) connects these subtopics.

One of the earliest discoveries of the scientific age was that Earth is not the center of the universe. It is now known that Earth is a planet in space, one of a family of planets and other bodies that circle a yellow star in a vast galaxy of other stars. Like countless other worlds that are known to exist, Earth has a beginning and a history. That history can be read by carefully and thoughtfully observing the world and the universe.

<u>Objects in the Universe</u>

Objects in the sky, such as the sun and the moon, have patterns of movement. These patterns can be observed through changes in shape or placement in the sky based on time of day or season (grade 4). By recognizing these patterns, people have developed calendars and clocks and explained such phenomena as moon phases, eclipses, and seasons (grade 8).

It was previously thought that Earth was the center of the universe, but it is now known that the sun is the central and largest body in the solar system, which includes Earth and other planets and their moons as well as other objects such as asteroids and comets. Objects in the solar system are kept in predictable motion by the force of gravity (grade 8).

According to the "big bang" theory, the entire contents of the known universe expanded explosively into existence from a hot, dense state 13.7 billion years ago. Early in the history of the universe, stars coalesced out of clouds of hydrogen and helium and clumped together by gravitational attraction into billions of galaxies. When heated to a sufficiently high temperature by gravitational attraction, stars begin nuclear reactions, which convert matter to energy and fuse light elements into heavier ones (grade 12).

History of Earth

Theories of planet formation and radioactive dating of meteorites have led to the conclusion that the sun, Earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. Early Earth was very different from today's planet. Initially, there was no life and no molecular oxygen in the atmosphere. There is evidence that one-celled organisms—the bacteria—were the first forms of life on our planet, appearing about 3.5 billion years ago. These bacteria are thought to be responsible for adding oxygen to Earth's atmosphere, making it possible for a wider diversity of life forms to evolve (grade 12).

Earth processes seen today, such as erosion and mountain building, have made possible the measurement of geologic time though methods such as observing rock sequences and using fossils to correlate the sequences at various locations. Fossils also provide evidence of how life and environmental conditions have changed (grade 8). Early methods of determining geological time, such as the use of index fossils and stratigraphic sequences, allowed for the relative dating of geologic events. However, absolute dating was impossible until the discovery that certain radioactive isotopes in rocks have known decay rates, making it possible to determine how many years ago a given rock sample formed (grade 12).

Earth's surface changes over time. Some changes are due to slow processes, such as erosion and weathering; and others are due to rapid processes such as volcanic eruptions, landslides, and earthquakes (grade 4). Changes caused by violent earthquakes and volcanic eruptions can be observed on a human time scale, but many geological processes, such as the building of mountain chains and shifting of entire continents, take place over hundreds of millions of years. Water, ice, waves, and wind sculpt Earth's surface to produce distinctive landforms (grade 12).

Earth Structures

Content statements related to Earth Structures fall into two subtopics: Properties of Earth Materials and Tectonics. The study of Earth materials has contributed to understanding dynamic processes, which are, in turn, driven by the movement of vast tectonic plates. Conversely, the development of tectonic theory has made it possible to locate and extract Earth materials for a wide variety of human uses.

Properties of Earth Materials

Earth materials that occur in nature include rocks, minerals, soils, water, and the gases of the atmosphere. Natural materials have different properties, which sustain plant and animal life (grade 4). Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers, with each having a different chemical composition and texture (grade 8). Some Earth materials have properties that make them useful either in their present form or designed and modified to solve human problems and enhance the quality of life (grade 4).

Rocks and rock formations bear evidence of the conditions and forces that created them, ranging from the violent conditions of volcanic eruptions to the slow deposition of sediments. The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has a different physical and chemical composition at different elevations (grade 8).

Tectonics

A basic understanding of geological history, described above, forms the foundation for later understanding of tectonics. Earth's internal structure is layered with a lithosphere, hot convecting mantle, and dense metallic core. Lithospheric plates, on the scale of continents and oceans, constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events such as earthquakes, volcanic eruptions, and mountain building result from these plate motions (grade 8).

Although continental drift was first suggested as early as the late 16th century and further developed in the early 1900s, it was not widely accepted until more convincing evidence emerged as a result of extensive exploration of the sea floor. By the late 1960s, mapping of the Mid-Atlantic Ridge, evidence of sea floor spreading, and subduction led to the more general theory of plate tectonics. The current explanation is that the outward transfer of Earth's internal heat propels the plates comprising Earth's surface across the face of the globe, pushing the plates apart where magma rises to form mid-ocean ridges, and pulling the edges of plates back down where Earth materials sink into the crust at deep trenches (grade 12).

Earth as a whole has a magnetic field that is detectable at the surface with a compass. Earth's magnetic field is similar to the field of a natural or human-made magnet with north and south poles and lines of force. For thousands of years, people have used

compasses to aid navigation on land and sea (grade 8). Crucial evidence in support of tectonic theory came from studies of the magnetic properties of rocks on the ocean floor (grade 12).

Earth Systems

Earth Systems is organized according to three subtopics: Energy in Earth Systems, Climate and Weather, and Biogeochemical Cycles. The explorers of the 16th century who circumnavigated the planet were the first to become aware of global weather and climate patterns. As science began to mature and diversify in the 19th and 20th centuries, those who scientifically studied the planet did so from the perspective of the traditional disciplines, such as geology, oceanography, and meteorology. Currently, working with vastly improved technologies, most scientists take an Earth systems perspective, including the study of how energy moves through Earth systems and the integration of disciplines to better understand Earth's biogeochemical cycles.

Energy in Earth Systems

The sun warms the land, air, and water and helps plants grow (grade 4). The sun is the major source of energy for phenomena on Earth's surface. The sun drives convection within the atmosphere and oceans, producing winds, ocean currents, and the water cycle. Seasons result from annual variations in the intensity of sunlight and length of day due to the tilt of Earth's rotation axis relative to the plane of its yearly orbit around the sun (grade 8).

Earth's systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational/thermal energy from Earth's original formation (grade 12).

Climate and Weather

Weather changes from day to day and over the seasons. Scientists use tools for recording and predicting weather changes (grade 4). Global patterns of atmospheric movement influence local weather (grade 8).

Climate is determined by energy transfer from the sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover, atmospheric gases, and Earth's rotation, as well as static conditions such as the position of mountain ranges and oceans, seas, and lakes (grade 12). Oceans have a major effect on climate because water in the oceans holds a large amount of heat (grade 8).

Biogeochemical Cycles

Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical forms. Elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of biogeochemical cycles (see textbox that follows). Movement of matter through Earth's systems is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in coal and other fossil fuels, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life (grade 12).

Water, which covers the majority of Earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle." Water evaporates from Earth's surface, rises and cools as it moves to higher elevations, condenses as clouds, falls as rain or snow, and collects in lakes, oceans, soil, and underground (grade 8).

Natural ecosystems provide an array of basic processes that affect humans. These processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients (grade 12). The supply of many Earth resources such as fuels, metals, fresh water, and farmland is limited.

Humans change environments in ways that can either be beneficial or detrimental for themselves and other organisms (grade 4). Humans have devised methods for extending the use of Earth resources through recycling, reuse, and renewal (grade 4). However, other activities—reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming—have changed Earth's land, oceans, and atmosphere. Studies of plant and animal populations have shown that such activities can reduce the number and variety of wild plants and animals and sometimes result in the extinction of species (grade 8).

Crosscutting Content: Biogeochemical Cycles

To demonstrate an understanding of biogeochemical cycles, students must draw on their knowledge of Matter and Energy (Physical Science), Structures and Functions of Living Systems (Life Science) and Earth Systems (Earth and Space Science).

Essentially fixed amounts of chemical atoms or elements cycle within the Earth system, and energy drives their translocation and transformation. Examples of biogeochemical cycles include water, carbon, and nitrogen. The basic processes underlying the translocation of matter (e.g., changes of state, gravity) and transformations involving the rearrangement of atoms in chemical reactions are described in Physical Science (p. 31) and the role of living organisms in cycling atoms between inorganic and organic forms is described in Life Science (p. 43).

Biogeochemical cycles are described more fully in the "Earth Systems" section of Table 10, Earth and Space Science Content Statements for Grades 4, 8, and 12 (p. 59).

The following grade 12 content statements illustrate the crosscutting nature of biogeochemical cycles. They are not intended to represent an exhaustive catalog of all statements related to this crosscutting content.

Physical Science	Life Science	Earth and Space Science
P12.7: A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other chemical reactions, atoms interact with one another by sharing electrons to create a bond. An important example is carbon atoms, which can bond to one another in chains, rings, and branching networks to form, along with other kinds of atoms—hydrogen, oxygen, nitrogen, and sulfur—a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.	**L12.5:** The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in an ecosystem, some energy is stored in newly made structures, but much is dissipated into the environment as heat. Continual input of energy from sunlight keeps the process going.	**E12.12:** Movement of matter through Earth's systems is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in coal and other fossil fuels, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12

Grade 4	Grade 8	Grade 12
Earth in Space and Time		
Objects in the Universe: From patterns in the sky (4) to a model of the solar system (8) to a vision of the universe (12).		
E4.1: Objects in the sky have patterns of movement. The sun, for example, appears to move across the sky in the same way every day, but its path changes slowly over the seasons. The moon appears to move across the sky on a daily basis much like the sun. **E4.2:** The observable shape of the moon changes from day to day in a cycle that lasts about a month.	**E8.1:** In contrast to an earlier theory that Earth is the center of the universe, it is now known that the sun, an average star, is the central and largest body in the solar system. Earth is the third planet from the sun in a system that includes seven other planets and their moons, as well as smaller objects, such as asteroids and comets. **E8.2:** Gravity is the force that keeps most objects in the solar system in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.	**E12.1:** The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin approximately 13.7 billion years ago when the universe began in a hot, dense state. According to this theory, the universe has been expanding ever since. **E12.2:** Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars and billions of galaxies. **E12.3:** Stars, like the sun, transform matter into energy in nuclear reactions. When hydrogen nuclei fuse to form helium, a small amount of matter is converted to energy. These and other processes in stars have led to the formation of all the other elements.

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Earth in Space and Time		
History of Earth: From evidence of change (4) to estimating the timing and sequence of geologic events (8) to theories about Earth's history (12).		
E4.3: The surface of Earth changes. Some changes are due to slow processes, such as erosion and weathering, and some changes are due to rapid processes, such as landslides, volcanic eruptions, and earthquakes.	**E8.3:** Fossils provide important evidence of how life and environmental conditions have changed in a given location. **E8.4:** Earth processes seen today, such as erosion and mountain building, made possible the measurement of geologic time through methods such as observing rock sequences and using fossils to correlate the sequences at various locations.	**E12.4:** Early methods of determining geologic time, such as the use of index fossils and stratigraphic sequences, allowed for the relative dating of geological events. However, absolute dating was impossible until the discovery that certain radioactive isotopes in rocks have known decay rates, making it possible to determine how many years ago a given rock sample formed. **E12.5:** Theories of planet formation and radioactive dating of meteorites and lunar samples have led to the conclusion that the sun, Earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. **E12.6:** Early Earth was very different from today's planet. Evidence for one-celled forms of life—the bacteria—extends back more than 3.5 billion years. The evolution of life caused dramatic changes in the composition of Earth's atmosphere, which did not originally contain molecular oxygen. **E12.7:** Earth's current structure has been influenced by both sporadic and gradual events. Changes caused by violent earthquakes and volcanic eruptions can be observed on a human time scale, but many geological processes, such as the building of mountain chains and shifting of entire continents, take place over hundreds of millions of years.

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Earth Structures		
Properties of Earth Materials: From natural and human-made materials (4) to soil analysis and layers of the atmosphere (8).		
E4.4: Earth materials that occur in nature include rocks, minerals, soils, water, and the gases of the atmosphere. **E4.5:** Natural materials have different properties, which sustain plant and animal life. **E4.6:** Some Earth materials have properties that make them useful either in their present form or designed and modified to solve human problems and enhance the quality of life, as in the case of materials used for building or fuels used for heating and transportation.	**E8.5:** Rocks and rock formations bear evidence of the minerals, materials, temperature/pressure conditions, and forces that created them. Some formations show evidence that they were deposited by volcanic eruptions. Others are composed of sand and smaller particles buried and cemented by dissolved minerals to form solid rock again. Still others show evidence that they were once earlier rock types that were exposed to heat and pressure until they changed shape and in some cases melted and recrystallized. **E8.6:** Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers with each having a different chemical composition and texture. **E8.7:** The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. The atmosphere has a different physical and chemical composition at different elevations.	

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Earth Structures		
Tectonics: From the basics of tectonic theory and Earth magnetism (8) to the physical mechanism that drives tectonics and its supporting evidence (12).		
	E8.8: The Earth is layered with a lithosphere; hot, convecting mantle; and dense, metallic core. **E8.9:** Lithospheric plates on the scale of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions. **E8.10:** Earth as a whole has a magnetic field that is detectable at the surface with a compass. Earth's magnetic field is similar to the field of a natural or human-made magnet with north and south poles and lines of force. For thousands of years, people have used compasses to aid in navigation on land and sea.	**E12.8:** Mapping of the Mid-Atlantic Ridge, evidence of sea floor spreading, and subduction provided crucial evidence in support of the theory of plate tectonics. The theory currently explains plate motion as follows: the outward transfer of Earth's internal heat propels the plates comprising Earth's surface across the face of the globe. Plates are pushed apart where magma rises to form mid-ocean ridges, and the edges of plates are pulled back down where Earth materials sink into the crust at deep trenches.

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Earth Systems		
Energy in Earth Systems: From role of the sun (4) to the sun's observable effects (8) to internal and external sources of energy in Earth systems (12).		
E4.7: The sun warms the land, air, and water and helps plants grow.	**E8.11:** The sun is the major source of energy for phenomena on Earth's surface. The sun provides energy for plants to grow and drives convection within the atmosphere and oceans, producing winds, ocean currents, and the water cycle. **E8.12:** Seasons result from annual variations in the intensity of sunlight and length of day, due to the tilt of Earth's rotation axis relative to the plane of its yearly orbit around the sun.	**E12.9:** Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from Earth's original formation.
Climate and Weather: From local weather (4) to global weather patterns (8) to systems that influence climate (12).		
E4.8: Weather changes from day to day and over the seasons. **E4.9:** Scientists use tools for observing, recording, and predicting weather changes from day to day and over the seasons.	**E8.13:** Global patterns of atmospheric movement influence local weather. Oceans have a major effect on climate because water in the oceans holds a large amount of heat.	**E12.10:** Climate is determined by energy transfer from the sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover, atmospheric gases, and Earth's rotation, as well as static conditions such as the positions of mountain ranges and of oceans, seas, and lakes.

Table 10. Earth and Space Science Content Statements for Grades 4, 8, and 12 (cont.)

Grade 4	Grade 8	Grade 12
Earth Systems		
Biogeochemical Cycles: From uses of Earth resources (4) to natural and human-induced changes in Earth materials and systems (8) to biogeochemical cycles in Earth systems (12).		
E4.10: The supply of many Earth resources such as fuels, metals, fresh water, and farmland is limited. Humans have devised methods for extending the use of Earth resources through recycling, reuse, and renewal. **E4.11:** Humans depend on their natural and constructed environment. Humans change environments in ways that can either be beneficial or detrimental for themselves and other organisms.	**E8.14:** Water, which covers the majority of Earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle." Water evaporates from Earth's surface, rises and cools as it moves to higher elevations, condenses as clouds, falls as rain or snow, and collects in lakes, oceans, soil, and underground. **E8.15:** Human activities, such as reducing the amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, have changed Earth's land, oceans, and atmosphere. Studies of plant and animal populations have shown that such activities can reduce the number and variety of wild plants and animals and sometimes result in the extinction of species.	**E12.11:** Earth is a system containing essentially a fixed amount of each stable chemical atom or element. Most elements can exist in several different chemical forms. Earth elements move within and between the lithosphere, atmosphere, hydrosphere, and biosphere as part of biogeochemical cycles. **E12.12:** Movement of matter through Earth's systems is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in coal and other fossil fuels, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life. **E12.13:** Natural ecosystems provide an array of basic processes that affect humans. These processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients.

Components of Science Content as Assessment Item Contexts

Science-literate citizens should be familiar with certain components of science content, such as the history and nature of science, and the relationship between science and technology. These features are highly valued by science educators and viewed as critical to the teaching and learning of science (AAAS, 1993; NRC, 1996). In Chapter Three, the nature of science is partially addressed through a discussion of scientific inquiry. Similarly, the relationship between science and technology is partially addressed in Chapter Three through a discussion of technological design. In addition, these components of science content will be incorporated into the contexts of assessment items; they will not be directly assessed because of time and resource constraints. Further details can be found in Chapter Four.

From Science Content to Science Practices

This chapter has presented the science content that defines the NAEP Science Assessment content domain. The content statements, as presented in this chapter, do not describe students' performances in observable terms. The next chapter, Chapter Three, will describe science practices and cognitive demands. It will also show how science content statements can be combined ("crossed") with science practices to generate performance expectations (i.e., descriptions of students' expected and observable performances on the NAEP Science Assessment). Based on these performance expectations, assessment items can be developed, and then, finally, inferences can be derived from student responses about what students know and can do in science. Chapter Three will provide an illustrative example of this process.

CHAPTER THREE: SCIENCE PRACTICES

Introduction

Chapter Two presented content statements that define the key science principles (as well as the facts, concepts, laws, and theories) to be assessed by NAEP in 2009. However, NAEP will assess not only science content statements but also the ways in which knowledge is used. This chapter defines what students should be able to do with the science content statements by articulating key science practices to be assessed by NAEP—Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, and Using Technological Design. These practices are useful for generating science-rich assessment items.

To assist assessment developers, the science practices can be associated with the cognitive demands that they place on students. This chapter employs a set of four cognitive demands: (1) "knowing that," (2) "knowing how," (3) "knowing why," and (4) "knowing when and where to apply knowledge." These cognitive demands help ensure NAEP assessment items are developed so as to elicit the kinds of knowledge and thinking that underlie the *Framework*'s performance expectations (see later in this chapter). They also provide a tool for interpreting students' responses on the assessment items.

This chapter shows how science content statements can be combined or "crossed" with practices to generate performance expectations, which then guide the development of assessment items. By comparing student responses to the particular science content and practice being assessed, inferences about what students know (about particular science principles) and can do (with respect to particular science practices) are made.

Two types of textboxes are used throughout this chapter. *Clarification* textboxes provide details on potentially confusing topics, such as the distinction between Identifying Science Principles and Using Science Principles. *Illustrative Item* textboxes provide assessment items that exemplify recommendations discussed in the text. Answers to selected-response items are indicated within the textbox; scoring guides for constructed-response items are provided in Appendix D. Although items in these textboxes may assess more than one content statement or practice, only the primary content and practice designations are provided. This follows NAEP practice, which uses only primary designations for items in the analysis and reporting of student responses.

Overview of Practices

Over the course of human history, people have developed many interconnected and validated ideas about the physical and biological world. These ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the natural world. Scientific ideas are generated and verified by observing natural phenomena, finding patterns in these observations, and constructing

theoretical models to explain these patterns.[17] These patterns and models can in turn be used to describe, measure, classify, explain, and predict other observations. Science knowledge is used to reason about the natural world and to improve the quality of scientific thought and action. Hence, NAEP will assess how well 4th, 8th, and 12th grade students can engage in the following broadly organized science practices:

- Identifying Science Principles
- Using Science Principles
- Using Scientific Inquiry
- Using Technological Design

Because these practices are closely related, these categories are not distinct and some overlap is expected.

The ability to communicate accurately and effectively is essential in science, and this expectation is a strand that runs across the practices. Accurate and effective communication may include (but is not limited to) writing clear instructions that others can follow to carry out an investigation; reading and organizing data in tables and graphs; locating information in computer databases; using audio, video, multimedia, and other technologies to access, process, and integrate scientific findings; using language and scientific terms appropriately; drawing pictures or schematics to aid in descriptions of observations; summarizing the results of scientific investigations; and reporting to various audiences about facts, explanations, investigations, and data-based alternative explanations and designs (AAAS, 1993; NRC, 1996; Partnership for 21st Century Skills, 2004). Quantitative reasoning is also fundamental to science. Quantitative reasoning is the capacity not only to calculate (e.g., determine density given an object's mass and dimensions) but also to model a system (e.g., determine the energy released from a chemical reaction).

Sources for the Development of Practices

The *Framework* developers examined a number of sources to develop the short list of practices to be assessed in the NAEP Science Assessment. The most important were the "Science as Inquiry" sections of the *National Standards* and "Chapter 12: Habits of Mind" in *Benchmarks*. The committee also consulted the *National Standards* and *Benchmarks* sections on "Science and Technology" and "The Designed World," and the Validities of Science Inquiry Assessments project (Quellmalz, Haertel, DeBarger, & Kreikemeier, 2005). Conducted by SRI International during 2001-05, this project classified assessment items according to the inquiry standards discussed in the *National Standards*. The practices described below are found in most of the above sources. Cognitive research on science learning, international frameworks, and state standards were also used as reference points.

[17] Because natural phenomena are understood and described based on collected observations, the terms "phenomena" and "observations" are intricately intertwined. For ease of communication, the *Framework* uses the term "observations" to represent both specific observations of a natural phenomenon and the phenomenon itself.

Identifying Science Principles

This category focuses on students' ability to recognize, recall, define, relate, and represent basic science principles specified in the Physical Science, Life Science, and Earth and Space Science content statements presented in Chapter Two. The content statements themselves are often closely related to one another conceptually. Moreover, the science principles included in the content statements can be represented in a variety of forms, such as words, pictures, graphs, tables, formulas, and diagrams (AAAS, 1993; NRC, 1996). NAEP will assess students' ability to describe, measure, or classify observations; state or recognize principles included in the content statements; connect closely related content statements; and relate different representations of science knowledge. The practices assessed in this category draw on "declarative knowledge," or "knowing that," which is described in the "Cognitive Demands" section later in this chapter. Identifying Science Principles comprises the following general types of performance expectations:

- Describe, measure, or classify observations (e.g., describe the position and motion of objects; measure temperature; classify relationships between organisms as being predator/prey, parasite/host, producer/consumer).
- State or recognize correct science principles (e.g., "mass is conserved when substances undergo changes of state"; "all organisms are composed of cells"; "the atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor").
- Demonstrate relationships among closely related science principles (e.g., connect statements of Newton's three laws of motion, relate energy transfer with the water cycle).
- Demonstrate relationships among different representations of principles (e.g., verbal, symbolic, diagrammatic) and data patterns (e.g., tables, equations, graphs).

Identifying Science Principles is integral to all of the other science practices.

The following two items illustrate the expectation that students recognize correct science principles. The first item assesses students' ability to correctly identify simple information about the location of bodies within the solar system ("declarative knowledge"). More than half of the 8th graders answered it incorrectly. Thirty-five percent of the students thought that the moon is sometimes closer to the sun than to the Earth.

Illustrative Item

The Earth's Moon is

A. always much closer to the Sun than it is to the Earth.
B. always much closer to the Earth than it is to the Sun.
C. about the same distance from the Sun as it is from the Earth.
D. sometimes closer to the Sun than it is to the Earth and sometimes closer to the Earth than it is to the Sun.

Key: B

E8.1, Identifying Science Principles
Source: NAEP 2000, Grade 8

Illustrative Item

Animals and plants are made up of a number of different chemical elements. What happens to all of these elements when animals and plants die?

A. They die with the animal or plant.
B. They evaporate into the atmosphere.
C. They are recycled back into the environment.
D. They change into different elements.

Key: C

L8.5, Identifying Science Principles
Source: TIMSS 2003, Grade 8[18]

Using Science Principles

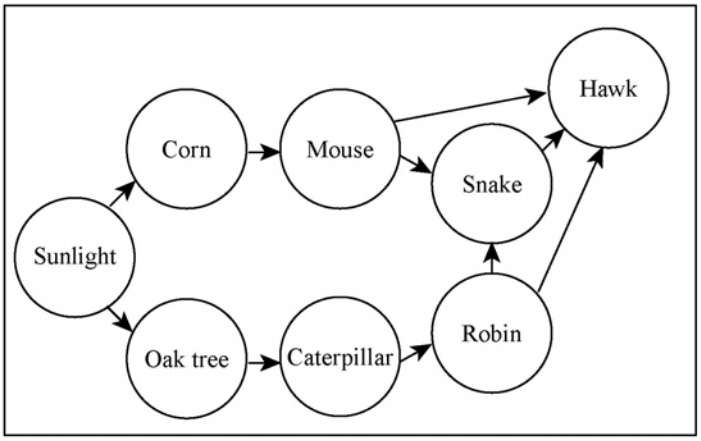
Scientific knowledge is useful for making sense of the natural world. Both scientists and informed citizens can use patterns in observations and theoretical models to predict and explain observations that they make now or that they will make in the future. The practices assessed in this category draw primarily on "schematic knowledge," or "knowing why," in addition to "declarative knowledge," which are described in the "Cognitive Demands" section later in this chapter. Using Science Principles comprises the following general types of performance expectations:

[18] TIMSS items appearing in the *Framework* are copyrighted © by the International Association for the Evaluation of Educational Achievement (IEA).

- Explain observations of phenomena (using science principles from the content statements).
- Predict observations of phenomena (using science principles from the content statements, including quantitative predictions based on science principles that specify quantitative relationships among variables).
- Suggest examples of observations that illustrate a science principle (e.g., identify examples where the net force on an object is zero; provide examples of observations explained by the movement of tectonic plates; given partial DNA sequences of organisms, identify likely sequences of close relatives).
- Propose, analyze, and/or evaluate alternative explanations or predictions.

The following item illustrates the expectation that students predict phenomena.

Illustrative Item



Look at the food web above. If the corn crop failed one year what would most likely happen to the robin population? Explain your answer.

(See Appendix D for item scoring guides.)

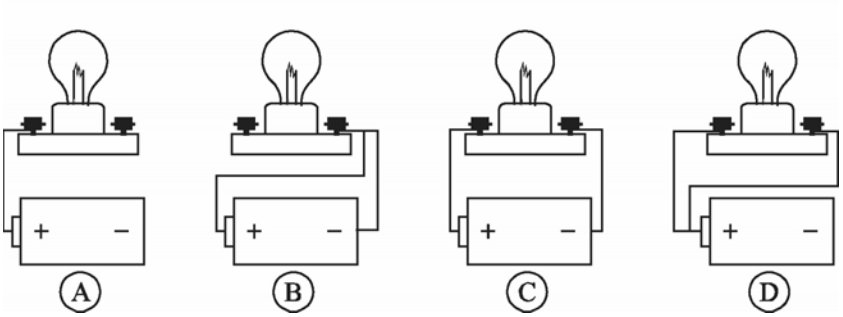
L8.6, Using Science Principles
Source: TIMSS 1999, Grade 8

The first two science practice categories—Identifying Science Principles and Using Science Principles—both require students to correctly state or recognize the science principles contained in the content statements. A difference between the categories is that Using Science Principles focuses on what makes science knowledge valuable or in other words, its usefulness in making accurate predictions about phenomena and in explaining observations of the natural world in coherent ways (i.e., “knowing why”). Distinguishing between these two categories draws attention to differences in the depth and richness of individuals’ knowledge of the content statements. Certain actions on the part of students

lead to an inference of Identifying Science Principles, while other actions lead to an inference of Using Science Principles. Assuming a continuum from "just knowing the facts" to "using science principles," there is considerable overlap at the boundary. The line between the Identifying and Using categories is not distinct. Consider the following item, which illustrates the expectation that students connect different representations. In this case, the student must identify the correct pictorial representation of a complete electrical circuit.

Illustrative Item

The pictures show a lightbulb connected to a battery.
Which bulb will light?



Key: C

P4.11, Using Science Principles
Source: TIMSS 2003, Grade 4

Student responses to this item are open to two interpretations. If students have had a great deal of exposure to these types of circuit representations, their responses would fall under Identifying Science Principles. If, however, these circuit representations are relatively novel for students, then they would need to do more reasoning and their responses would fall under Using Science Principles.

The following textbox provides further illustration of the distinction between *identifying* the boiling point of water (a fact) and *using* the relationship between boiling point and pressure (altitude) to explain or predict.

Clarification: Distinguishing between Identifying Science Principles and Using Science Principles—A Boiling Point Example

Grade 8 Content Statement: Matter—Properties of Matter:
P8.4: . . . Each element and compound has physical and chemical properties, such as boiling point, density, color, and conductivity, which are independent of the amount of the sample.

Distinguishing between the two categories of Identifying and Using Science Principles is a function of actions or performances. Using boiling point as an example, one might observe different responses to the question, "What is the boiling point of water?" Behaviors or actions might include:

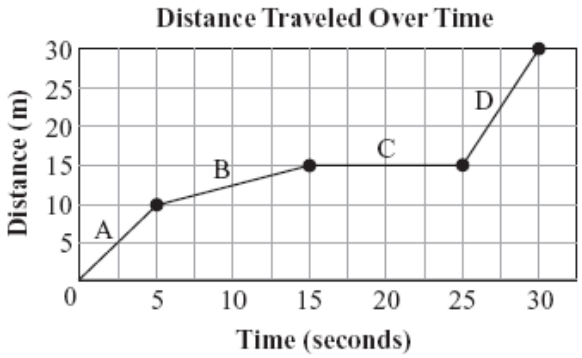
- Penciling in the oval corresponding to 100^0C in a selected-response item.
- Writing: "The boiling point of water is 100^0C at sea level."
- Writing: "The boiling point of water changes as pressure changes. So, even though water boils at 100^0C at sea level (1 atm pressure), it might boil at a lower temperature on top of a mountain because pressure is lower up there."

The above responses evoke different inferences about the science understanding of the individual responding. Both the first and second responses suggest that the question is only assessing knowledge of facts or the ability to identify a science principle; however, they illustrate the difference between recognizing a correct answer and retrieving that correct answer from memory. The third response contains even more sophisticated information, suggesting that the student can use a science principle to make predictions. Distinctions between these two categories can be clarified by examining student responses and conducting cognitive labs.

The following item set illustrates a combination of Identifying Science Principles and Using Science Principles. It also addresses the expectation that students interpret data presented in a graph and use the data to perform a mathematical calculation.

Illustrative Item

The graph below shows the distance traveled over time by a student walking down a hall. Use the information shown on the graph to do Numbers 7 and 8.



7. During which time interval was the student moving the fastest?

- ○ A
- ○ B
- ○ C
- ○ D

Key: D

P8.14, Identifying Scientific Principles

8. What was the average speed of the student from 0 seconds to 5 seconds?

Average speed: _____

(See Appendix D for item scoring guides.)

P8.14, Using Scientific Principles
Source: Colorado Department of Education 2002, Grade 8

Using Scientific Inquiry

Scientists make observations about the natural world, identify patterns in data, and propose explanations to account for the patterns. While scientists differ greatly from one another in what phenomena they study and in how they go about their work, scientific inquiry involves the collection of relevant data, the use of logical reasoning, and the application of imagination and evidence in devising hypotheses to explain patterns in data. Scientific inquiry is a complex and time-intensive process that is iterative rather than linear. Scientists are also expected to exhibit, indeed to model, the habits of mind—curiosity, openness to new ideas, informed skepticism—that are part of science literacy. This includes reading or listening critically to assertions in the media, deciding what evidence to pay attention to and what to dismiss, and distinguishing careful arguments from shoddy ones. These critical thinking and systems thinking skills are the basis for exercising sound reasoning, making complex choices, and understanding the interconnections among systems (Partnership for 21st Century Skills, 2004). Thus, Using Scientific Inquiry depends on the practices described above—Identifying Science Principles and Using Science Principles. Moreover, in addition to involving "declarative" and "schematic knowledge," Using Scientific Inquiry draws heavily on "procedural knowledge"—"knowing how" (e.g., knowing how to determine the mass of an object). This *Framework* focuses on a few key inquiry practices that are practical to measure in the NAEP Science Assessment. Using Scientific Inquiry comprises the following general types of performance expectations:[19]

- Design or critique aspects of scientific investigations (e.g., involvement of control groups, adequacy of sample).
- Conduct scientific investigations using appropriate tools and techniques (e.g., selecting an instrument that measures the desired quantity—length, volume, weight, time interval, temperature—with the appropriate level of precision).
- Identify patterns in data and/or relate patterns in data to theoretical models.
- Use empirical evidence to validate or criticize conclusions about explanations and predictions (e.g., check to see that the premises of the argument are explicit, notice when the conclusions do not follow logically from the evidence given).

Scientific inquiry is more complex than simply making, summarizing, and explaining observations; and it is more flexible than the rigid set of steps often referred to as the "scientific method." The *National Standards* makes clear that inquiry goes beyond "science as a process" to include an understanding of the nature of science (p. 105) and further states the following:

> It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by

[19] Additionally, 12th graders at the Advanced level are expected to be able to identify a scientific question for investigation. See Appendix C for Preliminary Achievement Level Descriptions.

> other scientists. Evaluation includes reviewing the experimental procedures, examining the evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations (p. 171).

In the NAEP Science Assessment, when students Use Scientific Inquiry, they are drawing on their understanding about the nature of science, including the following ideas (see *Benchmarks*):

- Arguments are flawed when fact and opinion are intermingled, or the conclusions do not follow logically from the evidence given.
- A single example can never support the inference that something is always true, but sometimes a single example can support the inference that something is not always true.
- If more than one variable changes at the same time in an experiment, the outcome of the experiment may not be clearly attributable to any one of the variables.
- The way in which a sample is drawn affects how well it represents the population of interest. The larger the sample, the smaller the error in inference to the population. But, large samples do not necessarily guarantee representation, especially in the absence of random sampling.

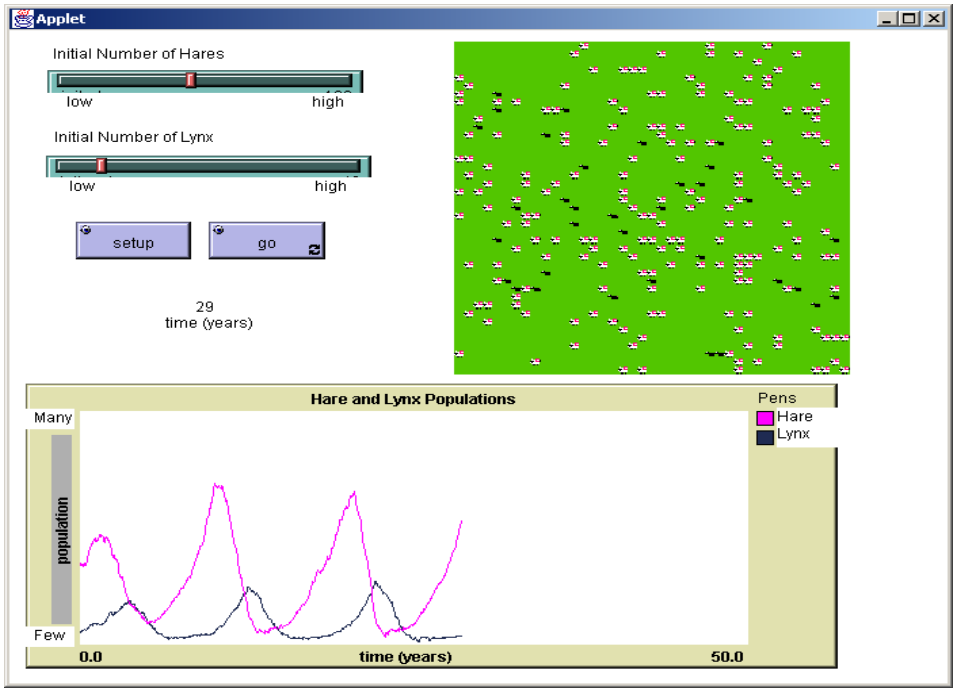
NAEP will assess students' abilities to Use Scientific Inquiry in two ways: students will be required to *do* the practices specified above, and students will *critique examples* of scientific inquiry. It is incorrect to assume that assessment of Using Scientific Inquiry is best or only achieved through hands-on performance tasks and ICTs. In both cases of *doing* and *critiquing*, some assessment tasks will also be presented as paper-and-pencil items. In *doing*, tasks may present data tables and ask students which conclusions are consistent with the data. Other tasks will be presented as hands-on performance and/or interactive computer tasks (e.g., where students collect data and present their results or where students specify experimental conditions on computer simulations and observe the outcomes). As to *critiquing*, students might be asked to identify flaws in a poorly designed investigation or suggest changes in the design in order to produce more reliable data. Tasks may be based on print or electronic media (e.g., items may ask students to suggest alternative interpretations of data described in a newspaper article). For more information on types of items, see Chapter Four.

The following middle school (grade 8) item illustrates the expectation that students conduct scientific investigations. By manipulating the simulation, students gather data and solve the problems given.

Illustrative Item

This interactive computer task is one module in an extended assessment of students' abilities to use a range of technologies to investigate a complex problem, "Should lynx be re-introduced into a national park?" Students accessed, organized, and analyzed data on the number of hares in the park over a 25-year period, researched factors that would impact the population, and created a graph to analyze the trend. (See Appendix D for description of the full task.)

This module allows students to interact with a simulated predator/prey (lynx/hare) population model. Students use the modeling tool to observe population trends that result from different parameter values for the lynx and hare populations. The screen shot below is an example of what students see after they have selected parameters and run the simulation. Note that it is a single screen shot and represents only a small subset of the many screens actually seen by students engaged in this interactive computer task. After students have run the modeling software, they are asked a series of questions (e.g., size of the hare population over time).



L8.6, Using Scientific Inquiry
Source: Quellmalz, Griffin, Hurst, Kreikemeier, Rosenquist, and Zalles (2004)

Using Technological Design[20]

In both the *National Standards* and *Benchmarks*, the term "technological design" refers to the process that underlies the development of all technologies, from paperclips to space stations. As pointed out in the *National Standards*, this meaning "is not to be confused with 'instructional technology,' which provides students and teachers with exciting tools—such as computers—to conduct inquiry and to understand science" (p. 24).

In the *Framework*, Using Technological Design describes the systematic process of applying science knowledge and skills to solve problems in a real-world context. The reason for including technological design in the science curriculum is clearly stated in the *National Standards*: "Although these are science education standards, the relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science" (p. 190). The *National Standards* defines technology and its relationship to science as follows:

> As used in the *Standards*, the central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs. Technology as design is included in the *Standards* as parallel to science as inquiry (p. 24).

As it is in scientific inquiry, the professional practice of technological design (also called *engineering design*) is complex and time-intensive. Because NAEP addresses the subject area of science, the use of technological design components in the 2009 NAEP Science Assessment will be limited to those that reveal students' abilities to apply science principles in the context of technological design. Students' abilities to Identify and Use Science Principles should provide the opportunities as well as the limits for assessment tasks related to Using Technological Design. For example, if students are asked to design a town's energy plan, they may be expected to consider the environmental effects of using natural gas versus using coal, but they would not be expected to consider the economic, political, or social ramifications of such a plan.

The *Framework* samples key components of Using Technological Design from the more complete descriptions found in the *National Standards* and *Benchmarks*. Using Technological Design comprises the following general types of performance expectations, all of which entail students using science knowledge to accomplish the following:

- Propose or critique solutions to problems, given criteria and scientific constraints.
- Identify scientific trade-offs in design decisions and choose among alternative solutions.
- Apply science principles or data to anticipate effects of technological design decisions.

[20] This practice is elaborated in some detail because it is new in NAEP Science Assessments.

The three components of Using Technological Design are elaborated below.

First, the technological design process is rooted in the definition of a *problem* that can be solved through a technological design process. The problem generally describes a human need or want and specifies criteria and constraints for an acceptable solution (International Technology Education Association, 2000). Only constraints that reflect the science content statements in this *Framework* will be considered in developing relevant NAEP assessment items. The engineer who designs a bridge, for example, must take into account the effects of wind and water currents by using relevant physics principles to simulate these effects on possible structures before the bridge is built.

Second, even if limited to the application of science principles, choosing between alternative solutions almost always involves *trade-offs*. As stated in *Benchmarks*:

> There is no perfect design. Designs that are best in one respect . . . may be inferior in other ways . . . . Usually some features must be sacrificed to get others. How such trade-offs are received depends upon which features are emphasized and which are down-played (p. 49).

The application of science principles may be used to compare alternative technological solutions to see which will better solve the problem and accomplish the goals of the project.

Finally, while the chosen solution may be intended to solve a human problem or meet a human need, the *effects* are not always as planned. When the automobile was invented, no one could have predicted the environmental and human health impacts of vehicle emissions. However, it is the job of scientists and engineers working together to apply their knowledge of the natural world to make such predictions. According to the *National Standards*, students in grades K-4 should know about the effects of design solutions:

> People continue inventing new ways of doing things, solving problems, and getting work done. New ideas and inventions often affect other people; sometimes the effects are good and sometimes they are bad. It is helpful to try to determine in advance how ideas and inventions will affect other people (p. 140).

In terms of cognitive demands, both “declarative (knowing that) knowledge” and “schematic (knowing why) knowledge” come into play for the three components of Using Technological Design, as does “strategic knowledge—knowing when and where to apply knowledge.”

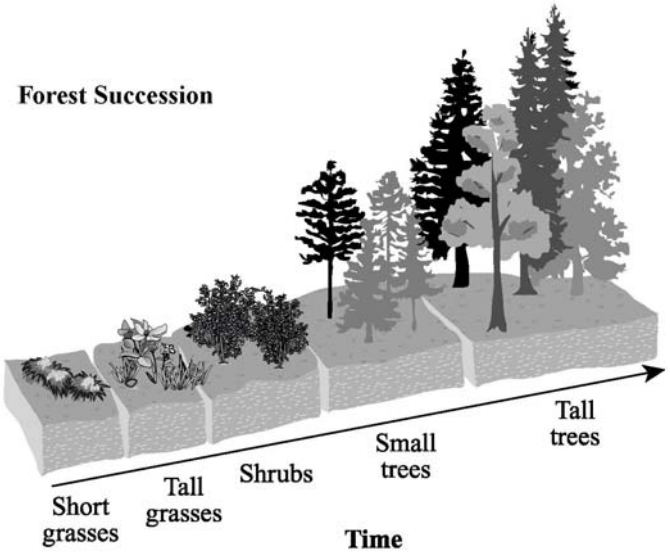
The role of technological design in U.S. science classrooms currently varies widely, and it is not possible to predict the extent to which it will be integrated into the school curriculum in the future. The role of technological design in NAEP Science will need to be revisited regularly, in response to its evolving role in school science.

Since Using Technological Design in the NAEP Assessment needs to have direct relevance to science, it is assumed that students have some understanding about the relationship between science and technology. The science-technology relationship is further discussed in Chapter Four as providing context for assessment items.

The following item illustrates the expectation that students apply science principles to anticipate the effects of a technological design decision.

Illustrative Item

Occasionally, a fire will destroy a forest, burning down trees and pushing wildlife out of their forest homes. However, the forest will grow back. Eventually, through the process of forest succession as shown below, short grasses and flowers begin to grow and animals make new homes.



Over time, shrubs and trees begin to grow. The forest returns to a lush habitat for the wildlife listed in the chart below.

Forest Wildlife

Ground-dwelling	Worms, beetles
Reptiles and amphibians	American toads, wood frogs, snakes, Eastern box turtles
Small animals	Squirrels, chipmunks
Medium to large animals	Opossums, raccoons, white-tailed deer, black bears
Airborne	Butterflies, moths, bees, wild turkeys, red-tailed hawks, bald eagles

A power company owns part of a forest that was destroyed by a fire. The forest could take decades to rebuild on its own. The company's department of environmental studies suggests planting new trees to help the forest rebuild.

Using the information in the scenario:

- Explain how planting trees could **benefit** the natural ecosystem.
- Explain how planting trees could **harm** the natural ecosystem.

(See Appendix D for item scoring guides.)

E8.15, Using Technological Design
Source: Washington Assessment of Student Learning, 2004, Grade 8

Summary of Practices

The general performance expectations for each of the four practices are summarized in Table 11. Dashed lines indicate that the boundaries between these categories are not distinct, and some overlap is to be expected.

Table 11. General Performance Expectations for Science Practices

← Communicate accurately and effectively →					
	Identifying Science Principles	Describe, measure, or classify observations	State or recognize correct science principles	Demonstrate relationships among closely related science principles	Demonstrate relationships among different representations of principles
	Using Science Principles	Explain observations of phenomena	Predict observations of phenomena	Suggest examples of observations that illustrate a science principle	Propose, analyze, and/or evaluate alternative explanations or predictions
	Using Scientific Inquiry	Design or critique aspects of scientific investigations	Conduct scientific investigations using appropriate tools and techniques	Identify patterns in data and/or relate patterns in data to theoretical models	Use empirical evidence to validate or criticize conclusions about explanations and predictions
	Using Technological Design	Propose or critique solutions to problems given criteria and scientific constraints	Identify scientific trade-offs in design decisions and choose among alternative solutions	Apply science principles or data to anticipate effects of technological design decisions	

Clarification: Sample Performance Expectations for a Life Science Content Statement

The examples below are all related to the following Grade 8 Life Science content statement:

L8.4: Plants are producers—they use the energy from light to make sugar molecules from the atoms of carbon dioxide and water. Plants use these sugars along with minerals from the soil to form fats, proteins, and carbohydrates. These products can be used immediately, incorporated into the plant's cells as the plant grows, or stored for later use.

All examples are also related to a specific situation:

Two different varieties of grass—one better adapted to full sunlight and one better adapted to shade—are each grown in sunlight and in shade.

The results of a controlled experiment along these lines might resemble the following:

Condition	**Grass Type A**	**Grass Type B**
Sunlight	"Better growth"*	"Less good growth"*
Shade	"Less good growth"*	"Better growth"*

* Several variables could be used to indicate growth: mass or dry mass of plants, thickness of stems, number of new sprouts, etc.

Identifying Science Principles

1. State from where a plant's food originates.
2. Classify the grass plants as producers or consumers.

The first performance calls for students to repeat information found in the content statement with little or no modification. The second performance asks students to use the definition of producers given in the content statement to classify or identify the plants.

Using Science Principles

1. Predict whether sugar will move up or down the stems of the grass plants and explain your prediction.
2. Explain where the mass of the growing grass originates.

These performances require students to use principles in the content statement to predict or explain specific observations (growing grass in this case). The content statement itself does not provide the answers to the questions.

Using Scientific Inquiry

1. Given a data table showing the mass of grass plants of each type grown in the sunlight and shade, draw conclusions about which variety of grass is better adapted to each condition.
2. List other variables that should be controlled in order to feel confident about your conclusions.

The first performance is related to the content statement in that the importance of light for plant growth is useful background information for students. However, the performance requires interpretation of new information (the data table) that has to do with differences among types of plants, while the content statement contains generalizations about all plants. Thus, the performance requires students to use the data to develop new knowledge that they had not had before. The second performance is in part an assessment of the students' understanding of experimental design. However, good answers would also require knowledge of this and related content statements to identify variables that are relevant to plant growth.

Using Technological Design

1. Given experimental results on the growth of different varieties of grass plants under sunlight and shade conditions, develop a plan for using different types of grass seed in different parts of a partially shaded park.

This performance requires students to use knowledge of the content statement and the experimental results in order to accomplish a practical goal, in this case, a park with grass growing well in areas that receive varying amounts of sunlight.

Performance Expectations

The NAEP Science Assessment will focus on how students bring science content (as described in Chapter Two) to bear as they engage in the practices described in this chapter. That is, science practices are not content-free skills; they require knowledge of the Physical, Life, and Earth and Space Sciences as well as knowledge about scientific inquiry and the nature of science (e.g., drawing conclusions from investigations).

Performance expectations are derived from the intersection of content statements and science practices. If the content statements from the Physical, Life, and Earth and Space Sciences are the columns of a table and the practices (Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, Using Technological Design) are the rows, the cells of the table are inhabited by performance expectations. Examples are provided in Table 12, which is based on Figure 1 in Chapter One. Note that performance expectation cells may overlap, since the content and practice categories themselves are not distinct (as indicated by dashed lines).

Table 12. Generating Examples of Grade 8 Performance Expectations

		Science Content		
		Physical Science content statements	**Life Science** content statements	**Earth and Space Science** content statements
Science Practices	**Identifying Science Principles**	Identify the units that might be used to measure the speed of an ant and the speed of an airplane. (See **P8.14**.)[21]	Identify the raw materials that plants use to make sugars. (See **L8.4**.)	Identify wind as the movement of air from higher to lower pressure regions. (See **E8.11**.)
	Using Science Principles	An object (e.g., a toy car) moves with a constant speed along a straight line. Predict (with justification) what might happen to this object's speed as it rolls downhill. (See **P8.16**.)	Explain why sugars are found to move primarily down the stem of a growing plant (e.g., potato, carrot) (See **L8.4**.)	Explain why mountain soils are generally thinner than floodplain soils. (See **E8.6**.)
	Using Scientific Inquiry	Design an experiment to determine how the speed of a battery-operated toy car changes as a result of added mass. (See **P8.16**.)	Criticize conclusions about likely consequences of consuming various diets based on flawed premises or flaws in reasoning. (See **L8.5**.)	Given data (indexed by month) on annual trends of incoming solar radiation for five cities, determine whether the location is in the Northern or Southern Hemisphere. (See **E8.12**.)
	Using Technological Design	Evaluate the following car designs to determine which one is most likely to maintain a constant speed as it goes down a hill. (See **P8.16**.)	Identify possible ecological side effects of agricultural fertilizer runoff into a lake. (See **L8.7**.)	Describe the consequences (e.g., erosion) of undercutting a steep slope for a road cut. (See **E8.4**.)

[21] In order to identify the science content statement on which each performance expectation is based, the content statement's unique code (from Tables 6, 8, and 10 in Chapter Two) is provided.

The content statements from Chapter Two on which these performance expectations are based are written in general terms. The process of creating performance expectations requires further clarification of the content statements themselves. As described in Chapter Two, this involves "detailing" the meanings of the content statements and setting boundaries on the content to be assessed at a given grade level. Moreover, if the crossing of content statements with practices were done for every science content statement and practice, the number of performance expectations generated could be unmanageably large. Selected example performance expectations for a single Earth and Space Science content statement are provided in Table 13. Additional examples are provided in the *Specifications.* These examples are illustrative, not exhaustive. It is expected that assessment developers will continue this process for all content and practices sampled for a particular NAEP Science Assessment.

Performance expectations are written with particular verbs indicating the desired performance expected of the student. The action verbs associated with each practice are not firmly fixed, and the use of any action verb must be contextualized. For example, when the science practice component, "*conduct* scientific investigations," is crossed with a states-of-matter content statement, this can generate a performance expectation that employs a different action verb, "*heats* as a way to evaporate liquids."

Generating and Interpreting Items

Neither the content statements from Chapter Two nor the practices discussed in this chapter will be assessed in isolation. All assessment items will be derived from a combination of the two (i.e., from performance expectations). Observed student responses to these items can then be compared with expected student responses in order to make inferences about what students know and can do. Following is an Earth and Space Science example of the process of generating and interpreting items from performance expectations. The item examples in Table 13 are of two types: *item suggestions* (descriptions of items to be developed) and *illustrative items* (released items from various large-scale assessments). Additional examples of the process of generating and interpreting items are provided in the *Specifications.*

Table 13. Earth and Space Science Example of Generating and Interpreting Items

Grade 8: Earth in Space and Time—Objects in the Universe
Content Statement **E8.2:** Gravity is the force that keeps most objects in the solar system in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.
Commentary This content statement encompasses two interrelated sets of concepts: 1. Gravity acts between and among all objects in the solar system, and it plays an essential role in the regular and predictable motions of planets around the sun and satellites around planets. • On Earth, gravity is experienced as a force that pulls everything "down" towards the center of the Earth. (A common naïve conception is that the atmosphere "pushing" things down causes gravity.) • Gravity is a force of attraction that is exerted by every object on every other object. • Gravity exists in space and on other planets. (A common naïve conception among students is that there is no gravity in space because space has no air.) • The almost circular motion of planets and satellites results from the force of gravity and the tendency of a body to continue moving through space in a straight line unless acted upon by a net force. 2. The regular and predictable motions of the Earth, the sun, and the moon cause the cyclic phenomena that can be observed in the sky. • The day-night cycle results from Earth's rotation on its axis once in 24 hours. • Annual changes in the visible constellations and the seasons result from Earth's revolution around the sun once every 365-1/4 days. • Moon phases result from the moon's orbit around the Earth about once a month, which changes what part of the moon is lighted by the sun and how much of the lighted part can be seen from Earth. Note connection between this content statement and the Physical Science subtopic, "Forces Affecting Motion." Students are not expected to use the inverse square relationship of gravitational force and distance to find the strength of the gravitational force between two objects. Students need not know that the motion of planets and satellites is elliptical and not circular.
Examples of Performance Expectations Identifying Science Principles. Students can: • Identify gravity as the force exerted by every object in the solar system on every other object. • Identify gravity as the force that keeps the moon circling Earth, rather than flying off into space. • Describe the regular motions of Earth through space, including its daily rotation on its axis, and its yearly motion around the sun.

Examples of Performance Expectations (cont.)

Using Science Principles. Students can:

- Explain that the orbit of one object around another is due to the tendency of an object to move in a straight line through space and the force of gravity between the two objects.
- Explain how the monthly pattern of moon phases observed from a point on Earth results from the moon's orbit around Earth, which changes what part of the moon is lighted by the sun and what portion of the lighted part can be seen from Earth.
- Distinguish between explanations for lunar (moon) phases and lunar eclipses.
- Explain that astronauts and other objects in orbit seem to "float" because they are in free fall, under the influence of gravity.

Using Scientific Inquiry. Students can:

- Arrange a set of photographs of the moon taken over a month's time in chronological order and explain the order in terms of a model of the Earth-sun-moon system.
- Design a plan for observing the sun over a year's time to find out how the length of the day is related to the rising and setting point of the sun on the horizon.
- Design a series of observations or measurements to determine why some objects—such as certain asteroids or comets—visit the solar system just once, never to return.

Using Technological Design. Students can:

- Choose among several (qualitative) methods for aiming a rocket so that it reaches the planet Mars and give a rationale that shows understanding of orbital motion.
- Use scientific trade-offs in deciding whether or not to support a plan to observe and predict orbits of asteroids that enter the inner solar system.
- Given a scenario in which a person is shipwrecked on an island in the ocean, critique plans to create a calendar to keep track of the passage of time.

Items to Assess Identifying Science Principles

Illustrative Item 1

What force keeps the planets in our solar system in orbit around the Sun?

A. gravitational
B. magnetic
C. electrical
D. nuclear

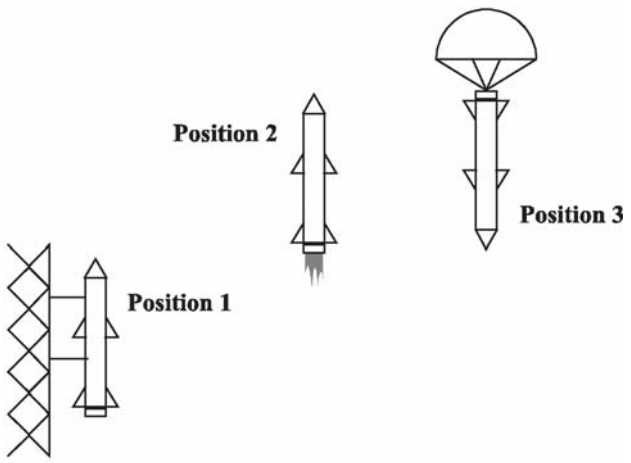
Key: A
Source: Adapted from Massachusetts Department of Education, Massachusetts Comprehensive Assessment System (MCAS), 2000, Grade 8[22]

[22] MCAS materials appearing in the *Framework* have been released to the public by the Massachusetts Department of Education and is available at no cost on the Department's website at http://www.doe.mass.edu/mcas/testitems.html

Items to Assess Identifying Science Principles (cont.)

Illustrative Item 2

The drawings show a rocket being launched from Earth and returning.



In which of these positions does gravity act on the rocket?

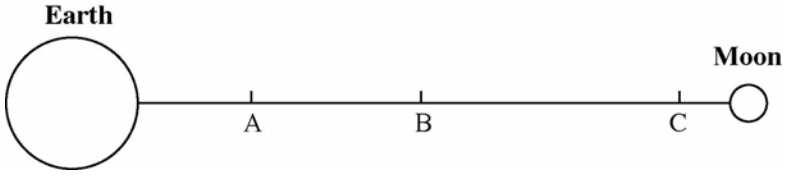
A. 3 only
B. 1 and 2 only
C. 2 and 3 only
D. 1, 2, and 3

Key: D
Source: TIMSS 1999, Grade 8

Items to Assess Using Science Principles

Illustrative Item

A space station is to be located between the Earth and the Moon at the place where the Earth's gravitational pull is equal to the Moon's gravitational pull.
On the diagram below, circle the letter indicating the approximate location of the space station.



Explain your answer.

Source: NAEP 1996, Grade 8

Items to Assess Using Science Principles (cont.)

Interpretation: The correct answer is C. Since the moon has 1/6 the amount of gravity as Earth, a body that experiences an equal gravitational force from Earth and the moon should be closer to the moon. Point C is the only point that is closer to the moon. Note: Point C is about 1/12 of the way between the moon and Earth; it should be 1/6 of the distance. (See Appendix D for the item scoring guide.)

Item Suggestion

Is there gravity in space? Which of the following gives the best response to this question?

A. No. You can see that astronauts float around weightless in their cabin.
B. No. There is no air in space, so gravity cannot exist there.
C. Yes. There must be gravity since planets keep circling the sun.
D. Some. The moon has one-sixth as much gravity as Earth, so we know there is some gravity in space.

Key: C

Interpretation: The correct answer is C. This question is drawn from a series of studies that show a common naïve conception—that there is no gravity in space because space has no air. The distractors are drawn from student interviews. It is likely that these naïve conceptions stem from images that students have seen of astronauts floating around in a "weightless" environment while in orbit. This item probes "schematic knowledge"—see "Cognitive Demands" section later in this chapter.

Item to Assess Using Scientific Inquiry

Item Suggestion

A student is presented with a set of photographs of the moon taken over a month's time. The photos are not presented in chronological order. The student is asked to arrange them in the order in which they were taken and explain the reason for moon phases.

Interpretation: This suggestion reflects items used frequently in curricular materials (e.g., Schatz & Cooper, 1994). Students are asked to find patterns in the data. First, they should be sufficiently familiar with the lunar cycle to arrange the photographs in order, either in a line to represent a chronology or in a circle to represent a cycle (tapping "declarative knowledge" and "procedural knowledge" to a lesser extent—see "Cognitive Demands" section later in this chapter). Then, students should be able to explain moon phases in terms of the moon circling Earth and the changing angle between the sun and moon as observed from Earth. This part of the item probes "schematic knowledge"—see "Cognitive Demands" section later in this chapter. This is a challenging question that many educated adults fail. However, studies show that middle school students can learn to do this by observing lunar phases and explaining them using a model of the Earth-sun-moon system (Barnett & Morran, 2002; Kavanagh, Agan, & Sneider, 2005).

Items to Assess Using Technological Design

Item Suggestion 1

NASA wants to launch a spacecraft with rockets from Earth so that it will reach and orbit Mars. Which of the following statements about this flight is WRONG?

A. In the first phase of its flight, the forces acting on the spacecraft are the thrust of the rocket engine, gravity, and friction from the Earth's atmosphere.
B. When the rocket engine shuts off, the only force acting on the spacecraft is the force of gravity.
C. Once the spacecraft is above the Earth's atmosphere and the rocket engine is off, it will travel at a constant speed since there is no gravity in space.
D. If the spacecraft is aimed correctly and has the proper speed, the spacecraft will reach Mars and require only engine braking to attain orbit.

Key: C

Interpretation: The correct answer is C, since there is gravity in space and planning for such a rocket flight would need to take into account the gravity from Earth, Mars, and the sun ("declarative knowledge"—see "Cognitive Demands" section later in this chapter). This question is drawn from a series of studies that show that the following naïve conceptions about gravity are common among many students at the middle school, high school, and even college levels: If a body is moving, there is a force acting on it in the direction of motion (Finegold & Gorsky, 1991; Gunstone & Watts, 1985; Sequeira & Leite, 1991); there is no gravity in space (Bar, Zinn, Goldmuntz, & Sneider, 1994; Chandler, 1991; Morrison, 1999); and gravity cannot act in space because there is no air in space (Bar & Zinn, 1998). One study showed that, with effective instruction, middle school students can overcome these naïve conceptions and learn that gravity does, in fact, act in space, where it keeps satellites and planets in their orbits (Bar, Sneider, & Martimbeau, 1997).

Item Suggestion 2

Decisions about whether or not to develop new technologies always concern trade-offs. For example, most scientists today believe that the extinction of the dinosaurs and many other species was caused by the collision of a large asteroid with Earth 65 million years ago. As a result, there is a proposal to develop two new technologies: (1) the detection and tracking of all asteroids large enough to do considerable damage if they should strike Earth, and (2) the development of means of sending a spacecraft to meet the asteroid in space and change its path. Write a paragraph describing:

a. whether or not you think it would be possible to develop these technologies based on your knowledge of science; and
b. some of the scientific trade-offs that should be considered in deciding whether or not to develop these new technologies.

Interpretation: Look for evidence that the students understand what asteroids are, that scientists have observed asteroids, and that observations taken at several points in time allow for the prediction of an asteroid's path. Also look for evidence that students understand that spacecraft can be built, launched, and navigated to intercept solar system bodies. (In fact, several spacecraft have intercepted asteroids and comets.) Regarding scientific trade-offs, look for evidence that students recognize the advantages of the proposed technologies (e.g., avoid a catastrophic collision in which billions of people and animals could die) as well as possible negative effects (e.g., break-up of the asteroid so there are many collisions rather than one, accidents on launch).

Learning Progressions

A learning progression is a sequence of successively more complex ways of reasoning about a set of ideas. For any important set of ideas in science, understanding increases over time as students learn more and more, moving from initially naïve knowledge of the natural world to increasingly more sophisticated knowledge and conceptual understanding; and this typically occurs in conjunction with educational experiences in and out of school (NRC, 2001). In other words, the progression from novice learner to competent learner to expert begins with the acquisition of relevant experiences, principles, concepts, facts, and skills and moves to the accumulation and organization of knowledge in a specific domain and finally to expertise *after extensive experience and practice* (e.g., Ericsson, 2002). The attention paid to growth of understanding may yield rich information about student progress.

Research has been conducted on students' learning progressions in some areas of science and at some levels of students' development. It is expected that this research will directly inform the development of assessment items at grades 4, 8, and 12. For example, the National Research Council (NRC) has commissioned papers on learning progressions in evolution (Catley, Lehrer, & Reiser, 2005) and in atomic molecular theory (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004). Learning progressions provide opportunities for assessing specific content in greater depth.

Several caveats about learning progressions are in order. First, learning progressions are not developmentally inevitable but depend upon instruction interacting with the student's prior knowledge and construction of new knowledge. Thus, learning progressions will need to invoke assumptions about instruction. Second, there is no single "correct order." There may be multiple pathways by which certain understandings can be reached. Which pathway is taken may be influenced by prior instructional experiences, individual differences, and current instruction (NRC, 1999c, 2001). Thus, learning progressions will necessarily be complex, involving multiple specific paths at the micro level, and will need to be described in ways that encompass such diversity. Third, actual learning is more like ecological succession with changes taking place simultaneously in multiple interconnected ways. Thus, attempts to describe specific sequences of learning performances, including those in the Catley et al. (2005) and Smith et al. (2004) papers, must inevitably be artificially constrained and ordered. Finally, the learning progressions suggested in the *Framework* and *Specifications* are partly hypothetical or inferential, since long-term longitudinal accounts of learning by individual students do not exist.

Table 14 uses a set of related science content statements across grades 4, 8, and 12 and follows the format of the science practices defined in the *Framework.* It illustrates how relevant research (e.g., Smith et al., 2004) can be used as an opportunity to assess content in greater depth—available research on student learning is used to inform the generation of related performance expectations across grades. The table includes examples of performance expectations for a possible learning progression for States of Matter. These *illustrative* performance expectations are not intended to denote a sense of content

priority or importance, nor should they be interpreted as a complete representation of the research currently available.

Table 14. Examples of Performance Expectations for States of Matter

Grade 4 (See content statement P4.3.)	**Grade 8** (See content statement P8.1.)	**Grade 12** (See content statement P12.1.)
Identifying Science Principles Classify samples of material as solid, liquid, or gas.	**Identifying Science Principles** Given an animation of molecules in motion, identify the substance that is being illustrated as a solid, liquid, or gas.	**Identifying Science Principles** Explain why ice is harder than liquid water in terms of the strength of the force between the molecules.
Using Science Principles Infer that a change of state (e.g., freezing or melting) affects the identity of an object, but not the identity of the material of which it is made.	**Using Science Principles** Predict how the mass of a sample of iodine will change after sublimation. Justify the prediction based on what occurs during sublimation at a molecular level.	**Using Science Principles** Use the concept of molecular arrangements and bonds to explain why graphite is very soft and diamond is very hard, even though they are both made of pure carbon.
Using Scientific Inquiry Collect, display, and interpret data showing how the temperature of a substance changes over time as it cools and becomes a solid.	**Using Scientific Inquiry** Plan and conduct an investigation to determine the melting point and boiling point of an unknown substance.	**Using Scientific Inquiry** Using molecular theory, explain the results of experiments showing how the volume of three different liquids changes when they are heated.
Using Technological Design Propose a method for determining for certain whether holiday chocolates that have been shaped by different processes (melting, freezing, reshaping, or breaking into pieces) have the same amount of chocolate in them.	**Using Technological Design** Choose the best solution for increasing the altitude of a hot air balloon, based on an understanding of the macroscopic and microscopic changes that occur when the gas inside the balloon is heated.	**Using Technological Design** Design an instrument to measure temperature as accurately as possible, taking into account both the thermal properties of liquids and solids to be used in the device, and structural shape and dimensions of the device.

Cognitive Demands

The four science practices—Identifying Science Principles; Using Science Principles; Using Scientific Inquiry; and Using Technological Design—articulate what students should know and be able to do with the science principles presented in Chapter Two. Certain ways of knowing and reasoning—cognitive demands—underpin these four science practices. Here, the four cognitive demands—"knowing that," "knowing how," "knowing why," and "knowing when and where to apply knowledge"—are discussed briefly (see *Specifications* for more detail). The goal is to further elucidate the descriptions of the science practices, to facilitate item specifications and item writing, and to provide a framework for interpreting students' responses. That is, the set of four

cognitive demands can be used as a lens to facilitate item development and to analyze student responses (Li & Shavelson, 2001; Shavelson, 2006; Shavelson, Ruiz-Primo, & Wiley, 2005), thereby checking expectations regarding what science content and practice(s) are being tapped by a given assessment item.[23]

"Knowing that" refers to "declarative knowledge." This cognitive demand sets up the expectation that students should know and reason with basic science facts, concepts, and principles (e.g., density is mass per unit volume) and that they should be able to recall, define, represent, use, and relate these basic principles as appropriate. This cognitive demand corresponds most closely to the science practice, Identifying Science Principles.

"Knowing how" refers to "procedural knowledge." This cognitive demand sets up the expectation that students can apply the science facts, concepts, and principles in doing science. For example, students should know how to perform simple (routine) and complex procedures such as systematically observing and recording which objects sink and float in water, using a balance scale, measuring an object's mass, calculating an object's density, and designing and interpreting the results of an investigation (e.g., manipulating one variable and holding others constant). "Procedural knowledge" underlies much of the science practice of Using Scientific Inquiry as defined in this *Framework.*

"Knowing why" refers to "schematic knowledge." This cognitive demand sets up the expectation that students can explain and predict natural phenomena, as well as account for how and why scientific claims are evaluated, argued and justified, or warranted (explaining and reasoning with principles and models). That is, this cognitive demand deals with students' understanding of how the natural world works, such as why some things sink and others float in water, why light is essential to the propagation of most plants, or why the moon changes phases. This cognitive demand overlaps considerably with the science understanding expected in Using Science Principles and also with Using Scientific Inquiry and Using Technological Design.

The last cognitive demand, "knowing when and where to apply knowledge," or "strategic knowledge," is commonly talked about as "transfer" of current knowledge to new situations (tasks or problems). "Strategic knowledge" involves knowing when and where to use science knowledge in a new situation *and* reasoning through the novel task to reach a goal. "Strategic knowledge" sets up the expectation that students can take their current knowledge and apply it to a somewhat novel situation. Such adaptation of knowledge to a particular problem and context underlies especially the practices of Using Scientific Inquiry and Using Technological Design.

The cognitive demands are related, not independent (similar to the science practices). That is, when explaining "why," a student will need to call on "knowing that" and, at times, in justifying "why," may have to call on "knowing how." And, depending on the

[23] More than one cognitive demand can be associated with the more complex science practices. These associations may shift according to the knowledge that students at different grade levels bring to an assessment task.

novelty of the task, “strategic knowledge (knowing when and where to apply knowledge)” may be called into play. Nevertheless, these related cognitive demands can be distinguished, and it is helpful to do so for item development and interpretation of student responses.

CHAPTER FOUR: OVERVIEW OF THE ASSESSMENT DESIGN

Introduction

This chapter provides an overview of the *Specifications*. It begins with a brief description of the 2009 NAEP Science Assessment and a discussion of how items can be set in certain contexts (e.g., history and nature of science) to illustrate components of science content that are not otherwise incorporated in the content statements. The types of items to be included in the assessment are described and examples are provided in *Illustrative Item* textboxes. Answers to selected-response items are indicated within the textbox; scoring guides for constructed-response items are provided in Appendix D. Although items in these textboxes may assess more than one content statement or practice, only the primary content and practice designations are provided. This follows NAEP practice, which uses only primary designations for items in the analysis and reporting of student responses. To capture the wide range of science content statements and practices, the assessment will contain an array of item types. Consideration is given to English language learners and students with disabilities. The chapter concludes with recommendations for small-scale special studies.

Overview of the Science Assessment

The NAEP Science Assessment will include items sampled from the domain of science achievement identified by the intersection of the content areas and science practices (i.e., performance expectations) at grades 4, 8, and 12. The types of items to be used on the assessment include selected-response (multiple-choice) items and constructed-response items (which include short and extended constructed-response items as well as concept-mapping tasks). Some “combination items” may require more than one response. Such combination items include item clusters, Predict-Observe-Explain (POE) item sets, hands-on performance tasks, and interactive computer tasks. The responses requested may be all selected-response, all constructed-response, or a mixture. At each of grades 4, 8, and 12, student assessment time will be divided evenly (50%-50%) between selected-response items and constructed-response items. Extra assessment time will be provided for a portion of the student sample so that hands-on performance tasks and interactive computer tasks can be administered.

At grade 4, the items will be distributed approximately evenly among Physical Science, Life Science, and Earth and Space Science. At grade 8, the balance shifts toward a somewhat greater emphasis on Earth and Space Science, whereas at grade 12, the balance shifts toward the Physical and Life Sciences with a lesser emphasis on Earth and Space Science.

Finally, the distribution of items across the science practices will be approximately 60% combining Identifying Science Principles and Using Science Principles, 30% Using Scientific Inquiry, and 10% Using Technological Design. Moving from grades 4 to 8 to 12, the emphasis on Using Science Principles increases, while the emphasis on

Identifying Science Principles decreases. The expectation is that, as students move up through the grades, their critical response skills and methodological and analytical capabilities will increase.

Assessment Item Contexts

There are certain components of science content, such as the history and nature of science, and the relationship between science and technology, with which science-literate citizens should be familiar. In Chapter Three, the nature of science is largely addressed through a discussion of the science practices (particularly Using Science Principles and Using Scientific Inquiry). The relationship between science and technology is partially addressed in a discussion of the Using Technological Design practice. The history and nature of science not only clarify facets of science practices but also the human aspect of science and the role science has played in various cultures. Students can see that science changes, and new conclusions can be made on the basis of new empirical data (e.g., development of the theory of plate tectonics, use of gaps in early versions of the Periodic Table to "discover" new elements). The reciprocal relationship between science and technology can be seen, for example, in that scientists use technological tools to empirically test proposed explanations for questions about the natural world; and engineers develop adaptations to the natural world to address human problems, needs, and aspirations based in part on science.

When items are written to particular content statements, they may be framed in these contextual components of science content. Aspects of the history and nature of science and the relationship between science and technology should thus be incorporated into the contexts of assessment items as illustrated in the item below.

Illustrative Item[24]

Ernest Rutherford found that when he fired alpha particles at a thin gold foil, some were scattered at large angles. What caused this scattering?

A. The gold's positive atomic nuclei attracted the negatively charged alpha particles.
B. The gold's negative atomic nuclei repelled the negatively charged alpha particles.
C. The gold's negative atomic nuclei attracted the positively charged alpha particles.
D. The gold's positive atomic nuclei repelled the positively charged alpha particles.

Key: D

P12.2, Identifying Science Principles

[24] The *Framework*'s developers created this item for illustrative purposes; it requires further development in that it is not a field-tested or published item.

Types of Items

The judicious selection of items lies at the heart of any effective assessment of science achievement. The Framework for the 1996-2005 NAEP Science Assessments called for three types of items: multiple-choice items (selected-response), open-ended paper-and-pencil items (constructed-response), and performance exercises. Multiple-choice items made up about 40% of the assessment, as measured by student response time, with open-response items comprising about 60% of assessment time. In addition, subsets of the students sampled were given an extra 20 minutes in grade 4 and 30 minutes in grades 8 and 12 to complete hands-on performance tasks. This *Framework* generally follows the 1996-2005 recommendations in item structure but goes beyond by specifying additional item types—some selected-response and others constructed-response. As noted above, the 2009 recommendation for item distribution by item format, in terms of student response time, is 50% selected-response and 50% constructed-response.

Two further considerations are the need to develop items that probe students' ability to use communication skills and quantitative reasoning skills in science (see p. 62). While there is no prescription in this *Framework* about the amount of assessment time to be spent on items that require specific forms of communication or application of mathematics, it is expected that items requiring these skills will be represented at all three grade levels. Further details will be provided in the *Specifications*.

Justification for Variation in Types of Items

Issues of time and cost are paramount in any assessment. Accordingly, most of the item formats on the NAEP Science Assessment will be rather traditional selected-response and short constructed-response. However, some more complex items (e.g., hands-on performance tasks) should be part of any science assessment.

Responses to complex items often correlate positively and cluster with responses to more efficient and simpler items. However, complex items are recommended in the *Framework* for the following reasons:

- Items may correlate positively with one another, but they do not necessarily measure the same thing, that is, positive correlations can arise even when the cognitive demands of the assessment items vary. Research has shown that items vary in their cognitive demands for different kinds of knowledge and reasoning (e.g., Leighton, 2004).
- The NAEP Science Assessment signals the kinds of tasks, problems, and exercises, along with the kinds of knowledge and reasoning, that should be expected of students as a result of what is taught in the science curriculum, consistent with the *National Standards* and *Benchmarks*.

For these reasons, the *Framework* calls for a variety of item types for the 2009 NAEP Science Assessment (see the *Specifications* for further details and explanation).

Definitions of Types of Items

The *Framework* distinguishes selected-response from constructed-response item formats. For selected-response formats, students respond to a question by selecting the answer they believe to be most scientifically justifiable from a given set of alternatives. In contrast, with constructed-response formats, students respond to a question by "generating" or "constructing" a response. The constructed-response might be a single word, a short answer, an essay explanation, a summary of a laboratory investigation using concrete materials, or typed responses to a computer simulation.

In addition to these two main item formats, there are combination items that generally require more than one response. These include item clusters, Predict-Observe-Explain (POE) item sets, hands-on performance tasks, and interactive computer tasks. These combination items can use an all-selected-response format, an all-constructed-response format, or a mixture of these two main item formats.

Following are the main types of items to be used on the 2009 NAEP Science Assessment:

1. Selected-response
    - Individual multiple-choice items
2. Constructed-response
    - Short constructed-response items
    - Extended constructed-response items
    - Concept-mapping tasks
3. Combination items
    - Item clusters
    - Predict-Observe-Explain (POE) item sets
    - Hands-on performance tasks
    - Interactive computer tasks

Item clusters and POE item sets may use selected-response items, constructed-response items, or both. For example, a set of Predict-Observe-Explain items might include a multiple-choice item in which students select a prediction and a short constructed-response item in which students are asked to write a justification for their prediction.

Hands-on performance tasks and interactive computer tasks also may use selected-response items, constructed-response items, or both. In recording their answers, students may be asked to respond to both selected-response and constructed-response items. For example, 12th graders might be asked to manipulate a computer simulation of a chemical reaction; a multiple-choice question could ask students to choose the correct mass of a reaction product; and a short, constructed-response question could ask students to describe how mass is conserved in chemical reactions.

Selected-Response Items

Selected-response items include individual multiple-choice items. Following is a description of these types of items.

Individual Multiple-Choice Items

Selected-response items most often take a multiple-choice format. Students read, reflect, and then select an answer from, say, four alternatives provided. The alternatives include the most scientifically justifiable response—the "answer"—as well as three "distractors." The distractors should appear plausible to students but should not be scientifically justifiable; and, when feasible, the distractors should also draw from current understanding about students' mental models and learning progressions. Whenever possible and especially when the focus is on Using Science Principles or "knowing why (schematic knowledge)," naïve conceptions, explanations, and predictions of the natural or human-made world should serve as distractors.

Of the following two multiple-choice items, both require Identifying Science Principles, and both tap the cognitive demand, "knowing that" (declarative knowledge). The first item taps simple factual content. The second item taps more conceptually sophisticated content. For some students, if they cannot easily recall the science content, this second item may require Using Science Principles (i.e., tapping more of "knowing why" than "knowing that").

Illustrative Item

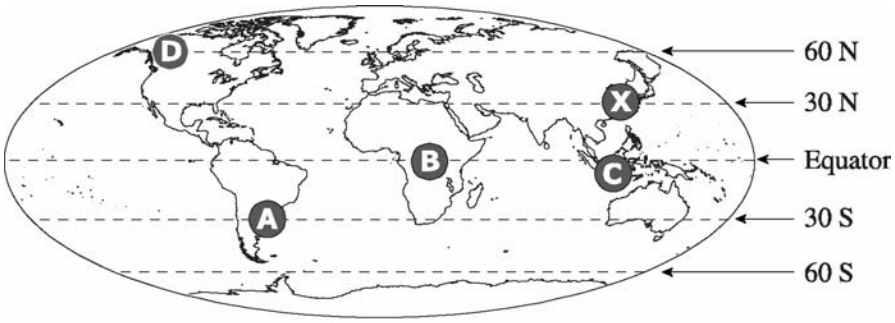
Air is made up of many gases. Which gas is found in the greatest amount?

A. Nitrogen
B. Oxygen
C. Carbon dioxide
D. Hydrogen

Key: A

E8.7, Identifying Science Principles
Source: TIMSS 1995, Grade 8

Illustrative Item



The diagram above shows a map of the world with the lines of latitude marked. Which of the following places marked on the map is most likely to have an average yearly temperature similar to location X ?

A. A
B. B *
C. C
D. D

Key: A

E8.12, Identifying Science Principles
Source: TIMSS 2003, Grade 8

Constructed-Response Items

Constructed-response items include short constructed-response items, extended constructed-response items, and concept-mapping tasks.

Short Constructed-Response Items

This item type generally requires students to supply the correct word, phrase, or quantitative relationship in response to the question given in the item, illustrate with a brief example, or write a concise explanation for a given situation or result. Thus, students must generate the relevant information rather than simply recognize the correct answer from a set of given alternatives, as in selected-response items. The following is an example of a short constructed-response item.

Illustrative Item

On a hot, humid day the air contains a lot of water vapor. What happens to the water vapor in the air when the air becomes very cold?

(See Appendix D for item scoring guides.)

P4.6, Identifying Science Principles
Source: TIMSS 2003, Grade 4

Extended Constructed-Response Items

This item type is generally multi-dimensional; that is, it taps into multiple content statements, practices, and/or cognitive demands. These types of items can provide particularly useful insight into students' level of conceptual understanding and reasoning. They can also be used to probe students' ability to communicate in the sciences. Such items generally present a situation within or across content areas and require students to analyze the situation, choose and carry out an alternative plan for addressing it, and interpret their response in light of the original situation. Students may also be given an opportunity to explain their responses, their reasoning processes, or their approach to a problem situation. However, care must be taken, particularly with 4th graders and English language learners, that language ability is not confounded with science ability.

The following item involves reasoning with "mental models" (on carbon cycling) and thus attempts to probe the practice of Using Science Principles and taps into the cognitive demand of "knowing why."

Illustrative Item

The biosphere (living organisms), the lithosphere (rocks and soils of the Earth's crust), and the atmosphere are all involved in the cycling of carbon atoms. Describe the role that each plays in the carbon cycle.

(See Appendix D for item scoring guides.)

E12.12, Using Science Principles
Source: New Standards Spring Field Test 1999 for High School[25]

Deleted:

[25] The New Standards Spring Field Test 1999 for High School is the property of the University of Pittsburgh and the National Council on Education and the Economy (NCEE) and may not be used, reproduced, or distributed without the express written permission of the University of Pittsburgh and NCEE.

Concept-Mapping Tasks

Concept-mapping tasks may be considered a complex item type because of the cognitive demands placed on students. Concept maps can be used as a reliable and valid assessment of students' ability to make connections among science principles (Ruiz-Primo & Shavelson, 1996a). Thus, concept-mapping tasks tap a science ability that is difficult to measure by other means. These tasks address the practice of Identifying Science Principles and the cognitive demand of "declarative knowledge," in particular the organization of this knowledge.

In a concept-mapping task, students should be given a set of six to eight concept terms and be asked to construct a map linking pairs of terms with directed arrows. Students should label each arrow with a word or phrase that explains the relationship between a pair of concept terms. An arrow-linked pair of concept terms is called a proposition. Students' concept maps can be evaluated as to the accuracy of propositions in their maps. The following textbox provides an illustrative set of instructions for a concept-mapping task and a sample student response. See the *Specifications* for detail about scoring concept maps.

Illustrative Item

Once they are familiar with how to construct concept maps, students might encounter a set of task instructions that resemble the following (adapted from Ruiz-Primo, Shavelson, et al., 2001, p. 107):

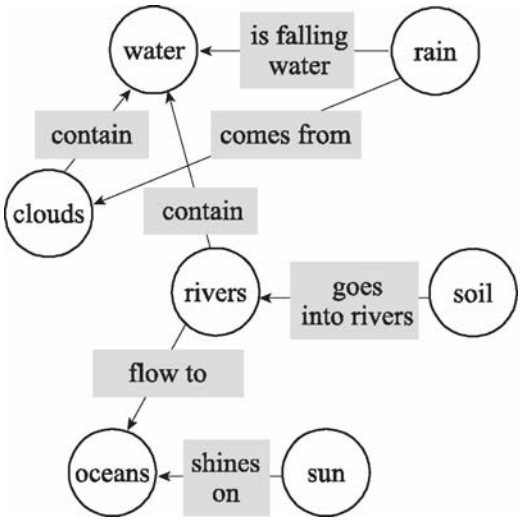
Examine the concept terms listed below. The terms selected focus on the topic, [insert topic].

Construct a concept map using the terms provided below. Organize the terms in relation to one another in any way you want. Draw an arrow between the terms you think are related. Label the arrow using phrases or only one or two linking words.

You can construct your map on the blank pages attached. When you finish your map, check that (1) all the lines have an arrow; (2) all the arrows have labels; (3) your concept map uses all the terms provided; and (4) your map shows what you know about [insert topic].

List of terms: [insert list of terms]

An eleven-year old student constructed the following concept map using terms associated with the water cycle:



E8.11, Identifying Science Principles
Source: White and Gunstone (1992, p. 16)

Combination Items

Combination items include item clusters, Predict-Observe-Explain item sets, hands-on performance tasks, and interactive computer tasks. Combination items may consist of an all selected-response format, an all constructed-response format, or a mixture.

Item Clusters

The NAEP Science Assessment should include item clusters, and their development should be guided by current research on different forms of these items. In this type of item set, two or more items focus on an important idea or "mental model." Hence, these items tap the practice of Using Science Principles and the cognitive demand of "knowing why." Where there is a rigorous body of research available on students' conceptions (as there is about the solar system), item clusters provide opportunities to assess students' understanding of a particular key science principle at some depth. This type of item set can probe the conceptions and "mental models" that underlie students' explanations of and reasoning about the natural world. For example, the following were part of a set of cluster selected-response items probing high school students' mental models in astronomy (percentages of student responses to each option are given in parentheses):

Illustrative Items

What causes day and night?

A. The earth spins on its axis. (66%)
B. The earth moves around the sun. (26%)
C. Clouds block out the sun's light. (0%)
D. The earth moves into and out of the sun's shadow. (3%)
E. The sun goes around the earth. (4%)

Key: A

E8.2, Using Science Principles

The main reason for its being hotter in summer than in winter is:

A. The earth's distance from the sun changes. (45%)
B. The sun is higher in the sky. (12%)
C. The distance between the northern hemisphere and the sun changes. (36%)
D. Ocean currents carry warm water north. (3%)
E. An increase occurs in "greenhouse" gases. (3%)

Key: B

E8.12, Using Science Principles
Source: Sadler (1998, pp. 274-276)

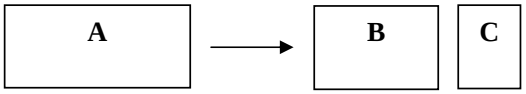
Another approach to probing students' conceptions of the natural world is to develop a cluster of ordered multiple-choice items. These items track students' performance along a learning progression from naïve understandings through more reasoned naïve conceptions to full and scientifically justified understandings. In this approach, the progression is first described and then divided into levels so that multiple-choice items can be designed specifically to assess the performance level that a student (or group of students) has reached. As noted earlier, constructed-response formats are not precluded for use in item clusters.

Predict-Observe-Explain (POE) Item Sets

These types of items ask the student to predict, observe, and/or explain as follows: A situation is described, and the student's task is to provide a prediction for what will happen (sometimes with justification), and/or to provide an explanation for what appears to be an anomaly. POE items tend to tap the practice of Using Science Principles and the cognitive demand of "knowing why" (schematic knowledge). For example, the following POE item was used with middle school students and focuses on prediction based on a mental model of buoyancy:

Illustrative Item[26]

Rich cut block A into two unequal parts. Part B is 2/3 of the original block A, and part C is 1/3 of the original block A. Block A sinks in water. What will happen to B and C when placed in water?



A. Both B and C will float.
B. B will sink; C will float.
C. B will subsurface float; C will float.
D. Both B and C will sink.

Key: D

P8.4, Using Science Principles
Source: Adapted from Shavelson (2006) and Shavelson et al. (2005)

As noted earlier, a POE item can take either a selected-response or a constructed-response format. In the selected-response format, students choose from a set of possible alternatives (based on known alternative mental models). In the constructed-response format, the student's task is to write out (with justification) a prediction or an explanation. In the POE selected-response item above, students are asked to *choose among a set of predictions* for whether the 1/3 and 2/3 parts of the block will sink or

[26] This item assumes that the entire block consists of a completely homogeneous material. The possibility that the block is made of heterogeneous material is unlikely to occur to middle school students.

float. They can choose an answer from several alternatives that include naïve conceptions among them. This item could be extended to further probe students' mental models of buoyancy. Students could be asked to justify their answers by selecting from a number of possible explanations, and again, these alternatives could include the correct explanation along with distractor explanations based on naïve conceptions. Or, instead of using a multiple-choice format, students could be told that the full block sinks in water and be asked to *write their prediction* (with justification) as to what will happen when the two parts are placed in water. Or, they could *observe* a simulation or video of what happens to the full block and the two parts and then be asked to *explain* what they have just observed.

Hands-On Performance Tasks

In hands-on performance tasks, students manipulate selected physical objects and try to solve a scientific problem involving the objects. These exercises, if carefully designed, can probe students' abilities to combine their science knowledge with the investigative skills reflective of the nature of science and inquiry. In large-scale assessments such as NAEP, uniform administration must be ensured. In the past, this has been accomplished through the use of standardized performance assessment kits, with each exercise proctored and scored by trained personnel. Special accommodations may be necessary for some students.

A particularly cogent criticism of most hands-on performance tasks administered in large-scale assessments is that, rather than tap into students' ability to inquire into a problem, typical performance assessments instead measure students' ability to follow step-by-step instructions to arrive at the expected answer. Assessment developers are likely to create these recipe-types of exercises since they need to take into account the vast differences in students' science courses and experiences. Given these differences, the absence of structure might produce unanticipated responses that might be problematic for the assessment either at the time the data are collected or when students' performances are scored by raters. Although both the concern for structure to make large-scale assessment manageable and the criticism of highly-structured performance tasks are well taken, there is evidence that valid performance exercises can be designed, developed, administered, and scored without encountering major problems (e.g., Ruiz-Primo & Shavelson, 1996b; Shavelson, Baxter, & Pine, 1991).

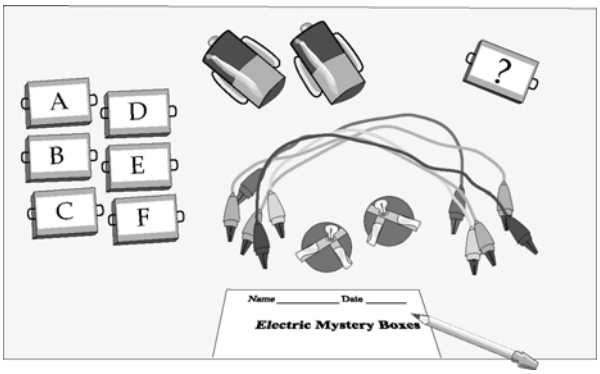
In designing hands-on performance tasks, the following should be kept in mind. The degree to which students engage in some aspect of scientific inquiry depends upon who selects the problem to be studied, who selects the procedures to be carried out in tackling the problem, and who selects the answer. In NAEP, the assessment should provide students with a challenging problem. However, students must be given the opportunity to determine scientifically justifiable procedures for addressing the problem and arriving at a solution. Indeed, the problem to be solved is in setting forth procedures that manipulate the variable of interest, control extraneous variables, and provide solid data to be used in arguing for and justifying a problem solution. In addition to allowing students to determine the procedures for carrying out the experiment, NAEP hands-on performance

tasks should be "content rich," in that they require knowledge of science principles to carry them out.

In brief, any hands-on performance task included in the NAEP assessment should present students with a concrete, well-contextualized task (problem, challenge) along with "laboratory" equipment and materials, and a response format that leaves the exercise process open. Students' scores should be based on both the procedures created for carrying out the investigation and the solution (Shavelson et al., 1991). The assessment, then, should provide the problem that draws on science principles and practices (performance expectation of interest) and leave students free to design and carry out the exercise to arrive at an answer or solution. The following item, designed for 5th graders, is an example of such a task.

Illustrative Item

Students are asked to identify the contents of each of the six boxes (A-F) by using the batteries, bulbs, and wires they are given to complete a circuit. This task requires knowledge of series circuits but leaves problem-solving procedures up to the student. (See Appendix D for further description of this task.)



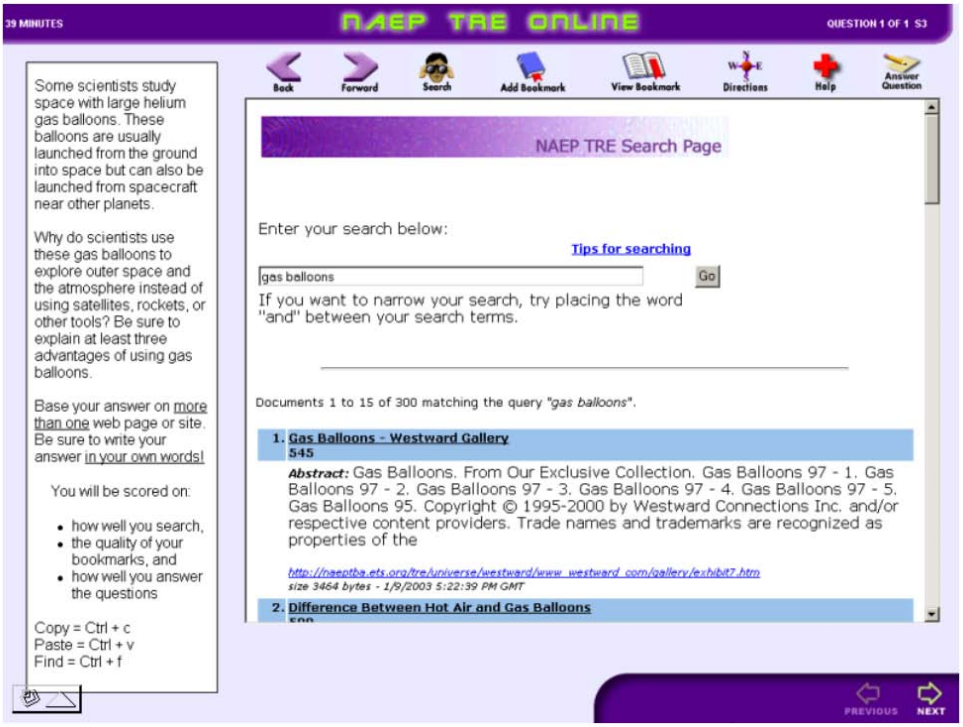
P4.11, Using Scientific Inquiry
Source: Shavelson et al. (1991)

Interactive Computer Tasks

The 2009 NAEP Science Assessment should include some but not necessarily all of the following four types of interactive computer tasks (ICTs): (1) information search and analysis, (2) empirical investigation, (3) simulation, and (4) concept mapping. Static screen shots are used throughout this *Framework* to illustrate examples of ICTs. Note that these screen shots represent only a small subset of the many screens students see when engaged in actual ICTs.

Information search and analysis items pose a scientific problem and ask students to query an information database to bring conceptual and empirical information to bear, through analysis, on the problem. The following is a screen shot from such an ICT developed for 8th graders.

Illustrative Item

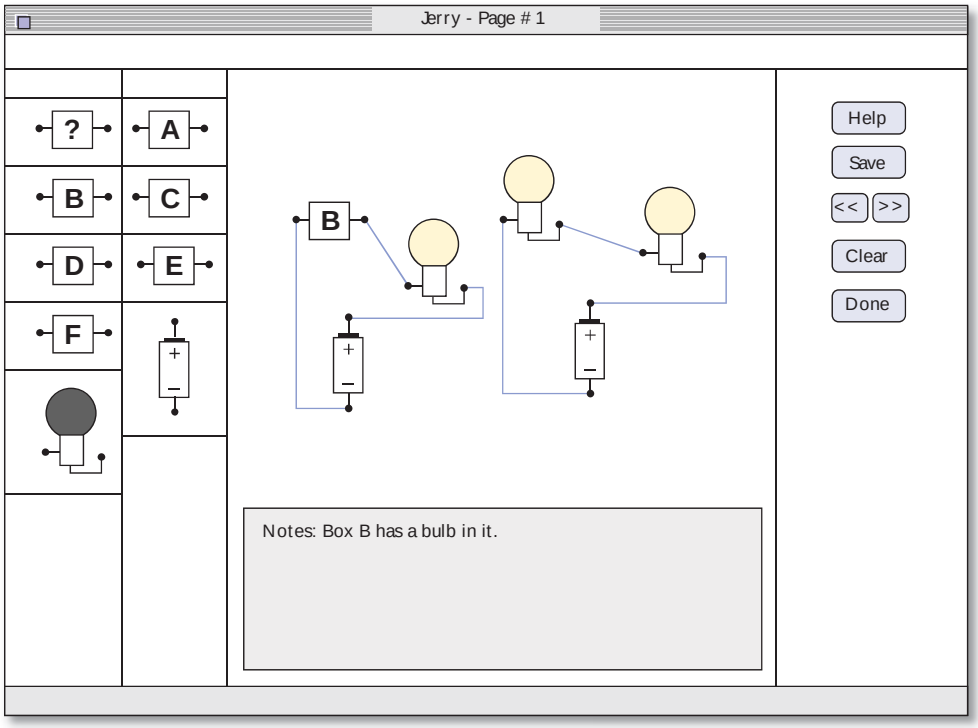


(See Appendix D for further description of this task.)

P8.16, Using Scientific Inquiry
Source: Persky, Bennett, Weiss, and Jenkins (2005)

Empirical investigation items put hands-on performance tasks on the computer and invite students to design and conduct a study to draw inferences and conclusions about a problem. Whether the computer simulated experiment assesses the same skills, knowledge, and understandings as hands-on performance tasks has not been established, and a special study is proposed to address this question (see p. 112). The following is a screen shot from a computer version of the Electric Mysteries task (see p. 102 and Appendix D for further description of this as a hands-on performance task).

Illustrative Item



P4.11, Using Scientific Inquiry
Source: Shavelson et al. (1991, p. 357)

Simulation items model systems (e.g., food webs), pose problems of prediction and explanation about changes in the system, and permit students to collect data and solve problems in the system. The following screen shot comes from such a simulation ICT.

Illustrative Item

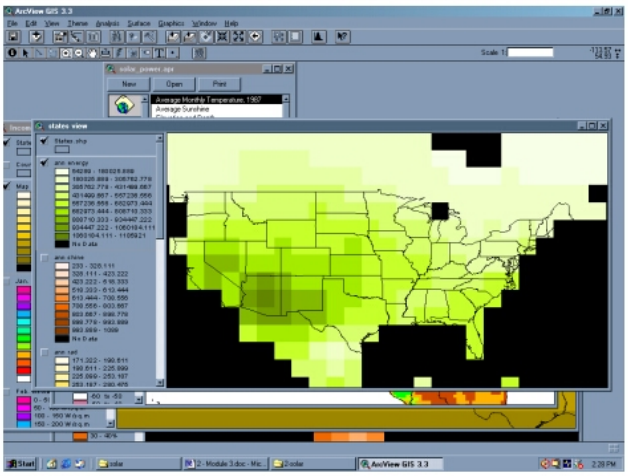
High school (grade 12) students are asked to identify locations appropriate for solar power generation. (See Appendix D for description of the full task.) In order to complete the task, they must:

- Evaluate GIS map visualizations.
- Compare and contrast visualizations of different types of data.
- Use analytical extension to perform computations with visualization data.

Provided below is an example of one of several tasks that a student completes:

Your task is to identify two states that will have a high annual solar energy and will be able to generate the maximum amount of electricity from their solar panels. Name two states that you predict will have a good annual electrical yield. In the rest of this performance assessment, you will generate visualizations and calculate which states will generate the best annual electricity yield from solar panels.

The following screen shot provides an example of a student response:



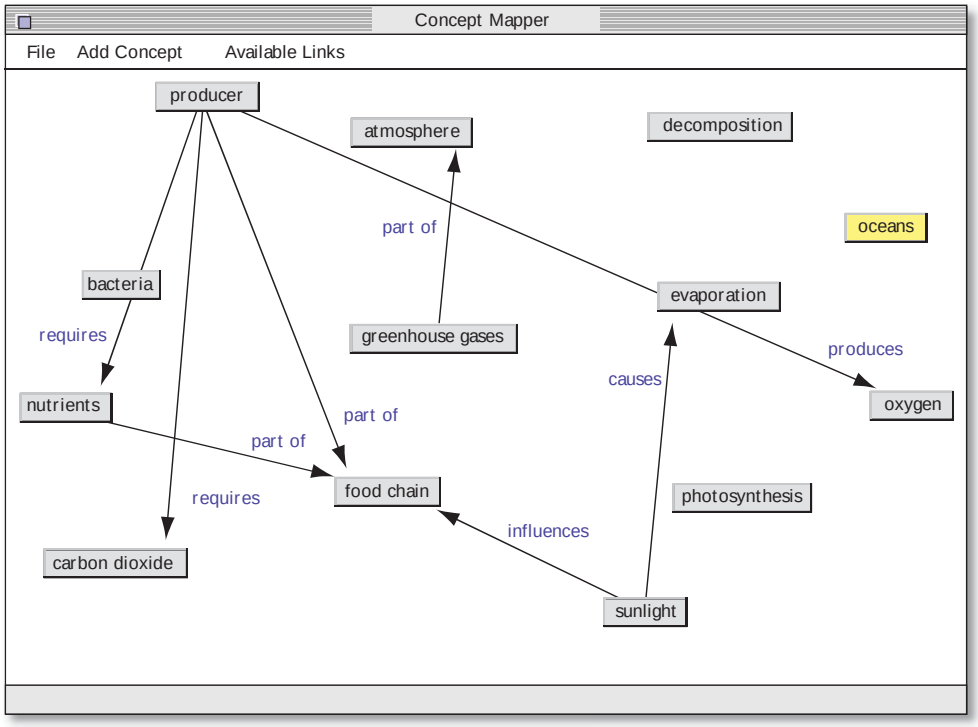
This visualization shows that the states with the most annual solar energy are Arizona and Nevada. This data alone, however, does not completely justify the location of the panels, due to temperature issues.

E12.10, Using Technological Design
Source: Quellmalz et al. (2004)

Finally, concept mapping can be done by providing concept terms and asking students to build propositions on the computer by linking pairs of terms with arrows and words or phrases. The following is a screen shot of a completed concept map.

Illustrative Item

In this task, middle and high school students used a customized software program to create concept maps. Students were given eighteen environmental science terms, as well as seven link labels.[27] Students could drag and drop these concepts onto the grid space of the mapping program and add, erase, and link the items in their newly constructed maps. (See Appendix D for further description of this task.)



L12.5, Identifying Science Principles
Source: Adapted from Herl, O'Neil, Chung, and Schacter (1999)

Computers and other media provide potential solutions to a variety of practical challenges posed by complex assessment exercises. The messiness and logistical challenges of hands-on performance tasks can be circumvented with computer simulation. Extensive databases can be presented to assess students' ability to select and evaluate information relevant to the situation or problem they are asked to address. Moreover, the difficulty of

[27] Link labels should not be provided to students on the 2009 NAEP Science Assessment. See the *Specifications* for details.

providing materials and training for complex tasks such as concept maps can, as well, be circumvented with computers. To avoid cheating and teaching to the concept map, concept terms can be randomly sampled for a particular map (Ruiz-Primo, Schultz, Li, & Shavelson, 2001).

ICTs should be used where the format offers advantages over other assessment modes. To summarize, these include, but are not necessarily limited to, testing student knowledge, skills, and abilities related to the following situations:

- For scientific phenomena that cannot easily be observed in real time such as seeing things in slow-motion (e.g., the motion of a wave) or speeded-up (e.g., erosion caused by a river). It is also useful when it is necessary to freeze action or replay it.
- For modeling scientific phenomena that are invisible to the naked eye (e.g., the movement of molecules in a gas).
- For working safely in lab-like simulations that would otherwise be hazardous (e.g., using dangerous chemicals) or messy in an assessment situation.
- For situations that require several repetitions of an experiment in limited assessment time, while varying the parameters (e.g., rolling a ball down a slope while varying the mass, the angle of inclination, or the coefficient of friction of the surface).
- For searching the Internet and resource documents that provide high-fidelity situations related to the actual world in which such performances are likely to be observed.
- For manipulating objects in a facile manner such as moving concept terms in a concept map.

Extended constructed-response items, concept-mapping tasks, and simulated performance tasks are especially strong candidates for interactive computer tasks. In this way, the complex science understandings and practices that need to be probed in the NAEP Science Assessment might very well be captured with less time, cost, and logistical challenges and with greater opportunity for divergent problem-solving tasks than has been the case in the past.

Distribution of Items

This section suggests appropriate item distributions. The three types of distribution, as measured by percentage of student response time at each grade level, are as follows:

- Items by content area—Physical Science, Life Science, and Earth and Space Science
- Items by science practice—Identifying Science Principles, Using Science Principles, Using Scientific Inquiry, and Using Technological Design
- Items by type—Selected-response items and Constructed-response items

Distribution of Items by Content Area

In the "Overview of the Science Assessment" section of this chapter, the distribution of items at each grade level by the three science content areas, as measured by percentage of student response time, were described as shown in Table 15.

Table 15. Distribution of Items by Content Area and Grade

	Grade 4 (% student response time)	Grade 8 (% student response time)	Grade 12[28] (% student response time)
Physical	33.3	30.0	37.5
Life	33.3	30.0	37.5
Earth and Space	33.3	40.0	25.0

Distribution of Items by Science Practice

The item distribution for the four science practices, as measured by percentage of student response time at each grade level, should have the following approximate allocations:

Table 16. Distribution of Items by Science Practice and Grade

	Grade 4 (% student response time)	Grade 8 (% student response time)	Grade 12 (% student response time)
Identifying Science Principles	30	25	20
Using Science Principles	30	35	40
Using Scientific Inquiry	30	30	30
Using Technological Design	10	10	10

Distribution of Items by Item Type

As measured by student response time, 50% of the assessment items at each grade level should be selected-response items and 50% should be constructed-response items (short constructed-response, extended constructed-response, concept-mapping tasks). Individual selected-response items and individual constructed-response items used within each of the item clusters, POE item sets, hands-on performance tasks, and ICTs should be included to count toward this 50%-50% distribution. If variation from the 50%-50% distribution becomes necessary as items are developed, preference should be given to constructed-response items.

With respect to the combination item types, the NAEP Science Assessment should contain *at least one of each* of the following at each grade level: item clusters, POE item

[28] These recommendations are based on NAEP data regarding students' 12th grade course-taking patterns. If these patterns change materially after 2009, these recommendations should be reconsidered.

sets, hands-on performance tasks, and ICTs. Also, it is highly recommended that, in grades 8 and 12, each assessment include at least one concept-mapping task.

Hands-on performance tasks and interactive computer tasks are administered to a subset of the students sampled. The number of hands-on performance and interactive computer tasks is specified in Table 17.

Table 17. Distribution of Items by Type of Item and Grade

	Grade 4 (# of tasks)	Grade 8 (# of tasks)	Grade 12 (# of tasks)
Hands-On Performance Task (HT)	$\geq$ 1	$\geq$ 1	$\geq$ 1
Interactive Computer Task (ICT)	$\geq$ 1	$\geq$ 1	$\geq$ 1
Total HT + ICT	$\geq$ 4	$\geq$ 4	$\geq$ 4

In any grade, the number of interactive computer tasks (ICTs) should not exceed the number of hands-on performance tasks (HTs). No student will be administered both an ICT and a HT.

Students with Disabilities and English Language Learners

As national and state testing increases, so does the demand that assessment systems include all students—for example, those with disabilities and those learning English—many of whom have not been included in these systems in the past. As NAEP looks to measure the educational progress of students in the nation's classrooms, assessment developers will encounter challenges that require giving deeper thought and consideration to the development of items providing as fair a context as possible for all students.

NAEP should strive to develop science assessments that allow for the participation of the widest possible range of students, so that interpretation of scores of all who participate leads to valid inferences about the levels of their performance, as well as valid comparisons across states and with state assessments. All students should have the opportunity to demonstrate their knowledge of the concepts and ideas that the NAEP Science Assessment is intended to measure.

According to the National Research Council:

> Fairness, like validity, cannot be properly addressed as an afterthought once the test has been developed, administered, and used. It must be confronted throughout the interconnected phases of the testing process, from test design and development to administration, scoring, interpretation, and use (1999b, pp. 80-81).

When assessments are first conceptualized, they need to be thought of in the context of the entire population that will be assessed (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 1999; NRC, 1999a; Thompson, Johnstone, & Thurlow, 2002). NAEP assessments, as well as all large-scale assessments today, need to be responsive to growing demands: increased diversity, increased inclusion of all types of students in the general curriculum, and increased emphasis and commitment to serve and be accountable for *all* students. Assessments need to measure the performance of students with a wide range of abilities and skill repertoires, ensuring that students with diverse learning needs receive opportunities to demonstrate competence on the same content.

Students with disabilities and English language learners each present challenges in how their science competencies can be assessed validly. Nevertheless, there are some commonalities, not the least of which is considerable heterogeneity within each of these groups as to assessment needs. In addition:

- Conceptual frameworks based on appropriate theories of language development and proficiency and of various forms of disabilities will be needed to build inclusive assessments.
- Financial and human resources will be needed over what is usually allocated in order to develop, administer, and interpret performance on relevant tasks.

Two general recommendations address both groups in the context of good assessment design for all students: readability of written text and alignment to content statements.

Students' ability to read and respond to written text often determines successful performance on assessments. Assessment items may pose an unfair disadvantage for some students if there is a heavy burden on reading skills when reading is not the target of the assessment. Language that is both straightforward and concise and that uses everyday words to convey meaning is needed. The goal of ensuring that language has these characteristics is to improve the comprehensibility of written text while preserving the essence of its meaning. The use of language that reduces the linguistic demands placed on students reduces the effect of reading skills and language proficiency on students' science performance and assessment scores. More information on reading level is provided in the *Specifications*.

Items on the NAEP Science Assessment must be aligned to the content statements and science practices with the same depth and breadth of coverage and the same cognitive demands as specified in the *Framework*. The emphasis in assessment design should be on accessibility using different formats, technologies, designs, and accommodations to include as many students as possible. It must be clear from the beginning that, to be equitable, assessments need to measure the achievement of all students on the same content and achievement standards.

To these ends, field tests should sample every type of student expected to participate in the final assessment administration, including students with a wide range of disabilities,

English language learners, and students across racial, ethnic, and socio-economic lines. Field-testing NAEP items with a broad range of students will not only help determine whether items are unclear, misleading, or inaccessible for certain groups of students, but will also help ensure that assessment procedures are accessible to students when the NAEP Science Assessment is fully implemented. Further detail on both recommendations can be found in the *Specifications.*

NAEP strives to assess all students selected by its sampling process. Rigorous criteria are applied to minimize the number of English language learners and students with disabilities excluded from NAEP assessments. Participating students with special needs are permitted to use accommodations, as stated in current NAEP policy:

> All special-needs students may use the same accommodations in NAEP assessments that they use in their usual classroom testing unless the accommodation would make it impossible to measure the ability, skill, or proficiency being assessed, or the accommodation is not possible for the NAEP program to administer (NCES, 2005a, Current Policy section, ¶ 4).

For more detail on NAEP's inclusion policy and permitted accommodations, see the *Specifications.*

Special Studies

Special studies bearing on aspects of the 2009 NAEP Science Assessment are presented in this *Framework*. Each would contribute to a further understanding of science assessment.

Group 1 Special Studies are recommended as having highest priority:

- "Exchangeability" of Hands-on Performance and Interactive Computer Investigations
- Impact of Variation in Item Format and Language Demand on the Performance of English Language Learners and Students with Disabilities
- Computer Adaptive Testing to Assess the Development of Student Understanding of Earth Systems

Group 2 Special Studies are recommended as having lower priority:

- Knowing What Students Know about Technological Design
- Extended Investigations by Students

Note that the order in which studies are listed does *not* imply priority within Group 1 or Group 2. Group 1 Special Studies are presented below, and Group 2 Special Studies are located in Appendix E.

Group 1 Special Studies

"Exchangeability" of Hands-on Performance and Interactive Computer Investigations

Inquiry is at the heart of knowing and doing science. A fundamental aspect of inquiry is the design, conduct, and interpretation of empirical investigations to answer a question or test a hypothesis. While a full assessment of inquiry is not possible on any test that is given on demand, hands-on performance investigations attempt to approximate this aspect of inquiry under time, space, cost, and logistic constraints. For this reason, hands-on performance investigations have been a part of the NAEP Science Assessment since 1996.

These hands-on performance investigations (HI), however, have been criticized as costly, logistically difficult, and too highly structured. On the other hand, interactive computer tasks or, in this case, interactive computer investigations (ICI), are logistically simpler and lower in cost, as well as more open-ended. Consequently, the purpose of this study is to explore whether ICI and HI are exchangeable. The question is *not* whether ICI could replace HI either on NAEP or in the classroom—it should not. Even if these two approaches produce quite similar performances and scores, each affords somewhat different opportunities; simulations are just that and are not exchangeable with actual practice. This is an assessment question: can the cost and logistical challenges of HI be reduced with ICI and *still measure the same competencies as reliably and validly?* Some research suggests that the two methods of assessing student inquiry are, to a fair degree, exchangeable (e.g., Pine, Baxter, & Shavelson, 1993; Rosenquist, Shavelson, & Ruiz-Primo, 2000). Yet, further research is needed on several different investigations to provide a satisfactory answer for large-scale assessment.

Specifically, this study would address the following research questions:

- Does choice of ICI or HI limit the questions that may be asked? Specifically, is there something of value in HI that cannot be asked if the ICI is administered?
- Are scores on HI and ICI equally reliable?
- Are scores on HI and ICI of equal magnitude?
- To what extent does performance on HI predict performance on ICI of the same investigation?
- Do scores on HI and ICI correlate fairly equally with scores on another measure of science inquiry or achievement?
- Are similar thinking processes evoked by HI and ICI?
- Do the answers to these questions depend on individual differences among students, such as gender, English proficiency, race/ethnicity, socio-economic status, and geographic location? (Also of interest is variation in student access to computers, which may be confounded with the other variables listed here.)

Impact of Variation in Item Format and Language Demand on the Performance of English Language Learners and Students with Disabilities

English language learners and students with disabilities do not perform as well on standardized achievement assessments, even accounting for background. Recent studies, for example, have pointed to a systematic relationship between the linguistic complexity of the assessment and the test scores of English language learners (e.g., Abedi, 2003) and students with certain disabilities such as those related to reading and information processing. Science assessments, with their heavy verbal load, may exacerbate performance disparities. In cases where this relationship is demonstrable and test items are high in language complexity, the differences become sources of measurement error and construct irrelevant variance, so that the nature of the assessment item must be addressed. Until this dimension of the assessment item is more clearly understood, any interpretation of the performance of English language learners or students with disabilities on a content assessment is problematic; language proficiency, for example, and science understanding cannot be disentangled.

Preliminary results from several studies of scaffolded science assessments that are designed to minimize language complexity and provide alternative response modalities—including graphic organizers or drawn representations of the concepts—indicate that English language learners and students with disabilities may be able to demonstrate content knowledge at a higher level if a variety of response options are available to them (Dalton, Morocco, Tivnan, & Rawson, 1994; Delgado, 2005). Further research is needed to clarify the relationship between language complexity, scaffolded assessment items, and the performance of English language learners and students with disabilities.

Specifically, this study would address the following research questions:

- Can the language complexity of a content-based assessment be systematically measured?
- Can content-based assessment items be designed to minimize the language demand while conserving the content information obtained?
- If the content-based assessment contains a graphic response modality, do English language learners and students with disabilities demonstrate higher understanding of the content concept being assessed relative to more linguistically demanding response modalities?
- When the content-based assessment with a graphic response option is also computer-based, is there a further benefit in terms of content concept conservation and these students' performance?

Computer Adaptive Testing to Assess the Development of Student Understanding of Earth Systems[29]

A common critique of large-scale assessment is that its necessary reliance on easily-scored, decontextualized, and decomposed items has led to an impoverished range of potential learning activities from which valid and reliable measures might be derived (Resnick & Resnick, 1992). Among attempts to find alternatives have been (a) the Facets approach (Minstrell, 1998), which posits a strong model of "facets" of student knowledge for certain science topic areas and uses coordinated sets of multiple-choice items to hone in on students' particular conceptions and misconceptions and (b) the progress variable approach (Masters, Adams, & Wilson, 1990), which posits a learning progression and uses Item Response Theory to scale students' responses to (typically open-ended) items to estimate in which part of the learning progression students are most likely located.

This special study combines the strengths of each of these approaches to develop a new type of "branching" item that can be used to investigate (a) the more complex types of knowledge structures and (b) complex procedural steps involving contingencies such as those common in inquiry-related contexts, and yet maintain the efficiency of traditional multiple-choice testing. Specifically, the Facets approach will contribute its strong knowledge structure and convenient scoring, and the progress variables approach will contribute the interpretational framework of the learning progression and the flexible statistical modeling available through recent advances in item response modeling (De Boeck & Wilson, 2004). Together, these make possible the utilization of item bundles such as that shown in Figure 3 to provide both the usual result in terms of student ability estimation, as well as potentially more educationally informative results such as the prevalence of particular classes of misconceptions among the student body.

[29] Currently, a number of states are using computerized testing, consisting largely of translating traditional paper-and-pencil items into computer-based delivery systems. The study suggested here, as well as the first study on p. 112, makes more extensive use of the capabilities inherent in computer-based assessments.

Figure 3. Storyboard Showing Item Design for a "Branching" Item Bundle on Ions and Atoms (adapted from Scalise, 2004)

Matter Composition: Ions and Atoms Item Bundle

1. Lead-based paint contains Pb^{2+} ions and lead pipes are made up of Pb atoms
The main difference between Pb^{2+} ion and Pb atom is:
A. They are basically the same. (go to question 2)
B. They have a different number of electrons. (go to question 3)
C. They have a different number of protons (3)
D. They are different but not in the ways described. (go to question 2)
E. I don't know (0)

2. Choose the answer with which you most agree.
Pb^{2+} ion and Pb atom are the same except:
A. Pb^{2+} has ionic bond and Pb has atomic bonds. (3)
B. Pb^{2+} ion and Pb are similar but used differently. (1)
C. Pb^{2+} is a liquid, Pb is a sold. (2)
D. Pb^{2+} requires two Pb atoms. (2)

3. Pick the best answer below:
A. Pb^{2+} has 2 fewer electrons than Pb. (go to question 4)
B. Pb^{2+} has a larger e- density cloud. (3)
C. Pb^{2+} is positively charged so has 2 extra valence electrons. (4)

4. Electrons can be thought of as arranged in shells or orbitals.
Select the ground state electron configuration for carbon:
A. $1s^2 2s^1 2p^3$ (7)
B. $1s^2 2s^2 2p^2$ (go to question 5)
C. $1s^2 2s^2 2p^1$ (6)
D. None of these (5)

5. Certain main group elements exhibit multiple oxidation states, including Group 14 of which carbon is a member. It would seem that a possible oxidation state for carbon is +2, with two electrons available for bonding in half-filled $2p_x$ and $2p_y$ orbitals. Based on valence bond theory, show an electron configuration justifying the formation of four bonds for carbon rather than two and describe the type of orbitals formed. EXPLAIN your answer as fully as possible.
(All respondents who reach this screen will be scored as an 8.
Answers submitted here will be used to build distractors for this question.)

Possible scores and parameters for this item bundle under iota model (assume constraint on cases):

score	0	1	2	3	4	5	6	7	8
# paths	1	1	2	3	1	1	1	1	1
parameters	δ_{71}	δ_{72}	δ_{73}, ι_{731}	$\delta_{74}, \iota_{741}, \iota_{742}$	δ_{75}	δ_{76}	δ_{77}	δ_{78}	δ_{79}

Specifically, this study would address the following research questions:

- Can the "branching" item type be developed and delivered in a logistically efficient way for use in NAEP?
- Can the information from sets of "branching" item bundles be used to provide reliable, valid, and useful information on both student overall ability in science and the classification of students into educationally-useful categories?

The study would focus on a specific Earth system that is of practical and environmental significance such as the biogeochemical carbon cycle. Understanding this system and related environmental issues (e.g., global climate change) requires connected understandings in the Physical, Life, and Earth and Space Sciences, many of which are characterized in the *Framework*. For example, students who understand global warming understand how photosynthesis, cellular respiration, and fossil fuel combustion affect carbon dioxide concentrations in the atmosphere. This connected understanding can be tracked as a learning progression.

APPENDIX A

NAEP SCIENCE STEERING COMMITTEE, PLANNING COMMITTEE, PROJECT STAFF, AND CONTRIBUTING GROUPS

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Contributing Groups

In developing this *Framework*, the National Assessment Governing Board (NAGB) benefited from the extraordinary efforts of hundreds of individuals and organizations across the nation. Although these individuals and organizations provided valuable comments and feedback on draft documents, they were not asked to endorse the final version of this *Framework*. NAGB wishes to acknowledge their contributions by listing them below. While every effort has been made to ensure the accuracy and comprehensiveness of this list, we apologize for any omissions or errors.

External Framework Review Panel

Penny J. Gilmer, Professor of Chemistry & Biochemistry, Florida State University
Eric Pyle, Associate Professor of Geology & Environmental Sciences, James Madison University
Gail Richmond, Associate Professor of Biology & Science Education, Michigan State University

Presentations and/or Feedback Sessions

American Association for the Advancement of Science
- Section Q meeting

Center for Assessment and Evaluation of Student Learning
- Annual conference

Council of Chief State School Officers
- Education Information Management Advisory Consortium (EIMAC)
- National Conference on Large-scale Assessment
- Mega-SCASS Conference

Council of State Science Supervisors
- Thirteen regional feedback meetings with at least 368 total participants representing 44 states, DC, the U.S. Department of Education, and the Department of Defense
- National feedback meeting
- Annual meeting

InterAcademy Panel (I.A.P.)
- Workshop on the Evaluation of Inquiry-Based Science Education Programs

NAEP State Coordinators and State Science Supervisors
- Three online WebEx sessions
- Poll on technological design

National Research Council
- Board on Science Education
- Committee on Science Learning K-8

National Science Teachers Association
- National and regional conventions
- Online survey with 1,769 total responses, representing all 50 states and DC

Smithsonian Institution
- Presentation to education staff

Triangle Coalition for Science and Technology Education
- Annual conference

U.S.-China Education Leaders Forum on Math and Science Education

Testimony at NAGB Public Hearing, October 2005, Washington, DC

Achieve (represented by Jean Slattery)
American Association for the Advancement of Science (represented by Alan Leshner)
Intel Foundation (represented by Wendy Hawkins)
International Technology Education Association (represented by Kendall Starkweather)
Museum of Science, Boston (represented by Patti Curtis)
National Academy of Engineering (represented by William Wulf)
National Science Teachers Association (represented by Gerald Wheeler)
Thomas B. Fordham Foundation (represented by Michael Petrilli)

NAGB Invitational Science and Industry Discussion Forum, May 2005, Atlanta, GA

Lela Blackburn, Atlanta Public Schools
Pete Briggs, Scientific Atlanta
Robert DeHaan, Emory University
Victor De Jesus, Georgia Tech Research Institute
Maynard Hammond, Scientific Atlanta
Stewart Holm, Georgia Pacific
Lamar May, Lockheed Martin (retired)
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Chris Miller, Cytec Surface Specialties
Bob Moore, Southern Regional Education Board
Paul Ohme, CEISMC
Rick Paulus, EMS Technologies
Randy Rowe, GE Energy
Ken Stefanini, Georgia Power
Marion Usselman, CEISMC
Donna Whiting, CEISMC

In addition, NAGB received feedback on the draft *Framework* via hundreds of individual letters and e-mails. The authors of these letters and e-mails included scientists; teachers; university administrators and professors; education researchers; curriculum developers; assessment and measurement specialists; as well as representatives from science industry, museums and science centers, community interest groups, professional organizations, and government agencies at the federal, state, and district levels.

APPENDIX B

STEERING COMMITTEE GUIDELINES

The *Framework* is Informed by the *National Standards* and *Benchmarks*.

The *Framework* should reflect the nation's best thinking in science instruction and thus be guided by two national documents: *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993). Both of these documents were subject to extensive internal and external reviews during their development.

Informed by the *National Standards* and *Benchmarks*, the *Framework* should emphasize knowledge and use of science concepts, appropriate linking of science facts to concepts, relationships among concepts, and major themes unifying the sciences. The *Framework* should also incorporate investigative skills.

The *Framework* Reflects the Nature and Practice of Science.

The *National Standards* and *Benchmarks* include standards addressing science as inquiry, nature of science, history of science, and the designed world. The *Framework* should emphasize the importance of these aspects of science education and should include the expectation that students will understand the nature and practice of science. Science is a self-correcting process, a way of knowing where theories are continually modified and refined based on new research findings. Students should demonstrate the ability to accomplish the following:

- Make warranted inferences from evidence
- Use evidence to justify conclusions based on scientific investigations
- Demonstrate reasoning skills in the application of science content and in understanding the connections between science concepts
- Exercise skepticism when evaluating, using, and discarding data
- Understand and use models to describe and do science
- Apply content knowledge and skills to solve problems as they occur in the natural world
- Understand and apply knowledge of links and commonalities of science across fields

The scientific disciplines are no longer practiced in isolation, and research that cuts across discipline boundaries is common. The *Framework* should

- Identify some of the science concepts and skills that cut across the assessed content areas;
- Address science in both the natural and designed world; and
- Clearly define and identify commonalities and differences between "science" and "technology" or "technological design."

The *Framework* should also address social and historical contexts, which are keys to understanding how the scientific community has arrived at its current body of knowledge.

The *Framework* Incorporates Key Attributes of Effective Assessment.

The *Framework* should use assessment formats that are consistent with the objectives being assessed. It should be guided by the best available research on assessment item design and delivery.

The *Framework* should be inclusive of student diversity as reflected in gender, geographic location, language proficiency, race/ethnicity, socio-economic status, and disability condition. The assessment should be designed and written to be accessible by the majority of students and to minimize the need for special accommodations for both students with disabilities and English language learners. Students with special needs should be provided accommodations to allow them to participate in the assessment.

The *Framework* should reflect knowledge about the acquisition of key science concepts over time, based on research about how students learn. The existing research findings should make clear, when possible, what the progression of science knowledge looks like across the grade levels. Concepts should be represented in a manner that reflects how students progress through a discipline and across disciplines. Assessment items should reflect students' potential for applying concepts and more varied and complex situations over time.

Critical content and skills should be articulated and assessed across grades 4, 8, and 12 (vertically), as well as across the fields of science (horizontally), by creating items that are deliberately layered to achieve these goals. An example of measuring similar constructs within and across subjects is the progression of increasingly sophisticated understanding about energy from elementary to middle to high school in the content areas of biology, chemistry, Earth science, and physics.

A variety of assessment formats should continue to be used in the NAEP assessment, including well-constructed multiple-choice and open-ended items as well as performance tasks. In addition, multiple methods of assessment delivery should be considered, including the appropriate uses of digital-based technology. The *Framework* should consider use of digital delivery systems for the assessment including Web-based or CD-ROM formats. The use of embedded simulations that can represent scientific phenomena such as data, representations, and factors captured within laboratory experiments and use of an adaptively designed series of assessment items should also be considered. Advances in machine scoring of text should provide the opportunity for increased use of open-response format questions. The assessment format and delivery system employed should offer accessibility to the widest range of students.

Each achievement level—Basic, Proficient, and Advanced—should include a range of items assessing various levels of cognitive knowledge that is broad enough to ensure each is measured with the same degree of accuracy. Descriptions of Basic, Proficient, and Advanced must be as clear as possible.

The Assessment Provides Data for Research.

NAEP assessment results are increasingly being used to review state student assessments and compare student achievement across states. The *Framework* should address the important uses of assessment data both to conduct research to better understand science learning and to improve science achievement. Data from the assessment should be collected in such a way as to provide information that accomplishes the following:

- Supplies details of the attributes (e.g., race/ethnicity, gender) of the students being assessed;
- Provides results by student gender, race/ethnicity, and socio-economic level;
- Describes the academic preparation of the teachers of the students being assessed;
- Describes the nature of the educational system of the students being assessed;
- Relates the instructional delivery and materials, professional development of the teachers, and the learning environment to the results from assessment; and
- Provides feedback to educators for improving science instruction and learning.

The *Specifications* Document is Closely Aligned with the *Framework*.

The connections among the *Framework*, the *Specifications*, and the assessment items themselves, should be transparent, have a consistent level of specificity, and be coherent.

The *Specifications* should be written with consistent detail across all fields, domains, and expectations of the *Framework*:

- The *Specifications* should have a consistent structure across all areas.
- The expected science knowledge that represents the target for assessment should be described in a clear and consistent format. The content addressed in the *Specifications* should reflect the standards and focus on the significant information and knowledge that students should retain (e.g., big ideas, fundamental understandings) over time.
- The verbs used in the *Specifications* should describe the expected action to be taken in the assessment (e.g., identify, describe, evaluate, relate, analyze, demonstrate).
- Expectations across the content areas should match in level of specificity and scope.
- The *Specifications* should follow the idea of learning trajectories. To assess overarching concepts or themes, the assessment specifications should reflect a scaffolded or layered understanding of growth in knowledge of the concepts.

APPENDIX C

NAEP SCIENCE
PRELIMINARY ACHIEVEMENT LEVEL DESCRIPTIONS

NAEP Science Preliminary Achievement Level Descriptions

Congress authorized the National Assessment Governing Board to develop appropriate student achievement levels on the National Assessment of Educational Progress (NAEP). The achievement level descriptions are statements of what students should know and be able to do on NAEP at grades 4, 8, and 12. To fulfill its statutory responsibility, the Governing Board developed a policy to guide the development of achievement levels for all NAEP subjects. Three levels of achievement were identified to provide the public, educators, and policymakers with information on student performance on NAEP. These levels—Basic, Proficient, and Advanced—are used as a primary means of reporting NAEP results to describe "how good is good enough" at grades 4, 8, and 12.

Table 18 displays the Board's generic policy definitions for Basic, Proficient, and Advanced achievement that pertain to all NAEP subjects and grades.

Table 18. Generic Achievement Level Policy Definitions for NAEP

Achievement Level	Policy Definition
Advanced	This level signifies superior performance.
Proficient	This level represents solid academic performance for each grade assessed. Students reaching this level have demonstrated competency over challenging subject matter, including subject-matter knowledge, application of such knowledge to real-world situations, and analytical skills appropriate to the subject matter.
Basic	This level denotes partial mastery of prerequisite knowledge and skills that are fundamental for proficient work at each grade.

During the framework development process, the project committees are asked to develop preliminary achievement level descriptions, based on the generic policy definitions, to guide item development. Essentially, the purpose of these statements is to provide examples of what students performing at the Basic, Proficient, and Advanced achievement levels should know and be able to do in terms of the science content and practices identified in the *Framework*. The intended audiences for these preliminary descriptions are the NAEP assessment development contractor and item writers. The descriptions are used to ensure a broad range of items (covering Basic, Proficient, and Advanced levels) is developed at each grade level.

Tables 19 to 21 present the preliminary achievement level descriptions for grades 4, 8, and 12 to clearly illustrate the science content and practices expected at each grade level. Members of the Planning Committee used their expert judgment to draft these preliminary descriptions and were partially guided by the following considerations:

- Advanced descriptions could be composed of highly challenging science content and highly challenging components of a given science practice.
- Basic descriptions could be composed of both moderately challenging content and practice components.
- Proficient descriptions could be composed of a mixture of highly and moderately challenging content and practice components.

The preliminary descriptions include only *illustrative* statements drawn from the *Framework*'s science content and practices. The statements are not intended to represent the entire set of objectives from the content and practice dimensions, nor do the preliminary achievement level descriptions denote a sense of priority or importance based on the statements selected. In addition, these descriptions should be interpreted neither as assessment items nor as suggestions for assessment items. Although adjectives are not explicitly included in every statement, each was written with the expectation that student performances would be "good" and "reasonable." For example, the phrase "design an investigation" implies "design an organized and logical investigation" and "propose a framework" implies "propose a rational framework."

After the assessment is administered, broadly representative panels engage in a standard-setting process to determine the achievement level cut scores on the NAEP scale. The cut-scores represent the minimum score required for performance at each NAEP achievement level. A second outcome of this standard-setting process is a set of paragraphs, derived from the preliminary achievement level descriptions, to be used in reporting the NAEP science results to the general public and other audiences. At each grade level, there will be paragraphs describing what students should know and be able to do at the Basic, Proficient, and Advanced levels in terms of the science content and practices identified in the *Framework*.

Further information on NAEP achievement levels can be found at www.nagb.org.

Table 19. Grade 4 Preliminary Achievement Level Descriptions

	BASIC	PROFICIENT	ADVANCED
	Identifying Science Principles	**Identifying Science Principles**	**Identifying Science Principles**
Physical Science	Compare properties of solids and liquids	Describe the changes in physical properties that result when substances are heated and cooled	Identify properties of gases, liquids, and solids (e.g., whether made of one or more substances)
Life Science	Identify the foods that animals eat as sources of energy and building blocks for growth and repair	Describe life cycles of familiar plants and animals	Relate an organism's survival with conditions in the environment that meet the organism's basic needs
Earth and Space Science	Describe changes in the apparent shape of the moon over a month's time	Describe the change in the apparent path of the sun, as viewed in the Northern Hemisphere between June and December	Relate the changes in the location of sunrise with time of year
	Using Science Principles	**Using Science Principles**	**Using Science Principles**
Physical Science	Describe what happens when a given amount of liquid is poured from a tall and narrow container into a broad and shallow container	Explain why a metal container filled with a hot liquid feels hotter to the touch than a foam container filled with the same hot liquid	Explain what happens to the gas in a helium balloon when it is punctured in a closed room
Life Science	Describe how familiar animals meet their basic needs for food, air, water, and shelter	Predict how a change in a plant's environment will affect the plant's survival	Explain why animals need food and plants need nutrients
Earth and Space Science	Explain why some rivers become muddy during or after heavy rains	Provide three examples of weathering and erosion	Relate periods of erosion to weather events or seasons

Table 19. Grade 4 Preliminary Achievement Level Descriptions (cont.)

	BASIC	PROFICIENT	ADVANCED
	Using Scientific Inquiry	**Using Scientific Inquiry**	**Using Scientific Inquiry**
Physical Science	Order magnets by strength based on data describing the number of objects (e.g., paper clips) attracted to each of the magnets	Critique several proposed investigations comparing the heat produced by burning different quantities of wax	Design an investigation to demonstrate the relationship between the length of a vibrating string and the waves produced
Life Science	Construct a bar graph from numerical data showing changes in the height of a plant over time	Select the best designed investigation from descriptions of several different ways to investigate the effects of light intensity on a plant	Design an investigation to demonstrate how a change in an environment changes the number of a familiar kind of animal in the environment
Earth and Space Science	Identify a thermometer as a tool for measuring temperature	Construct a bar graph from data showing average monthly temperatures over a twelve month time period	Design an investigation to relate weather data to the changes in seasons
	Using Technological Design	**Using Technological Design**	**Using Technological Design**
Physical Science	Choose materials that are identified as good thermal insulators for use in containers to keep hot beverages from cooling off	Propose a method for testing materials to determine which are the best thermal insulators	Apply information about the thermal properties of materials to design a beverage container which keeps hot beverages hot and cold beverages cold for as long as possible
Life Science	Select from three drawings of shelters for an animal, the one that will meet most of the animal's basic needs	Apply information about an animal's basic needs to design a shelter for the animal	Analyze and explain how the design of a shelter or den, as constructed by an animal, meets its needs
Earth and Space Science	Explain how to use the motion of the sun to determine if it is morning or afternoon	Choose from among three different drawings the best method of using the motion of the sun to tell the approximate time of day	Explain how to safely observe and record the motion of the sun during the day so as to construct a means of telling the approximate time of day

Table 20. Grade 8 Preliminary Achievement Level Descriptions

	BASIC	PROFICIENT	ADVANCED
	Identifying Science Principles	**Identifying Science Principles**	**Identifying Science Principles**
Physical Science	Recognize that acids are a class of compounds that exhibit common chemical properties	Describe properties of acids such as color changes with acid/base indicators and the tendency to react with bases	Relate the properties of elements that form acids with their position in the Periodic Table
Life Science	Identify producers and consumers as components of living systems	Describe the functions of consumers in ecological systems	Relate the functions of consumers to the energy flow in ecological systems
Earth and Space Science	Describe the location of Earth in the solar system	Relate the phases of the moon and the length of a day and a year to the motions of Earth, the moon, and the sun	Relate the force of gravity to the regular motion of bodies in the solar system
	Using Science Principles	**Using Science Principles**	**Using Science Principles**
Physical Science	Explain the physical properties of solids, liquids, and gases, using the idea that matter is composed of tiny particles in motion	Explain chemical properties of metals using the structure of atoms	Predict the properties of an element based on its position in the Periodic Table
Life Science	Give examples of producers and consumers in aquatic ecosystems	Predict the effect of a reduction in the population of predator species on the population of a species on which it preys	Evaluate an alternative explanation for patterns observed in an ecosystem's population data
Earth and Space Science	Predict the effect of a reduction of the amount of light from the sun reaching Earth	Explain how the tilt of Earth's rotation axis produces annual variation in the intensity of sunlight on the Earth's surface	Predict how changes in axial tilt would affect annual variations in the intensity of sunlight on the Earth's surface at different latitudes

Table 20. Grade 8 Preliminary Achievement Level Descriptions (cont.)

	BASIC	PROFICIENT	ADVANCED
	Using Scientific Inquiry	**Using Scientific Inquiry**	**Using Scientific Inquiry**
Physical Science	Use physical and chemical properties to classify substances as metals or non-metals	Select the best designed investigation from descriptions of several different ways to demonstrate that water does not change chemically when it changes state	Design an investigation to measure the temperature of water when it changes state (phase diagrams)
Life Science	Describe simple patterns in population data	Conduct a survey of an ecosystem's population data and propose an explanation for patterns observed in the data	Design a survey of an ecosystem's consumer populations and propose an explanation for patterns in the data based on energy flow through the system
Earth and Space Science	Apply a framework for analyzing the constituent minerals and texture of a rock	Analyze properties of a rock formation to draw valid conclusions about the conditions under which it was formed	Propose a framework for classifying rocks, based on constituent minerals, texture, and environment of formation
	Using Technological Design	**Using Technological Design**	**Using Technological Design**
Physical Science	Interpret a distance versus time graph of two different types of parachutes (showing how far they have fallen in equal time intervals) to determine which is better at slowing the jumper's fall	Construct a graph based on a table showing how far two different types of parachutes have fallen in equal time intervals. Determine which parachute is better at slowing the jumper's fall and describe the evidence that supports that determination	Design a method for measuring and comparing the effectiveness of two new types of parachutes to see which is best at slowing the fall of a jumper
Life Science	Apply information about consumers and producers to critique the design of a self-sustaining terrarium	Apply information about consumers and producers to design a self-sustaining terrarium	Apply information about energy flow to critique a plan for managing the deer population in a forest ecosystem located near fields where corn is grown
Earth and Space Science	Identify the possible effects on the environment of cutting down a forested area to establish a new field to grow corn	List the scientific trade-offs that need to be taken into account when cutting down a forested area to establish a new field to grow corn	Taking into account the scientific trade-offs involved in converting forested lands to fields for growing corn, propose what can be done to reduce some of the negative environmental impacts while allowing for increased food production

Table 21. Grade 12 Preliminary Achievement Level Descriptions

	BASIC	PROFICIENT	ADVANCED
	Identifying Science Principles	**Identifying Science Principles**	**Identifying Science Principles**
Physical Science	State the difference between exothermic and endothermic chemical reactions	Describe the increases in kinetic, rotational, and vibrational energy that result when a substance is heated	Explain the melting of a solid crystal in terms of the energy of the constituent molecules, ions, or atoms
Life Science	State modern scientific ideas about evolution such as natural selection and common descent	Describe fossil, anatomical, and molecular evidence for biological evolution	Make connections among the following related science principles: the potential of a species to increase its numbers; the genetic variability of its offspring; limitations on the resources required for life; and the ensuing selection of those organisms better able to survive and leave offspring
Earth and Space Science	State the law of superposition in an undisturbed sequence of rock layers—that younger rock layers sit atop older rock layers below	Classify some geological processes as happening on a human time scale, such as earthquakes, and other processes occurring on a geological time scale, such as mountain building	Use index fossils and type sections to assign sequences of rocks to geological eras
	Using Science Principles	**Using Science Principles**	**Using Science Principles**
Physical Science	Give an example of an element that has an isotope	Predict some common chemical reactions, given a choice of reactants (e.g., metals and non-metals, acids and bases)	Explain the difference between ionic and covalent bonding
Life Science	Use antibiotic resistance as an example of principles of biological evolution	Predict the spread of infectious disease based on basic concepts of evolution	Use basic concepts of evolution to explain antibiotic resistance and invasive species
Earth and Space Science	Explain the process of mountain building using the theory of plate tectonics	Explain the location of deep sea trenches as an outcome of geologic processes	Propose geologic processes that explain structures found on a geologic map

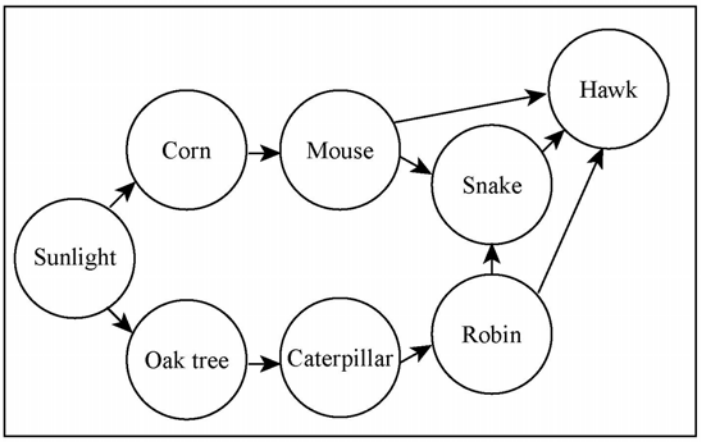
Table 21. Grade 12 Preliminary Achievement Level Descriptions (cont.)

	BASIC	PROFICIENT	ADVANCED
	Using Scientific Inquiry	**Using Scientific Inquiry**	**Using Scientific Inquiry**
Physical Science	Describe patterns of physical and chemical properties within rows of the Periodic Table	Select the best-designed demonstration among descriptions of how to illustrate the translational, vibrational, and rotational motion of molecules	Design an investigation to determine the effect of surface area on evaporation rate
Life Science	Use information contained in a food web to illustrate energy conservation in an ecosystem	Select the best-designed investigation among descriptions of ways to determine the effect of fertilizers on the growth of plants	Design a strategy for estimating the quantity of plant material required to produce a kilogram of beef
Earth and Space Science	Analyze photographs of rock layers to determine the order in which the layers were deposited	Describe how radioactive dating is used to estimate the age of rock formations and sequence data to provide relative age information	Integrate fossil, stratigraphic, structural, and rock-type information to identify past spatial relationships between environments
	Using Technological Design	**Using Technological Design**	**Using Technological Design**
Physical Science	A railway company wants to purchase the fastest bullet train on the market. Select the fastest train based on data about distance traveled by each of two trains and the time it took to travel that far	A railway company wants to purchase the fastest bullet train on the market. Design a test of two trains (consider what is to be measured, instruments to be used, and how data are to be collected)	A railway company wants to purchase the fastest bullet train on the market. List science-based criteria and constraints that might be used to select the best train and propose a method to compare two trains on these criteria and constraints
Life Science	Given a description of plants and animals in a stable ecosystem, identify from a list of possibilities what changes might occur if people migrate into the area	Given a description of plants and animals in a stable ecosystem, list some of the changes that might occur if people migrate into the area; and describe how those changes could affect the entire food web	Given a description of plants and animals in a stable ecosystem, list some of the changes that might occur if people migrate into the area; and describe what the new residents could do to limit those changes and avoid affecting the entire food web
Earth and Space Science	Given data on increasing levels of carbon dioxide in the atmosphere, select from a list some of the anticipated effects of this carbon dioxide buildup	Given data on increasing levels of carbon dioxide in the atmosphere, list both positive and negative effects of this carbon dioxide buildup	Given data on increasing levels of carbon dioxide in the atmosphere, list positive and negative effects of this buildup and science-based actions people might take to reduce or prepare for any negative effects

APPENDIX D

SAMPLE ITEMS AND SCORING GUIDES

Item Source: TIMSS 1999, Grade 8 (*Framework*, p. 65)



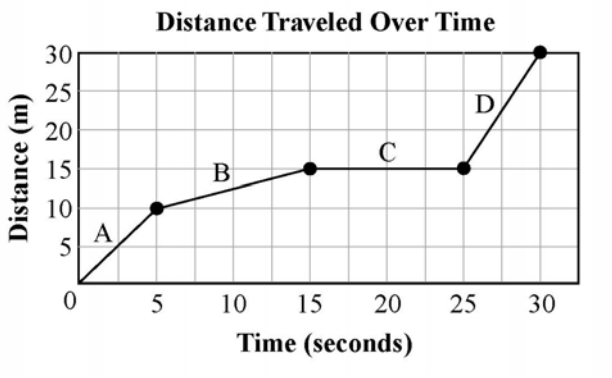
Look at the food web above. If the corn crop failed one year what would most likely happen to the robin population? Explain your answer.

Note: A correct response must include a feasible explanation directly relating the predicted change in robin population to the effect of corn crop failure on prey/predator relationships indicated in the food web. Responses do not have to use the specific terms **decrease**, **increase**, and **same**, as long as the explanation is clear with respect to the effect on the robin population. If more than one effect is given, assign the code corresponding to the first correct explanation.

Code	Response	Item: S022141
	Correct Response	
10	Robin population may **decrease**. Explanation based on predators (snakes/hawks) eating more robins if mice die. *Examples:* *Goes down. The mice would starve and the snake would eat the robins.* *There would be less robins because the mouse population would decrease and the snakes (and/or hawks) would eat more of the robins.*	
11	Robin population may **increase**. Explanation based on predators (snakes/hawks) dying due to lack of food (mice). *Examples:* *It would go up because the snakes die if the mouse starves.* *There could be more robins because there are fewer snakes (and/or hawks) to eat them.*	
12	Robin population would stay the **same** with a feasible explanation. *Example:* *It would not change because the mouse would find other grain to eat so the snake would be unaffected.*	
19	Other acceptable explanation.	
	Incorrect Response	
70	Robin population would **decrease**. Incorrect explanation based on robins starving if snakes die (confuses prey/predator relationship). *Examples:* *Decreases because there are less snakes to eat.* *When corn dies, then snakes, then robins starve.*	
71	Robin population would **decrease**. Incorrect explanation based on the robin needing corn to survive. *Example:* *Decrease because they need the corn.*	
72	Robin population would stay the **same.** Incorrect explanation based on the robins not needing corn to survive or not being connected to corn in the food web. (Does not consider the effect of predators.) *Examples:* *Nothing because the robin only eats insects.* *Nothing would happen. The corn is on a different chain in the food web.*	
73	Mentions **only** that the whole food web will be upset and/or all the animals will die. *Example:* *The whole food web would erupt and everything would die.*	
79	Other incorrect (including crossed out/erased, stray marks, illegible, or off task).	
	Nonresponse	
99	BLANK	

Item Source: Colorado Department of Education, 2002, Grade 8
(*Framework*, p. 68)

The graph below shows the distance traveled over time by a student walking down a hall. Use the information shown on the graph to do Numbers 7 and 8.



7. During which time interval was the student moving the fastest?

- ○ A
- ○ B
- ○ C
- ○ D

Key: D

8. What was the average speed of the student from 0 seconds to 5 seconds?

   Average speed: _____

Scoring: Average speed is 2 m/s. (The student traveled 10 meters in 5 seconds.)

Item Source: Quellmalz et al., 2004 (*Framework*, p. 71)

Lynx/Hare Task

This is an interactive computer task in which students are expected to conduct a scientific investigation regarding the question of whether or not lynx should be introduced into a national park in order to reduce the abiding overpopulation of hares. Students are directed to complete six modules, which make use of different computer programs in order to determine the best solution for the proposed question:

Module 1 asks the student to access, organize, analyze, and interpret data that they are given about the populations of hares over the past four years, using Word processor, Spreadsheet, or Presentation software.

Module 2 asks the student to determine a better way to analyze and display some disorganized data that show how many lynx and hares were present each year over the past 25 years.

Module 3 first asks the student to submit a web search that will give insight into the relationship between lynx and hare populations. It subsequently asks the student to critically evaluate the relevance of several given web searches.

Module 4 asks the student to collect information on specific questions regarding the lynx/hare question, to take notes on the information given on the web sites, and to include citations for each site.

Module 5 asks the student to use a modeling program to predict the results of adding more lynx to the parks through viewing population trends over several years. Students are then asked questions based on what they have observed in the modeling tool regarding increases or decreases in the hare population if lynx are or are not added to the park.

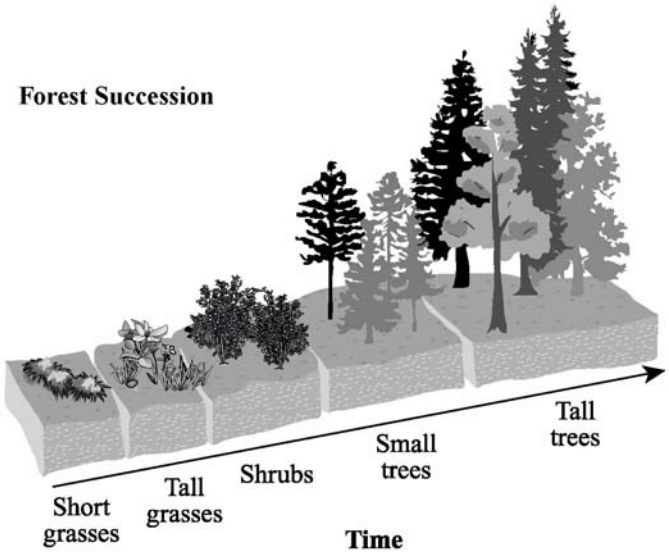
Module 6 asks the student to create a presentation with Word processor or Presentation software in order to communicate the problem, the findings, and any recommendations that resulted from the newly completed research.

Scores for this task are given for inquiry skills and technology use, along with the appropriate use of concepts within their explanations and recommendations.

For more information, see http://ipat.sri.com/tasks/pred_prey/subtasks/taskstud.html

Item Source: Washington Assessment of Student Learning, 2004, Grade 8 (*Framework*, p. 75)

Occasionally, a fire will destroy a forest, burning down trees and pushing wildlife out of their forest homes. However, the forest will grow back. Eventually, through the process of forest succession as shown below, short grasses and flowers begin to grow and animals make new homes.



Over time, shrubs and trees begin to grow. The forest returns to a lush habitat for the wildlife listed in the chart below.

Forest Wildlife

Ground-dwelling	Worms, beetles
Reptiles and amphibians	American toads, wood frogs, snakes, Eastern box turtles
Small animals	Squirrels, chipmunks
Medium to large animals	Opossums, raccoons, white-tailed deer, black bears
Airborne	Butterflies, moths, bees, wild turkeys, red-tailed hawks, bald eagles

A power company owns part of a forest that was destroyed by a fire. The forest could take decades to rebuild on its own. The company's department of environmental studies suggests planting new trees to help the forest rebuild.

Using the information in the scenario:

- Explain how planting trees could **benefit** the natural ecosystem.
- Explain how planting trees could **harm** the natural ecosystem.

Scoring Rubric

2-point response: The response demonstrates that the student can analyze how human societies' use of natural resources affects the quality of life and the health of ecosystems.

The student explains one reasonable way planting the trees could **benefit** the natural ecosystem.
AND
The student explains one reasonable way planting the trees could **harm** the natural ecosystem.

Example responses:

Benefits of planting the trees include, but are not limited to—

- providing a habitat for animals,
- providing a canopy, which would help to prevent soil erosion,
- creating root systems, which would anchor soil in place, and
- creating shade, which would help maintain sunlight levels and inhibit the introduction of nonnative plant species.

Harms of planting the trees include, but are not limited to—

- disrupting the natural flow of animals re-entering the forest,
- inhibiting the growth of other plants,
- decreasing the diversity of tree species growing in the forest, and
- introducing foreign species into an area, which may affect native species of plants and animals.

1-point response: The response demonstrates that the student can partially analyze how human societies' use of natural resources affects the quality of life and the health of ecosystems.

The student explains one reasonable way planting trees could **benefit** the environment.
OR
The student explains one reasonable way planting trees could **harm** the environment.

0-point response: The response demonstrates that the student can do little or no analysis of how human societies' use of natural resources affects the quality of life and the health of ecosystems.

Note: Benefits/harms to the natural ecosystem that only relate to humans shall not be credited score points.

Annotated Example of a 2-point response:

Explanation of how planting trees could benefit the natural ecosystem:
The ecosystem will rebuild more quickly, and that would give the
animals a new habitat more quickly.
Explanation of how planting trees could harm the natural ecosystem:
It could disrupt the natural order of the ecosystem. If some
smaller plants don't get a chance to grow first, the trees might
push them out.

Annotation:

The response demonstrates that the student can analyze how human societies' use of natural resources affects the quality of life and the health of ecosystems.

The student explains one reasonable way planting the trees could **benefit** the natural ecosystem, "The ecosystem will rebuild more quickly, and that would give the animals a new habitat more quickly." (1 point)

The student explains one reasonable way planting the trees could **harm** the natural ecosystem, "If some smaller plants don't get a chance to grow first, the trees might push them out." (1 point)

Annotated Example of a 1-point response:

Explanation of how planting trees could benefit the natural ecosystem:
More plants and trees would mean giving off more oxygen. more shade.
more food for forest animals.
Explanation of how planting trees could harm the natural ecosystem:
There could be a very big storm and trees fall an houses.

Annotation:

The response demonstrates that the student can partially analyze how human societies' use of natural resources affects the quality of life and the health of ecosystems.

The student explains one reasonable way planting the trees could **benefit** the natural ecosystem: "More food for forest animals." (1 point)

The student explains one way planting the trees could **harm** the human structure: "Trees falling on houses" but not the natural ecosystem. (0 points)

Annotated Example of a 0-point response:

Explanation of how planting trees could benefit the natural ecosystem:
have more trees
Explanation of how planting trees could harm the natural ecosystem:
half the plants will die

Annotation:

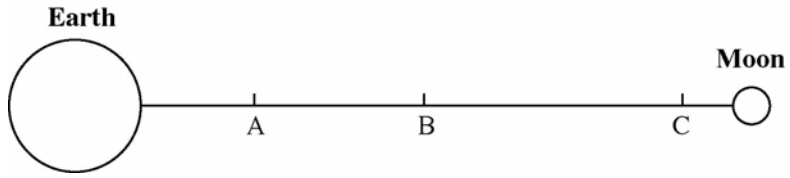
The response demonstrates that the student can do little to no analysis of how human societies' use of natural resources affects the quality of life and the health of ecosystems.

The student states one factor, "have more trees," but does not explain one reasonable way planting the trees could **benefit** the natural ecosystem. (0 points)

The student states a possible harm "half the plants will die" but does not explain how planting the trees could cause this **harm** to the natural ecosystem. (0 points)

Item Source: NAEP 1996, Grade 8 (*Framework*, p. 83)

A space station is to be located between the Earth and the Moon at the place where the Earth's gravitational pull is equal to the Moon's gravitational pull.
On the diagram below, circle the letter indicating the approximate location of the space station.



Explain your answer.

Scoring Rationale: Student demonstrates ability to explain the role of gravity in a man-made satellite and relates the force of gravity to the mass (size) of the object pulling it.

3 = Complete - Student circles point C and gives a correct explanation that gravitational pull depends on mass and distance, thus the station must be closer to the Moon because the Moon's mass is less than that of the Earth.
2 = Partial - Student circles point C and explains that the moon has less gravity than the Earth but does not link it to mass.
1 = Unsatisfactory/Incorrect - Student circles A, B, or C and gives an incorrect explanation or no explanation.

Sample Student Responses

Complete (Level 3)

Explain your answer.

Point C because the earth has a stronger gravitational pull because of its size so the station would have to located nearer to the moon to equal pulls

Partial (Level 2)

Explain your answer.

The Earth has a greater gravitational pull than the moon so it needs to be closer to the moon.

Unsatisfactory/Incorrect (Level 1)

Explain your answer.

It would be right in the middle due to gravitational focus

Item Source: TIMSS 2003, Grade 4 (*Framework*, p. 96)

On a hot, humid day the air contains a lot of water vapor. What happens to the water vapor in the air when the air becomes very cold?

Note: Priority should be given to Code 10. If a response mentions condensation or freezing, then Code 10 should be given even if other correct codes apply. Responses that mention ONLY that the water vapor becomes cold or rises without any mention of a change of state (explicitly or implicitly) are scored as incorrect (Code 70 or 71).

Code	Response	Item: S031382
	Correct Response	
10	Refers to **condensation** or **freezing** (or equivalent). *Examples: It freezes.* *It condenses.* *Condensation.* *It condenses and turns into rain.*	
11	Mentions cloud formation or a form of precipitation (e.g., rain, snow, fog, etc.) *Examples: The water vapor changes to rain.* *It changes to snow.* *Water vapor turns into clouds.* *It rises into the clouds and becomes rain droplets.* *It turns foggy.* *It rains.*	
19	Other correct *Examples: It falls to the ground.*	
	Incorrect Response	
70	Mentions only that the water becomes cold. [No mention of a change of state or precipitation.] *Examples: The water vapor becomes cold.* *Its temperature drops.*	
71	Mentions only that water vapor rises (or similar). [No mention of condensation or precipitation.] *Examples: The water vapor will rise on a hot day.*	
79	Other incorrect (including crossed out/erased, stray marks, illegible, or off task) *Examples: It disappears.*	
	Nonresponse	
99	Blank	

Item Source: New Standards Spring Field Test 1999 for High School
(*Framework*, p. 96)

The biosphere (living organisms), the lithosphere (rocks and soils of the Earth's crust), and the atmosphere are all involved in the cycling of carbon atoms. Describe the role that each plays in the carbon cycle.

Scoring guide:

Score point	Description
4	The response describes the cycling of carbon among all three reservoirs. The response is complete and detailed, showing evidence of logical reasoning. There is no evidence of misconceptions.
3	The response describes the cycling of carbon between two of the reservoirs. The response may contain omissions or minor errors.
2	The response describes the presence of carbon compounds in two or more reservoirs but may not link the reservoirs. The response may contain errors or misconceptions.
1	The response is largely incomplete, lacks detail, and contains errors of fact and reasoning.
0	The answer may contain words from the question, but does not add any information that might answer the question.
Off topic	Off-topic response.
Blank	No marks were made in the student response section.

Background information for appropriate response:

Carbon forms a variety of compounds. Carbon monoxide (CO) and carbon dioxide (CO_2) are carbon compounds that exist as gases in the atmosphere. Organic carbon compounds come in a wide variety of forms in living organisms: sugars, carbohydrates, cellulose, starches, collagen, chitin, amino acids, proteins, lipids, and nucleic acids. These organic compounds are also to be found in soil due to decaying and decomposition. The carbonate ion (CO_2^{-2}) combines with different positive ions to form carbonate compounds found in rocks and soil.

Producers (green plants) take carbon dioxide from the air and convert it to sugar, using solar energy (photosynthesis). Additional nutrients (including carbonate ions from the soil) are taken into the plant via its root system. These nutrients are rearranged and turned into the wide array of carbon compounds listed above, along with the sugar compounds formed via photosynthesis. As consumers eat producers, the carbon compounds are broken down and rearranged into carbon compounds used by the consumer organism.

When any living organism dies, the carbon compounds are broken down and returned to the soil by decomposer organisms. Huge sediment layers of dead marine organisms, which once had chitin cell walls or shells, compress under the weight of continuing sediments and the ocean. Uplifting of these layers form sedimentary cliffs and rocks. Weathering and erosion continue to change the carbon compounds into forms that will again be incorporated into living organisms.

Producer, consumer, and decomposer organisms harness the chemical bond energy stored in food via cellular respiration. Cellular respiration releases carbon dioxide back into the atmosphere.

The score is based on evidence of: Geochemical cycling of carbon.

Item Source: Shavelson et al., 1991 (*Framework*, pp. 102, 104)

Electric Mysteries

The following is a brief description of two warm-up tasks:

1. Students are asked to connect one battery, one bulb, and wires so the bulb lights. They are then asked to draw a picture of this simple circuit.
2. Given mystery box "?," students are asked to identify whether it contains a battery or a wire. They are told that they can determine the contents of the mystery box by connecting it in a circuit with a bulb.

The following is an excerpt from the main task instructions given to students:

Find out what is in the six mystery boxes A, B, C, D, E, and F. They have five different things inside, shown below. Two of the boxes will have the same thing. All of the others will have something different inside.

[The five options—two batteries, a wire, a bulb, a battery and a bulb, nothing at all—are presented in words and drawings. Drawings are not provided here.]

For each box, connect it in a circuit to help you figure out what is inside. You can use your bulbs, batteries, and wires in any way you like.

When you find out what is in a box, fill in the spaces on the following pages.

The following is an example of the student response format:

Box A: Has _____ inside.

Draw a picture of the circuit that told you what was inside **Box A**:

The following is a brief description of the scoring system:

For each of the six boxes (A-F), students' responses are scored on two components: (1) identification of the contents of the box and (2) the circuit used to make the conclusion. For each box, if both components are correct, the student receives 1 point; if one or both components are incorrect, the student receives 0 points. Total maximum score is 6 points.

Item Source: Persky et al., 2005 (*Framework*, p. 103)

TRE Web Search Task

In this task, students are asked to use a search engine to determine why scientists use large helium gas balloons to explore outer space and the atmosphere instead of using satellites, rockets, or other such tools. One open-ended question and several multiple-choice questions are presented to students. Students are scored on how well they performed the search, the quality of the bookmarked pages, and how well the questions were answered.

A complex scoring framework is used to assess students' proficiency on the task. A "student model" is created which describes the "theory" of how different skills are linked together. For this task, there are five component skills: problem-solving in technology-rich environments, computer skill, scientific inquiry skill, exploration, and synthesis. An "evidence model" is created that describes how the students' responses are connected to each of these skills. Once students begin the task, every action is recorded and connected to one or more skills in the student model. Then, a three-step process is used to evaluate this record. The first step is "feature extraction," which shows what action the student took, when the action was taken, and any value that was associated with that action. The second step is "feature evaluation," which gives the scores for the actions taken based on developed rules that show the best way to complete the task. The third step is "evidence accumulation," which systematically combines responses into summary scores that detail the inferences that can be made from the students' responses.

This task incorporates a multifaceted evaluation process that can uncover the many skills involved in a single task or module. Thus, this module can provide a more comprehensive evaluation of students' skills and aptitudes than traditional test questions.

Item Source: Quellmalz et al., 2004 (*Framework*, p. 105)

Solar Power Task

This is an interactive computer task in which students act as energy consultants to identify which two states will generate the most amount of electricity from photovoltaic cells. There are four modules in which students use a series of map visualizations and other data to reach and to present their final conclusions. Ultimately, students are asked to create a presentation to one state, recommending that the state apply for federal funds marked for solar energy use.

Module 1 asks the student to review and apply background information on the conditions that both optimize and reduce solar energy production. They are also asked to conduct simple analysis using the "ArcView" map visualization program.

Module 2 asks the student to explore several datasets to identify states with high incoming solar radiation and to manipulate the ArcView program and its "Map Calculator" tool. The student uses the ArcView program to generate visualizations and to calculate which states will generate the best monthly and annual electricity yields from solar panels.

Module 3 asks the student to determine what other data may be necessary in order to create the most compelling recommendation to the states.

Module 4 asks the student to create a presentation to one of the two states determined to have the highest capacity for solar energy production. The student uses the newly gathered data to support the recommendation to the state.

Both generic and item-specific rubrics are used for scoring, which include scores for content (math and science), the use of problem solving or inquiry strategies (planning and thorough communication), and usage of technological tools.

For more information, see
http://ipat.sri.com/tasks/solarpower/subtasks/solar_tasks.html

Item Source: Adapted from Herl et al., 1999 (*Framework*, p. 106)

Concept-Mapping Task

In this task, students use a custom software program to create a concept, or knowledge, map. Students are given eighteen environmental science terms: atmosphere, bacteria, carbon dioxide, climate, consumer, decomposition, evaporation, food chain, greenhouse gases, nutrients, oceans, oxygen, photosynthesis, producer, respiration, sunlight, waste, and water cycle. They are also given seven link labels: causes, influences, part of, produces, requires, used for, and uses. Students can then drag and drop these concepts onto the grid space of the mapping program and add, erase, and link the items in their newly constructed maps. The concept maps are scored based on semantic content, organizational structure, number of terms used, and number of links made.

Additionally, students explore a simulated World Wide Web space, which allows them to search for relevant environmental science information to improve their concept maps. Students can bookmark Web pages they believe to be helpful to the construction of their concept maps. This portion of the task is scored based on relevant information found, the hypertext links that were selected (browsing), keyword searching, and the accessing of three or more highly relevant Web pages for a single concept (focused browsing).

While performing the concept-mapping task, students are able to access real-time feedback, which compares students' maps to experts' maps and gives corresponding feedback as to which items are correct and which need improvement. A score is also assigned to how often a student accessed feedback, a measure of monitoring one's learning.

This computer-based assessment provides a detailed view into not only the ultimate performance of the student but also the steps of the thought processes that were employed to generate the ultimate product or answer (in this case, the concept map).

APPENDIX E

GROUP 2 SMALL-SCALE SPECIAL STUDIES

Knowing What Students Know about Technological Design

Knowledge about technology and the technological design process are prominent in both the *National Standards* and *Benchmarks*. The *National Standards* states, "Although these are science education standards, the relationship between science and technology is so close that any presentation of science without developing an understanding of technology would portray an inaccurate picture of science" (p. 190). Despite taking some time for schools to include technology in the curriculum for all students, there is growing recognition that technology should be an important component. The number of states that include technology in their standards is increasing. In 2001, 30 states included technology in their state standards; by 2004, the number had increased to 38 (73%) (Meade & Dugger, 2004). Consequently, the process of technological design is being included in NAEP as parallel to—though with less emphasis than—the process of scientific inquiry.

Since relatively few questions on NAEP will probe Using Technological Design, this study proposes the development of an additional set of questions to probe in depth students' understanding of this practice.

Specifically, this study would address the following research question:

- What do students know about *technological design* in the contexts of agricultural technologies, energy generation technologies, and technologies related to Earth materials and resources?

Extended Investigations by Students

Science education standards nationally and locally emphasize scientific inquiry. In many states, this goal requires student engagement in projects that can take days, weeks, and even months as they undertake genuine investigations. Important outcomes of these projects include a range of skills that are a crucial feature of high quality science education but that cannot be assessed adequately in a 50-minute assessment (NRC, 2005). They include, for example, gauging the quality of students' (a) reasoning while framing their research questions, (b) planning for data collection and the execution of that plan, (c) ability to meet unpredictable challenges that arise during any actual, ongoing scientific investigation, (d) persistence in seeking productive explanations for their observations and revising plans for the investigation, (e) lines of argument in deciding how to alter their experimental approach in the light of new evidence, (f) engagement with fellow students and/or the teacher in interpreting an observation or result and deciding what to do about it, and (g) deliberations when settling on the defensible conclusions that might be drawn from their work.

In many countries, teachers are the ones expected to make assessments of student work during extended projects. Often their judgments of student achievement are made during ongoing classroom activities that are part of the regular curriculum. The assessments provided by the teachers are incorporated into an overall score that also includes results

of the short, timed tests. In some places, a defined percentage of the total score is based on teachers' judgments about achievement associated with investigative projects.

This study, then, might include both a national sample of students and an exploration of what other countries do under similar circumstances. Specifically, the study would address the following research questions:

- What methods can be or have been developed to assess student achievement with respect to the ability to conduct extended scientific investigations?
- To what extent are shorter investigations interchangeable for the extended investigation and to what extent are they not?

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