Public Comment Period
Assessment Framework Review Guidance and Instructions for Submission

Thank you for your interest in the 2028 NAEP Science Assessment Framework. We value the constructive feedback of all NAEP stakeholders and seek to gather a wide range of perspectives as part of our public comment period.

To be considered by the Steering and Development panels, all feedback must be submitted through the formal submission process via https://www.naepframeworkupdate.org/. All feedback must be received via the form by April 17, 2023 at 11:59 p.m. ET. We cannot accept feedback through emails, letters, social media, or webinar comments. Any comments received through these means will not be considered official feedback and will not be included in the panels' and Governing Board's reviews.

How to Access the Working Draft and Submit Feedback

- **Go to www.NAEPframeworkupdate.org.**
    - Click on "Working Draft."
    - Download the PDF linked on the page.
- **Review the document with the guiding questions.**
    - On the next page are guiding questions meant to support your review of the working draft. These questions are meant to prompt thinking and help reviewers organize feedback as they digest the lengthy and technical information.
    - Organize feedback and include line numbers to reference specific content within the working draft. This will help the Steering and Development panels more accurately review and interpret feedback.
- **Document your feedback via the online feedback form.**
    - Submit feedback via this form available at naepframeworkupdate.org. Be sure to reference line numbers and question numbers as necessary. You may wish to compose your feedback in a document like this one before transferring to the online form.
    - Contact naepscience@wested.org if you experience any technical difficulties.

Guiding Questions

Thank you for reviewing the NAEP Science Assessment Framework working draft. Your feedback is greatly appreciated. When you submit your comments, please address as many of the questions below as you can, responding to the issues that matter most to you.

OVERALL REPRESENTATION OF CONCEPTS AND SKILLS

- *Agree/Disagree* – I find the NAEP Science Framework to effectively highlight the latest and most relevant science concepts that students should know and be able to do.
- *Agree/Disagree* – The NAEP Science Framework is a good representation of what students should know and be able to do in science.
- *Yes/No* - Are there missing concepts or skills that you believe the NAEP Science Framework should consider?
    - If yes, what specifically should be included?
- *Yes/No* - Is there anything included with which you disagree?
    - If yes, what do you disagree with and why?
- *Agree/Disagree* – The organization of the framework is useful to understand the content and context of what students should know and be able to do in science.
    - If you disagree, what suggestions do you have to improve the organization of information?
- *Agree/Disagree* – The sample items are a useful representation of what the NAEP Science Framework is measuring.
- What other examples or sources of available items or tasks would be helpful to illustrate the three dimensions of science?
- *Yes/No* - I have recommendations for terms to include in a framework glossary to aid understanding of the framework.
    - If yes, which terms or phrases should be included?

ABOUT THE CONTENT

The Three Dimensions of Science (Chapter 2)

Disciplinary Concepts

- The physical sciences, life sciences, and Earth and space sciences concept statements (in Chapter 2) currently are written in different styles. Which style do you prefer, and why?
- For each of grades 4, 8, and 12, do the science concept statements represent what you believe should be assessed by NAEP? Why or why not?
- What are the science subtopics or concepts that you believe are the highest priority to be measured by NAEP? Why?
- What are the science subtopics or concepts that you believe are the lowest priority to be measured by NAEP? Why?

Science and Engineering Practices

- Across grades 4, 8, and 12, do the science and engineering practices represent what you believe should be assessed by NAEP? Why or why not?
- What are the science and engineering practices that you believe are the highest priority to be measured by NAEP? Why?

- What are the science and engineering practices that you believe are the lowest priority to be measured by NAEP? Why?
- Do you believe the NAEP Science Framework adequately reflects technology and engineering and the level at which students need to know and understand these concepts today? Why or why not?

Crosscutting Concepts

- Across grades 4, 8, and 12, do the crosscutting concepts represent what should be assessed by NAEP? Why or why not?
- What are the crosscutting concepts that you believe are the highest priority to be measured by NAEP? Why?
- What are the crosscutting concepts that you believe are the lowest priority to be measured by NAEP? Why?

Overview of the Assessment Design (Chapter 3)

Three-dimensional Assessment Design

- Do you agree with the description of the assessment design below? Why or why not?
  "The NAEP Science assessment should be three-dimensional whenever possible. Each item and each multi-part item should be at least two dimensional and three dimensional if appropriate. Item sets and scenario-based tasks should be three dimensional. No item will be one dimensional."

Balance of Assessment

- For each of grades 4, 8, and 12, do you believe there is an appropriate percentage of items for the various disciplinary concept domains and item types? Why or why not?

Reporting Results of the NAEP Science Assessment (Chapter 4)

Contexts for Student Learning

- NAEP assessments are administered with contextual questionnaires that are used to interpret student achievement results. What are the science-specific topics or questions that you believe are the highest priority for contextualizing NAEP results? Why?
- The extent of changes to a framework has implications for whether assessment results from the updated framework can be validly compared with results from the previous framework (i.e., continuing trend lines from 2009 to 2028 and beyond). To what extent do you consider it important to prioritize comparisons with previous NAEP science results? To what extent do you consider it important to implement the recommended changes even if they pose a significant risk to maintaining trend lines in NAEP science?

ADDITIONAL COMMENTS

Is there any additional feedback you'd like to provide not covered in the prompts above? If so, please provide the feedback in the comment box. Where possible, please include line numbers to reference specific changes.

- *Yes/No* - Are you comfortable with your name and affiliation being included with your comments, which may be shared and discussed publicly in upcoming Governing Board meetings and materials?

2028 NAEP Science Framework Working Draft

Table of Contents

Chapter 1 – Overview

What is NAEP?

The National Assessment of Educational Progress (NAEP), often called The Nation's Report Card, is the largest nationally representative and continuing assessment of what students in public and private schools in the United States know and are able to do in various subjects. Since 1969, NAEP has been a common measure of student achievement across the country in science, mathematics, reading, and seven other subjects. NAEP results enable comparisons of what sampled students know and can do among states and jurisdictions, among various demographic groups, and over time. By law and by design, NAEP does not produce results for individual students or schools.

NAEP is a congressionally mandated project of the National Center for Education Statistics (NCES), located within the U.S. Department of Education's Institute of Education Sciences. The National Assessment Governing Board (Governing Board) is an independent, nonpartisan organization responsible for setting policy for NAEP. The 26 members of the Governing Board include governors, state legislators, state and local school officials, educators, researchers, business representatives, and members of the general public who are appointed by the U.S. Secretary of Education.

The NAEP Authorization Act of 2002 (NAEP, P.L. 107-279) is the governing statute of NAEP. This law stipulates that NCES develops and administers NAEP and reports NAEP results. Under the law, the Governing Board's responsibilities include determining the assessment schedule, developing the assessment frameworks that provide the blueprints for the content and design of the assessments, and setting the achievement levels. NAEP assessments are administered to students in Grades 4, 8, and 12 at the national level and sometimes also for states and districts that volunteer to participate at the state level or in the Trial Urban District Assessment (TUDA) program.

By law, NAEP assessments shall not evaluate personal beliefs or publicly disclose personally identifiable information, and NAEP assessment items shall be secular, neutral, and nonideological and free from racial, cultural, gender, or regional bias. Although broad implications for academic subject matter may be inferred from the assessment, NAEP does not specify how any subject area should be taught; nor does it prescribe a particular curricular approach to teaching any subject area.

The Governing Board has a continuing commitment to equity in our educational systems. It advances this goal by designing assessments that are inclusive and accessible for the full diversity of students who are administered the NAEP assessments. The assessments align with the recent standards in large-scale assessment by continuing to strive to minimize test bias to the maximum extent possible (American Educational Research Association [AERA], American Psychological Association [APA], & National Council on Measurement in Education [NCME], 2014; International Test Commission, 2019; Joint Task Force on Assessment of the International Reading Association and the National Council of Teachers of English, 2010). Finally, the assessments will gather data that afford opportunities to examine malleable contextual variables that may lead to greater understanding of differential student achievement.

The NAEP Science Framework and Assessment

NAEP assessment frameworks are designed to inform NAEP assessment development. They describe the subject matter to be assessed and the assessment questions to be asked as well as the assessment's design and administration. The major purpose for this NAEP Science Assessment Framework is to identify what science should be measured on NAEP at Grades 4, 8, and 12 beginning in 2028. The most recent updates of the NAEP Science Assessment Framework were completed in 2005 and were reflected in the 2009 and subsequent NAEP Science Assessments.

The 2028 NAEP Science Assessment Framework is intended for a general audience. A second document, the *Assessment and Item Specifications for the 2028 NAEP Science Assessment Framework*, will be developed to serve as the "test blueprint" with additional information about test development; it will be intended for a more technical audience, including NCES and the contractors who will develop the NAEP Science Assessment. In accordance with Governing Board policy, the 2028 NAEP Science Assessment Framework focuses on "important, measurable indicators of student achievement to inform the nation about what students know and are able to do without endorsing or advocating a particular instructional approach."

This document describes an assessment framework, not a curriculum framework. It lays out the basic design of the assessment by describing the science knowledge and skills that should be assessed and the types of questions that should be included. It also describes how various assessment design factors should be balanced across the assessment. In broad terms, this framework attempts to answer this question: What science knowledge, skills, and practices are to be assessed on NAEP at Grades 4, 8, and 12? It does not cover all relevant content for each grade level; some concepts, practices, and activities in school science are not suitable to be assessed on NAEP, although they may well be important components of a school curriculum. This document also does not attempt to answer this question: How should science be taught? That is a state or local decision and not suitable to be specified by NAEP.

The NAEP Science Assessment has been administered on a digital platform since 2019. Each student who is randomly selected for the NAEP assessment receives a sample of questions that take one hour to complete. At the beginning of the assessment session, students interact with a tutorial that presents all the information needed to take the assessment on the digital platform. Assessment items include both selected response and constructed response formats and represent a variety of item types. When students finish answering assessment questions, they participate in a survey that is administered on the same platform as the assessment, answering both general questions and science-related questions (e.g., about participation in science activities in and out of school). Data from these questionnaires, along with surveys completed by the participating students' science teachers and school administrators, provide context to student achievement in science.

The NAEP Science Assessment is a resource—a national wake-up call—because it offers a window into the state of our K–12 education system and what our children are learning. The results provide educators, policymakers, elected officials, and parents across the country with invaluable information regarding how our children are doing compared to other children in large urban districts, other states, and the nation. The NAEP Science Assessment results show us how student groups perform over time, which states and select urban districts are closing achievement gaps, academic trends over time, and how course-taking and grades correlate with high school graduation.

Development of the 2028 NAEP Science Assessment Framework Recommendations

During late summer and fall 2021, the Governing Board conducted a review of the 2019 NAEP Science Assessment Framework (NAGB, 2019) to determine whether and how it should be updated for assessments in 2028 and beyond. In accordance with Board policy, the review included an open comment period and commissioned papers and discussions with science educators and experts. Based on this review and other relevant research, at its May 2022 quarterly Board meeting the Governing Board determined that the NAEP Science Assessment Framework needed to be updated. The Board unanimously adopted a charge to the Steering and Development Panels who develop recommendations for the updated framework with the following guidance:

- NAEP must account for greater convergence in state science standards but cannot endorse the standards of any particular state or group of states.
- NAEP should remain forward-looking and consider what students should know and be able to do in science to be successful in college and careers.
- Updates should consider whether the definition of student achievement in science needs to incorporate relevant aspects of the 2018 NAEP Technology and Engineering Literacy (TEL) Framework.
- Updates to the NAEP Science Assessment Framework should prioritize relevance, utility, and validity and include strong justifications for the updates where the changes may create challenges to maintaining trend lines.
- Updates should balance the emphasis on content and practices to ensure that the measurement of skills does not occur in isolation from content knowledge.
- Updates should be bound by considerations of feasibility, including technical issues (i.e., ensuring that the framework can be operationalized), cost (e.g., accounting for scenario-based tasks being more expensive than other item types) and the NAEP legislation (including but not limited to the requirements for NAEP to be nonsectarian).
- Updates should support the development of assessment items reflective of students who have a wide range of knowledge and skills in science.

The comprehensive, deliberative process of developing recommendations to update the 2028 NAEP Science Assessment Framework was guided by Governing Board policy that specifies that the work be undertaken by broadly representative panels of educators, state and local school administrators, policymakers, researchers and technical experts, assessment specialists, and other content experts and users of assessment data. In accordance with its current policy on assessment framework development, the Governing Board conducted an open call for panelist nominations from mid-June through mid-July 2022. Extensive and targeted outreach was conducted to hundreds of stakeholder groups and individuals representing education, policy, industry, assessment, research, and other science-related areas.

The Board evaluated applications with the goal of constructing a balanced panel of stakeholders. The following factors were prioritized: individuals specifically nominated to represent a national organization, given the critical need to engage various constituencies; panelist role; experience and expertise overall and the specific sub–content areas covered by the framework; demographic characteristics, including race, gender, and geography; previous experience with and stance on the Next Generation Science Standards (NGSS), including both NGSS developers and critics, and practitioners in states that have adopted NGSS standards, NGSS-alike standards, and non-NGSS standards; and different perspectives on issues relevant to the Board charge. Thirty individuals were invited to serve on the Development and/or Steering Panels, and all agreed to participate. The role of the Steering Panel is to formulate high-level guidance about the state of the field and how to implement the Board charge; the role of the Development Panel is to develop the content of the framework and specifications documents and engage in detailed deliberations about how issues outlined in the Board charge and Steering Panel discussions should be reflected in a recommended framework. Board policy specifies that the Steering Panel should include 30 members, of which 20 members serve as the Development Panel.

In July 2022, the Board awarded a contract to WestEd (as the result of a competitive bidding process) to carry out the process of convening the panelists to recommend updates to the NAEP Science Assessment Framework. In addition to the WestEd project staff and framework panelists, the development of recommendations was informed by a Technical Advisory Committee (a group of six measurement experts who provided feedback on technical issues) and an Educator Advisory Committee (a group of eight science educators who provided feedback on issues particularly relevant to practitioners).

One important change from previous NAEP framework updates is that the panelists were tasked with focusing primarily on developing a substantive outline of the framework (what is to be assessed and how). The public comment period is taking place on a working draft of the framework that is based on that substantive outline, earlier in the process from previous framework updates. An earlier public comment period allows NAEP stakeholders to have more information about the panel recommendations and to provide thoughtful feedback for the panel to consider before final recommendations are made to the Board for review and approval. Feedback from public comment will be discussed with the Governing Board at the May 2023 quarterly meeting, and revisions (along with the development of additional narrative text to provide more detail for NCES to use in implementing the framework) will be produced for discussion at the August 2023 quarterly meeting. The goal is for the Board to take action on the final framework at the November 2023 quarterly meeting.

Updates to the Construct for NAEP Science

The National Research Council (NRC) of the National Academy of Sciences released *A Framework for K-12 Science Education* (NRC, 2012) in 2012. The Framework provides a sound, evidence-based foundation for assessment standards by drawing on current scientific research—including research on the ways students learn science effectively—and identifies the science all K–12 students should know and be able to do. Science education is built around three interrelated and equally important dimensions that are defined by the NRC Framework: Science and Engineering Practices; Disciplinary Core Ideas; and Crosscutting Concepts. As a result, most current state science standards have established sophisticated expectations of understanding scientific ideas and practices:

- application of the three dimensions to make sense of phenomena and complex problems
- inclusion of technology and engineering
- centrality of phenomena and problems based in real-world contexts
- emphasis on sensemaking that integrates the three dimensions of science
- focus on learning challenging ideas across time

The Steering and Development Panels used the NRC Framework as a foundational resource in responding to the Board charge and in making recommendations for updating the assessment construct for NAEP Science. They also discussed what claims they want to be able to inform when the results are reported.

Definition of the construct that NAEP is measuring:

Science achievement is the ability to use relevant disciplinary concepts (Physical Science, Life Science, Earth and Space Sciences), crosscutting concepts, and science and engineering practices to identify and address problems, make sense of phenomena, and evaluate information to make informed decisions.

Claims:

Students reason scientifically using disciplinary concepts (Physical Science, Life Science, Earth and Space Sciences), crosscutting concepts, and science and engineering practices to address problems in the natural and designed world.

Students reason scientifically using disciplinary concepts (Physical Science, Life Science, Earth and Space Sciences), crosscutting concepts, and science and engineering practices to make sense of phenomena in the natural and designed world.

Students reason scientifically using disciplinary concepts (Physical Science, Life Science, Earth and Space Sciences), crosscutting concepts, and science and engineering practices to evaluate information and make decisions in the natural and designed world.

Exhibit 1. Summary of Proposed Changes in the 2028 NAEP Science Assessment Framework

Topic	Change	Rationale
NAEP Science Construct	The framework working draft defines the construct of science achievement and explains how this construct is operationalized using the three dimensions of science. This clearly defined construct helps to ensure that the assessment is measuring what it intends to measure (i.e., construct validity) by outlining exactly what is included and not included, helping to ensure that items can capture this construct and not elements outside of this construct.	Precisely defined constructs help to ensure that an assessment measures the construct it intends to measure rather than aspects not part of that construct, which creates construct-irrelevant variance. Without a precisely defined construct, it is hard to know whether items and other design features work toward measuring the intended construct or whether they might, in fact, be measuring something else.
Three Dimensions of Science	NAEP Science “content” has been redefined as any knowledge and reasoning skills that students need to know and be able to do on the NAEP Science Assessment. The content now includes updated and renamed science content statements (now disciplinary concepts) and science practices (now science and engineering practices), along with the addition of crosscutting concepts. These are now referred to collectively as the “three dimensions of science.”	Prior NAEP Science frameworks organized what students should know and be able to do into two buckets: science content and science practices. Based on research presented in the NRC Framework, it is recommended that the science content covered on the NAEP Science Assessment now consist of science disciplinary concepts, crosscutting concepts, and science and engineering practices.

	Disciplinary concepts are well tested theories and explanations developed by scientists organized into three major groupings: Physical Science; Life Science; and Earth and Space Sciences.	While the science ideas are still organized into three broad disciplinary groupings (Physical Science, Life Science, and Earth and Space Sciences), NAEP Science Content Statements have been renamed as NAEP Disciplinary Concepts and updated to reflect shifts in expectations evident from reviews of state and national standards, policy documents from leading professional organizations, and expectations for science achievement on U.S. and international assessments. For more details on changes, see Chapter 2.
	NAEP Crosscutting Concepts have been added to the NAEP Science "content" and are defined as concepts used across all science disciplines that provide scientists and engineers and thus also students tools for asking productive questions and organizing their thinking.	With the introduction of the NAEP Science Crosscutting Concepts, based on findings reported in research on science learning, the updated definition of science achievement now describes the need for an assessment that can provide evidence about what students know and can do with all three dimensions of science. For more details on changes, see Chapter 2.
	NAEP Science Practices have been renamed as "NAEP Science and Engineering Practices" and updated to describe the skills and knowledge necessary to develop scientific explanations of phenomena or design engineering solutions to problems.	NAEP Science Practices have been renamed as "science and engineering practices" and updated to reflect shifts in expectations evident from reviews of state and national standards, policy documents from leading professional organizations, and expectations for science achievement on U.S. and international assessments. For more details on changes, see Chapter 2.
Technology and Engineering	Technology and engineering concepts that are relevant to science achievement have been integrated into the updated science and engineering practices.	The addition of technology and engineering concepts to NAEP Science reflect shifts in expectations evident from reviews of state and national standards, policy documents from leading professional organizations, and expectations for science achievement on U.S. and international assessments. The framework draft incorporates concepts that represent the overlap between the NRC Framework and the current NAEP Framework for TEL. For more details on changes, see Chapter 2.

Assessment Design	The framework working draft calls for students to use the three dimensions of science. Assessment items should require students to bring the three dimensions of science together to engage with the item. Items, item sets, and scenario-based tasks should be three dimensional whenever possible. No item will be one dimensional.	With the updated definition of science achievement, and the incorporation of the three dimensions of science, the assessment design needs to reflect the need for students to address all three dimensions in their demonstration of what they know and can do in science. For more details on changes, see Chapter 3.
	The working draft provides expanded recommendations and guidance on the following: • use of diverse tasks, phenomena, and contexts for items • considerations for language complexity • elimination of concept maps and replacement of hands-on tasks (HOTs) with scenario-based tasks	NAEP assessment items should be reflective of students who have a wide range of knowledge and skills in science from broad and diverse backgrounds. Feasibility is also a consideration, and HOTs are costly to administer and require additional personnel for implementation. Scenario-based tasks can address the same content as HOTs, but with easier administration and implementation. For more details on changes, see Chapter 3.
	The framework working draft calls for an even distribution of items across the three disciplines (Physical Science, Life Science, Earth and Space Sciences) and item types (selected response and constructed response) across Grades 4, 8, and 12.	Prior NAEP Science Assessment Frameworks called for differing distribution levels (higher percentage of Earth and Space Sciences at Grade 8, lower percentage of Earth and Space Sciences at Grade 12) based on NAEP data regarding students' course-taking patterns. Recommended distributions reflect shifts in expectations evident from reviews of state and national standards, policy documents from leading professional organizations, and expectations for science achievement on U.S. and international assessments. For more details on changes, see Chapter 3.

Chapter 2 - The Three Dimensions of the NAEP Science Assessment Framework

The NAEP Science Assessment Framework gives guidance on assessing science achievement. This requires assessment items that draw on the three dimensions of science learning:

- Disciplinary Concepts—well-tested theories and explanations developed by scientists organized into three major disciplinary groupings: Physical Science, Life Science, and Earth and Space Sciences
- Crosscutting Concepts—concepts used across all science disciplines that provide scientists and engineers and thus also students with tools for applying their knowledge of science to new phenomena or problems
- Science and Engineering Practices—ways of working to develop scientific explanations of phenomena or design engineering solutions to problems

Each of these dimensions is described in more detail below. Assessments will elicit evidence of students' use of these dimensions together to make sense of phenomena. This is essential to authentic assessment of science achievement.

NAEP SCIENCE DISCIPLINARY CONCEPTS

Science knowledge continues to develop yearly, but it is neither possible nor desirable to try to teach and assess more science for K–12 students every year. Rather, it is important to select the core ideas from each disciplinary area, framed in an up-to-date way, to describe a base of knowledge for use that will allow students to become adults who can continue to learn scientific ideas throughout their lives, and build the interest and engagement with science that will allow those who choose to do so to enter careers that require going well beyond this base. The core ideas assessed as the NAEP Disciplinary Concepts below follow those recommended by the panel of distinguished scientists and educators who developed the NRC document A Framework for K–12 Science Education.

These ideas progress across the years of K–12 education. The tables below delineate the progressions across the Grades 4, 8, and 12 tested by NAEP. Similar ideas, presented at a growing level of sophistication, are grouped in rows of the tables. Some ideas have no entry at Grade 4 because their development is expected to begin later in the sequences of learning used by most schools across the U.S. Since NAEP testing occurs midyear, the level defined here represents not a grade-level endpoint but rather an indication of what science ideas a student should be able to use to help develop models and explanations of phenomena or to design solutions to problems by the time of NAEP testing.

NAEP science testing will organize the multiple disciplines of science into three major groupings and several subgroupings:

- **Physical Science**
    - Matter and Its Properties
    - Motion and Forces
    - Energy
    - Waves and Their Role as Carriers of Information
- **Life Science**
    - From Molecules to Organisms: Structures and Processes
    - Ecosystems: Interactions, Energy, and Dynamics
    - Heredity: Inheritance and Variation of Traits
    - Biological Evolution: Unity and Diversity
- **Earth and Space Sciences**
    - Earth's Place in Space
    - Earth's Systems
    - Earth and Human Activity

Each of these groupings encompasses ideas from more than one scientific discipline. These groupings are not intended to delineate courses but rather are used to provide a coherent organization of the ideas to be tested.

NAEP Physical Science Disciplinary Concepts		
Grade 4	Grade 8	Grade 12
Matter and Its Properties *How can the great variety of material substances and processes of change in matter be explained?*		
P4.1: A small set of pieces combined in different ways can build a great variety of objects. P4.2: Different types of matter (materials) have different properties. Each material can be classified using a number of its properties. Materials with different properties are needed for different uses. Many objects are made with parts from multiple different materials. [**Boundary:** Students should be able to interpret evidence about properties but are not expected to remember properties of materials. Students should not be expected to describe a substance.] P4.3: Many materials can be solid and liquid depending on temperature. [**Boundary:** Gas is not assessed at this grade level.]	P8.1: All substances are made from atoms. There are over 100 different types of atoms, which combine with one another in various ways. Atoms form molecules or extended structures. P8.2: Each pure substance can be identified by its characteristic properties. [**Boundary:** Students can use this idea to interpret data but are not expected to remember characteristic properties of various substances.] P8.3: Atoms contain electrically charged particles. [**Boundary:** At this level, students do not need to know any details of the substructure. They only use this idea to explain the existence of electrically charged objects.]	P12.1: Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. P12.2: Protons and electrons have electric charges of equal and opposite sign. Protons have a positive charge, and electrons have a negative charge. Neutrons do not have an electric charge; they are electrically neutral. In a neutral atom, the number of electrons is equal to the number of protons. Neutral atoms can lose electrons to become positively charged ions or gain electrons to become negatively charged ions. P12.3: The periodic table orders elements horizontally by the number of protons in the atom's

P4.4: Materials may be naturally occurring or human-developed, but all are made from naturally occurring materials. Human-developed materials are products of technological processes that refine or combine naturally occurring materials to produce new types of materials.	P8.4: Many substances can exist as solids, liquids, or gas depending on conditions of temperature and pressure. P8.5: Atoms contain electrically charged particles. [**Boundary:** At this level, students do not need to know any details of the substructure. They only use this idea to explain the existence of electrically charged matter objects.] P8.6: A model that describes gases as made of atoms or molecules that are too small to see moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects. P8.7: A model that describes liquids as made from molecules in contact with each other but freely moving around relative to each other can explain many observations. P8.8: A model that describes solids as made from atoms so that they move only by small vibrations and thus maintain the overall organization of the structure explains many properties. P8.9: The total mass or weight of matter does not change in any chemical process. When the mass or weight of matter present in a system changes, we know that matter has either left the system or entered it, even when we cannot see that happening. [**Boundary:** Mass and weight are not distinguished at this level, and students are not expected to remember atomic masses.] P8.10: In a chemical reaction, the atoms of the reacting substances are regrouped into new substances with different properties.	nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. P12.4: Electrical attractions and repulsions between charged particles explain both the stability of isolated atoms and the forces between two or more nearby atoms that cause them to form molecules, compounds, and extended materials (i.e., the formation of chemical bonds). P12.5: A stable molecule has less energy than the same set of atoms at rest far apart. One must provide at least this amount of energy to break the molecule apart. When molecules and atoms rearrange because of collisions among them, the rearrangements of atoms into new molecules result in changes in the sum of all bond energies in the set of molecules that are matched by changes in either kinetic energy or the energy of light absorbed or radiated in the process (or both). [**Boundary:** Students are only expected to work with simple molecules.] P12.6: The total number of atoms of each type does not change in any chemical process; that is, atoms are conserved in all such processes. Knowing that atoms are conserved during chemical processes, together with knowledge of the chemical properties of the elements, allows individuals to describe and predict chemical reactions. [**Boundary:** students are not expected to know details of the electron structures of various elements.] P12.7: The formation of sugar from carbon dioxide and water requires energy to occur and releases oxygen. In the photosynthesis process that occurs in green plants, this energy is provided by light that is absorbed as the reaction occurs. Other reactions, such as the burning of fuels in the presence of oxygen, release energy. [**Boundary:**

<table>
<tr>
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<td>Students are only expected to work with simple molecules.]

P12.8: In gases or liquids, the motion of atoms or molecules leads to collisions between them. Such collisions are necessary for chemical processes to occur. This provides a qualitative model to explain the rates of chemical reactions. Higher rates occur at higher temperatures because atoms are typically moving faster.

P12.9: In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

P12.10: Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.</td>
</tr>
<tr>
<td colspan="3">Motion and Forces
How can motion be described and quantified?
What makes the motion of an object change?</td>
</tr>
<tr>
<td>P4.5: An object is in motion when its position is changing. The speed of an object is a measure of how fast its position is changing (rate of change of position). Motion has both speed and direction.

P4.6: A force acts on a single object and is due to the effect of another object that may or may not be touching it. Each force has both a strength and a direction. Forces acting on an object can change its motion or balance against other forces to hold the object in place. [Boundary: The changes in motion introduced at this level are limited to obvious visible examples such as starting, stopping, or bouncing. Balanced forces on an object moving at a steady speed are not introduced.]

P4.7: An object at rest typically has multiple forces acting on it, but</td>
<td>P8.11: Positions of objects and the directions and magnitudes of forces and motions must be described with respect to an arbitrarily chosen reference frame and using arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. [Boundary: Single static reference frame only.]

P8.12: Each force has both a magnitude and a direction at any instant. Forces acting on the same object at the same instant can be added. The net force on an object is the sum of all the forces acting on the object. Any change in an object's shape, orientation, or motion occurs because of some forces acting upon it. [Boundary: Students should not be expected to treat noncollinear forces quantitatively.]</td>
<td>P12.11: The motion of any object can only be defined and measured relative to an arbitrary chosen frame of reference and using appropriate units. Linear motion is defined at any instant by velocity, which includes both speed and direction of motion, and acceleration, which also has a magnitude and a direction. Average motion over a period of time can similarly be defined. [Boundary: Rotational motion of a solid object is recognized as different from the linear motion of its center of mass but not treated quantitatively. Torques are not addressed.]

P12.12: Momentum is defined as the mass times the velocity of the object. The net force acting on an object causes its velocity and momentum to change following the pattern: Force = rate of change of momentum. For objects with fixed</td>
</tr>
</table>

they add to give zero net force on the object. [**Boundary:** Qualitative and conceptual, but not the quantitative addition of forces, are used at this level. Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.] P4.8: Forces that do not sum to zero can cause changes in the object's speed or direction of motion. [**Boundary:** Qualitative and conceptual, but not the quantitative addition of forces, are used at this level. Technical terms, such as magnitude, velocity, momentum, and vector quantity, are not introduced at this level, but the concept that some quantities need both size and direction to be described is developed.] P4.9: The patterns of an object's motion in various situations can be observed and recorded. When that past motion exhibits a regular pattern and no new forces act upon it, future motion can be predicted from the past pattern. P4.10: Objects exert forces on each other when they are touching or colliding with each other. P4.11: Some forces between objects do not require that the objects touch each other — for example, the earth exerts a gravitational pull on other objects near or far as well as those on its surface, and magnets push or pull on other magnets or magnetic materials at a distance. [**Boundary:** Students should be able to describe, predict and explain simple gravitational and magnetic phenomena qualitatively but not quantitatively.]	P8.13: For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction. P8.14: The change in motion of an object is determined by the sum of the forces acting on it; if the net force on the object is zero, it will remain at rest or continue moving in a straight line with the same speed and direction as before. P8.15: If the net force on an object at any instant is not zero, its motion will change speed and/or direction. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger net force causes a larger change in motion. [**Boundary:** Students should not be expected to treat noncollinear forces quantitatively.] P8.16: Electric and magnetic forces between two objects can pull them together or push them apart. The magnitude depends on the magnitude of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. P8.17: The gravitational forces between any two objects with mass will pull them toward each other. The gravitational force between any two masses is very small except when one or both of the objects have large mass—e.g., Earth and the sun. P8.18: Forces that act at a distance (electric, magnetic) can be explained by fields that extend through space and can be detected and mapped by their effect on a test object (a ball, a charged object, or a magnet, respectively).	masses, this simplifies to Force = mass times acceleration. [**Boundary:** Special relativity is not treated at this grade level.] P12.13: Since the forces between any pair of objects are equal in strength but in opposite directions, they result in equal and oppositely directed changes of momentum and thus in the conservation of the total momentum of the two objects. Hence total momentum is always conserved. If a system interacts with objects outside itself (is not isolated), the total momentum of the system can change. However, any such change is balanced by changes in the total momentum of objects outside the system. This can be due to matter carrying momentum entering or leaving the system or due to a force acting on the system from objects outside it. [**Boundary:** Students are expected to apply the concept of momentum and changes of momentum qualitatively only except when all forces and motions are collinear.] P12.14: Forces between objects at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy and momentum through space. Any object with mass is a source of a gravitational field and exerts an attractive force on any other mass. The strength of the pair of forces between any pair of masses is proportional to the product of their masses and depends on the distance between the two centers of mass. P12.15: Magnets or electric currents (moving electric charges) cause magnetic field patterns; electric charges or changing magnetic fields cause electric field patterns. Conversely, any electric field applies forces on any electric charge or moving magnet, and any magnetic field applies a force on any magnet or moving electric charge. Thus, electric and magnetic effects are intimately related. Any

		charge or magnet is affected by all the electric and magnetic fields in the region. [**Boundary:** students can explain the evidence for fields in space from their effects on test objects or analyze phenomena such as an electric motor but are not expected to predict detailed patterns of fields.] P12.16: Attraction and repulsion and magnetic effects between electric charges (their electromagnetic interactions) at the atomic scale explain the structure, properties, and atomic scale processes of matter and forces between surfaces in contact.
Energy *Why do we care about keeping track of energy?* *Why are so many different phenomena associated with energy?*		
P4.12: Objects in motion have energy. The faster a given object is moving, the more energy it has. P4.13: Energy can move from place to place by the motion of objects or by sound, light, heat, or electricity. [**Boundary:** At this grade level, no attempt is made to give a precise or complete definition of energy.] P4.14: When objects collide, the forces between them can transfer energy from one object to the other. Typically, a sound is produced, showing that some energy has been transferred to the air. P4.15: Electric currents can be used to produce motion, sound, heat, or light or to recharge a battery.	P8.19: The energy of motion is called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. P8.20: Any system of objects contains energy because of the gravitational, electric, and magnetic interactions between the objects. This energy is called potential energy. The amount depends on the relative positions of objects. P8.21: The term "heat," as used in everyday language, refers both to thermal motion (the motion of atoms or molecules within a substance) and the energy of radiation (infrared and light). In science, the term heat is used only for energy transferred between two objects or systems at different temperatures. The energy associated with the movement of atoms and molecules is called thermal energy. In all matter, the atoms are moving. The more thermal energy, the more the motion. [**Boundary:** relative motion of subatomic particles is not introduced.] P8.22: Temperature is not a measure of energy; the relationship between the temperature and the	P12.17: Energy is a quantitative property of any system. The amount of energy available for processes in that system depends on the motion and interactions of matter and radiation within that system. The availability of energy limits what can occur in any system. P12.18: The underlying unity of energy becomes evident at the microscopic scale, at which the different manifestations of energy can be modeled as either the motion of particles or energy stored in fields. [**Boundary:** the quantum model of radiation as a flux of particles is not introduced.] P12.19: Energy cannot be created or destroyed, but it can be transferred from one place to another and between systems. P12.20: Mathematical expressions, which quantify how the potential energy in a system depends on its configuration (e.g., positions of objects relative to nearby Earth's surface, compression of a spring) and how kinetic energy depends on the mass and speed of the moving object, allow the concept of conservation of energy to be used to predict and describe system behavior and to infer when energy

	total energy of a system depends on the types, states, and amounts of matter present. P8.23: Any object absorbs energy from, or loses energy to, the air or other matter it is touching depending on whether it is colder or hotter than the surrounding matter. Energy is spontaneously transferred out of hotter regions or objects and into colder ones. P8.24: Electric currents are generated in multiple ways using a variety of energy transfers to produce them. We use that energy to produce the movement of machines, heat, and/or light. All the energy so "used" is eventually transferred to the surrounding environment as thermal energy. P8.25: When two objects interact, each one exerts a force on the other that can cause energy to be transferred from one object to the other.	has transferred out of a system. [**Boundary:** students are not expected to remember formulae but to interpret and apply them when provided. Target formulae include PE = mgh for objects at a height *h* above Earth's surface and PE = 1/2 kx2 for energy in a compressed or stretched spring with spring constant *k*.] P12.21: When two objects interacting through a field change relative position, the energy stored in the field is changed. P12.22: Although energy cannot be destroyed, it can be converted to a less useful form, becoming thermal energy in the surrounding environment. P12.23: Nuclear fusion processes in the sun release energy that eventually leaves the sun's surface as radiation and particle flows. P12.24: Light and infrared radiation arriving on Earth from the sun is a major source of energy for life on Earth. Sunlight absorbed by plants provides the energy for photosynthesis to occur. The energy absorbed in earth and water is eventually reradiated as infrared radiation that transfers heat out of the atmosphere. The average temperature of the atmosphere is determined by how long the energy stays in the system until it is reradiated into space from the top of the atmosphere. P12.25: Solar cells are human-made devices that absorb sunlight and produce electrical currents. As such, solar cells serve to capture energy from the sun.
Waves and Their Role as Carriers of Information *How can information be encoded, and sent over long distances and decoded?* *What physical phenomena do we use to do this?*		
P4.16: Waves are regular patterns of motion in matter. Waves can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; it does	P8.26: A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. Waves carry energy from place to place and can be used to encode information.	P12.26: The speed of a wave depends on the type of wave and on properties of the medium through which it is passing. P12.27: Information can be digitized (e.g., a picture stored as

not move in the direction of the wave except when the water meets the beach. P4.17: Sound can make matter vibrate, and vibrating matter can make a sound. [**Boundary:** qualitative ideas about speed of vibration only] P4.18: An object can be seen when light produced by it or reflected from its surfaces enters the eyes. P4.19: Some materials allow light to pass through them, others allow only some light through, and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. P4.20 Mirrors can be used to redirect a light beam. [**Boundary:** The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.]	P8.27: Waves of the same type can differ in amplitude (height or intensity of the wave) and wavelength (spacing between wave peaks). [**Boundary:** The assessment at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.] P8.28: A sound wave needs a medium through which it is transmitted. The medium can be solid, liquid, or gas. P8.29: When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves. P8.30: Appropriately designed technologies make it possible to detect and interpret many types of signals that cannot be sensed directly. Many modern communication devices use digitized signals (sent as wave pulses) to encode and transmit information.	the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of pulses. P12.28: Many seemingly unrelated phenomena, from x-rays to radio waves, are electromagnetic waves like light but have very different wavelengths and frequencies. Electromagnetic waves are produced by patterns of motion of charges or magnets. The wave is a pattern of changing electric and magnetic fields. P12.29: Many frequencies of electromagnetic waves are absorbed in matter. Absorption and emission of such waves by a single atom occur only for characteristic (specific) frequencies for each type of atom, so these phenomena can be used to identify the presence of particular elements in materials. P12.30: Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. [**Boundary:** Details of quantum physics are not formally taught at this grade level.]
NAEP Life Science Disciplinary Concepts		
Grade 4	Grade 8	Grade 12
From Molecules to Organisms: Structures and Processes *How do organisms live, grow, respond to their environment, and reproduce?*		
L4.1: Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. [**Clarification:** Examples of structures could include thorns, stems, roots, colored petals, heart, stomach, lung, brain, and skin.]	L8.1: All living things are made up of cells, which are the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular). [**Clarification:** Emphasis is on developing evidence that living things are made of cells, distinguishing between living and	L12.1: Systems of specialized cells within organisms help them perform the essential functions of life, which involve chemical reactions that take place between different types of molecules, such as water, proteins, carbohydrates, lipids, and nucleic acids. [**Boundary:** Assessment does not include identification of specific cell or tissue types, whole-body

[**Boundary:** Assessment is limited to macroscopic structures within plant and animal systems.] L4.2: Reproduction is essential to the continued existence of every kind of organism. Plants and animals have unique and diverse life cycles. [**Clarification:** Changes organisms go through during their life form a pattern.] [**Boundary:** Assessment of plant life cycles is limited to those of flowering plants. Assessment does not include details of human reproduction.] L4.3: All animals need food in order to live and grow. They obtain their food from plants or from other animals. Plants need water and light to live and grow. [**Clarification:** Examples of patterns could include that animals need to take in food but plants do not, the different kinds of food needed by different types of animals, the requirement of plants to have light, and that all living things need water.]	nonliving things, and understanding that living things may be made of one cell or many and varied cells.] L8.2: Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell. [**Clarification:** Emphasis is on the cell functioning as a whole system and the primary role of identified parts of the cell, specifically the nucleus, chloroplasts, mitochondria, cell membrane, and cell wall.] [**Boundary:** Assessment of organelle structure/function relationships is limited to the cell wall and cell membrane. Assessment of the function of the other organelles is limited to their relationship to the whole cell. Assessment does not include the biochemical function of cells or cell parts.] L8.3: In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions. [**Clarification:** Emphasis is on the conceptual understanding that cells form tissues and tissues form organs specialized for particular body functions. Examples could include the interaction of subsystems within a system and the normal functioning of those systems.] [**Boundary:** Assessment does not include the mechanism of one body system independent of others. Assessment is limited to the circulatory, excretory, digestive, respiratory, muscular, and nervous systems.] L8.4: Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. [**Clarification:** Emphasis is on using models such as Punnett	systems, specific protein structures and functions, or the biochemistry of protein synthesis.] L12.2: All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins. [**Boundaries:** (1) Assessment does not include identification of specific cell or tissue types, whole-body systems, specific protein structures and functions, or the biochemistry of protein synthesis. (2) Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.] L12.3: Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. [**Clarification:** Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [**Boundary:** Assessment does not include interactions and functions at the molecular or chemical reaction levels.] L12.4: Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (through negative feedback) what is going on inside the living system. [**Clarification:** Emphasis is on the concept rather than cellular mechanisms of homeostasis.

	squares, diagrams, and simulations to describe the cause-and-effect relationship of gene transmission from parent(s) to offspring and resulting genetic variation.] L8.5: Animals engage in characteristic behaviors that increase the odds of reproduction. [**Clarification:** Examples of behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalization of animals and colorful plumage to attract mates for breeding. Examples of animal behaviors that affect the probability of plant reproduction could include transferring pollen or seeds and creating conditions for seed germination and growth. Examples of plant structures could include bright flowers attracting butterflies that transfer pollen, flower nectar and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.] L8.6: Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features for reproduction. [**Clarification:** Examples of behaviors that affect the probability of animal reproduction could include nest building to protect young from cold, herding of animals to protect young from predators, and vocalization of animals and colorful plumage to attract mates for breeding. Examples of animal behaviors that affect the probability of plant reproduction could include transferring pollen or seeds and creating conditions for seed germination and growth. *Examples of plant structures could include bright flowers attracting butterflies that transfer pollen, flower nectar and odors that attract insects that transfer pollen, and hard shells on nuts that squirrels bury.*]	Examples of investigations could include heart rate response to exercise, stomata response to moisture and temperature, and root development in response to water levels.] [**Boundary:** Assessment does not include the cellular processes involved in the feedback mechanism.] L12.5: In multicellular organisms, individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. (Asexual reproduction also occurs in some organisms.) Cellular division and differentiation produce and maintain a complex organism composed of systems of tissues and organs that work together to meet the needs of the whole organism. [**Boundary:** Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis.] L12.6: The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. [**Clarification:** Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [**Boundary:** Assessment does not include specific biochemical steps.] L12.7: The sugar molecules thus formed contain carbon, hydrogen, and oxygen: Their hydrocarbon backbones are used to make amino acids and other carbon-based

	L8.7: Genetic factors and local conditions affect the growth of the adult plant. [**Clarification:** Examples of local environmental conditions could include availability of food, light, space, and water. Examples of genetic factors could include large-breed cattle and species of grass affecting growth of organisms. Examples of evidence could include drought decreasing plant growth, fertilizer increasing plant growth, different varieties of plant seeds growing at different rates in different conditions, and fish growing larger in large ponds than they do in small ponds.] [**Boundary:** Assessment does not include genetic mechanisms, gene regulation, or biochemical processes.] L8.8: Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen into the atmosphere. These sugars can be used immediately or stored for growth or later use. [**Clarification:** Emphasis is on tracing movement of matter and flow of energy.] [**Boundary:** Assessment does not include the biochemical mechanisms of photosynthesis.] L8.9: Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. [**Clarification:** Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [**Boundary:** Assessment does not include details of the chemical reactions for photosynthesis or respiration.]	molecules that can be assembled into larger molecules (such as proteins or DNA), used, for example, to form new cells. [**Clarification:** Emphasis is on using evidence from models and simulations to support explanations.] [**Boundary:** Assessment does not include the details of the specific chemical reactions or identification of macromolecules.] L12.8: As matter flows and energy transfers through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. [**Clarification, part 1:** Emphasis is on using evidence from models and simulations to support explanations.] [**Boundary, part 1:** Assessment does not include the details of the specific chemical reactions or identification of macromolecules.] [**Clarification, part 2:** Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [**Boundary, part 2:** Assessment should not include identification of the steps or specific processes involved in cellular respiration.] L12.9: As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example, aerobic (in the presence of oxygen) cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken, and new compounds are formed that can transport energy to muscles. Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. Matter and energy are conserved in each change. This is true of all biological

<table>
<tr><td></td><td></td><td>systems, from individual cells to ecosystems.
[Clarification: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.]
[Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]</td></tr>
<tr><td colspan="3">Ecosystems: Interactions, Energy, and Dynamics
How and why do organisms interact with their environment and what are the effects of these interactions?</td></tr>
<tr><td>L4.4: Animals depend on their surroundings to get what they need, including food, water, shelter, and a favorable temperature. Animals depend on plants or other animals for food.

L4.5: Plants depend on air, water, minerals (in the soil), and light to grow.

L4.6: Plants depend on animals for pollination or to move their seeds around. Different plants survive better in different settings because they have varied needs for water, minerals, and sunlight.

L4.7: When the environment changes in ways that affect a place’s physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, some move to new locations, some move into the transformed environment, and some die.

L4.8: When the environment changes in ways that affect a place’s physical characteristics, temperature, or availability of resources, some organisms survive and reproduce, some move to new locations, some move into the transformed environment, and some die.</td><td>L8.10: The food of almost any kind of animal can be traced back to plants. Organisms are related in food webs in which some animals eat plants for food and other animals eat the animals that eat plants. Some organisms, such as fungi and bacteria, break down dead organisms (both plants or plant parts and animals) and therefore operate as “decomposers.” Decomposition eventually restores (recycles) some materials back to the soil. Organisms can survive only in environments in which their particular needs are met. A healthy ecosystem is one in which multiple species of different types are each able to meet their needs in a relatively stable web of life. Newly introduced species can damage the balance of an ecosystem.

L8.11: Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.

L8.12: Growth of organisms and population increases are limited by access to resources.

L8.13: In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction.</td><td>L12.10: Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.

L12.11: Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.

L12.12: Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. Some matter reacts to</td></tr>
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	L8.14: Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. L8.15: Matter cycles between the air and soil and among plants, animals, and microbes as these organisms live and die. Organisms obtain gases and water from the environment and release waste matter (gas, liquid, or solid) back into the environment. L8.16: Food webs are models that demonstrate how matter and energy are transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem. [**Clarification:** Emphasis is on the conservation of matter and flow of energy into and out of various ecosystems and definition of the boundaries of the system.] [**Boundary:** Do not include the use of chemical reactions to describe the process.] L8.17: Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	release energy for life functions, some matter is stored in newly made structures, and much is discarded. L12.13: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. [**Boundary:** Do not include the specific chemical steps of photosynthesis and respiration.] L12.14: A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. L12.15: Moreover, anthropogenic changes (changes induced by human activity) in the environment — including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

	L8.18: Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. The completeness or integrity of an ecosystem's biodiversity is often used as a measure of its health.	
Heredity: Inheritance and Variation of Traits *How are the characteristics of one generation passed to the next?* *How can individuals of the same species and even siblings have different characteristics?*		
L4.9: Many characteristics of organisms are inherited from their parents. L4.10: Other characteristics result from individuals' interactions with the environment, which can range from diet to learning. Many characteristics involve both inheritance and environment. [**Clarification:** Examples of the environment affecting a trait could include that normally tall plants grown with insufficient water are stunted and that a pet dog that is given too much food and little exercise may become overweight.] L4.11: Different organisms vary in how they look and function because they have inherited different characteristics from their parents. L4.12: The environment also affects the traits that an organism develops. [**Clarification:** Patterns are the similarities and differences in traits shared between offspring and their parents or among siblings. Emphasis is on organisms other than humans.] [**Boundary:** Assessment does not include genetic mechanisms of inheritance and prediction of traits. Assessment is limited to nonhuman examples.]	L8.19: Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. L8.20: In sexually reproducing organisms, variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. [**Clarification:** Emphasis is on conceptual understanding that changes in genetic material may result in making different proteins.] [**Boundary:** Assessment does not include specific changes at the molecular level, mechanisms for protein synthesis, or specific types of mutations.] L8.21: In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. L8.22: In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to	L12.16: Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no currently known function. [**Clarification Statement:** Emphasis is on using data to support arguments for the way variation occurs.] [**Boundary:** Assessment does not include the phases of meiosis or the biochemical mechanism of specific steps in the process.] L12.17: In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. L12.18: Environmental factors also affect expression of traits and hence affect the probability of occurrences of traits in a population. Thus, the variation and distribution of traits observed depends on both genetic and environmental factors.

	the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. [**Clarification:** Emphasis is on using models such as Punnett squares, diagrams, and simulations to describe the cause-and-effect relationship of gene transmission from parent(s) to offspring and resulting genetic variation.]	[**Clarification:** Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.] [**Boundary:** Assessment does not include Hardy-Weinberg calculations, the phases of meiosis, or the biochemical mechanism of specific steps in the process.]
Biological Evolution: Unity and Diversity *How can there be so many similarities among organisms yet so many different kinds of plants, animals, and microorganisms?* *How does biodiversity affect humans?*		
L4.13: Some kinds of plants and animals that once lived on Earth are no longer found anywhere. Fossils can provide evidence about these types of organisms that lived long ago and about the nature of their environments. [**Clarification:** Examples of evidence could include type, size, and distributions of fossil organisms. Examples of fossils and environments could include marine fossils found on dry land, tropical plant fossils found in Arctic areas, and fossils of extinct organisms.] [**Boundary:** Assessment does not include identification of specific fossils or present plants and animals. Assessment is limited to major fossil types and relative ages.] L4.14: Sometimes the differences in characteristics between individuals of the same species provide advantages in surviving, finding mates, and reproducing. [**Clarification:** Examples might include that plants that have larger thorns than other plants may be less likely to be eaten by predators and that animals that have better camouflage coloration than other animals do may be more likely to survive and therefore more likely to leave offspring.] L4.15: Populations of organisms live in a variety of habitats, and change in those habitats affects the organisms living there. Changes in	L8.23: The collection of fossils and their placement in chronological order (the fossil record) documents the existence, diversity, extinction, and change of many life-forms throughout the history of life on Earth. [**Clarification:** Emphasis is on finding patterns of changes in the level of complexity of anatomical structures in organisms and the chronological order of fossil appearance in the rock layers.] [**Boundary:** Assessment does not include the names of individual species or geological eras in the fossil record.] L8.24: Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. [**Clarification:** Emphasis is on explanations of the evolutionary relationships among organisms in terms of similarities or differences of the gross appearance of anatomical structures.] L8.25: Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully formed anatomy. [**Clarification:** Emphasis is on inferring general patterns of	L12.19: Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. [**Clarification:** Emphasis is on a conceptual understanding of the role each line of evidence has relating to common ancestry and biological evolution. Examples of evidence could include similarities in DNA sequences, anatomical structures, and order of appearance of structures in embryological development.] [**Boundary:** Assessment does not require familiarity with the details of specific technologies or organisms.] L12.20: Natural selection occurs only when there is both (a) variation in the genetic information between organisms in a population and (b) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. [**Clarification:** Emphasis is on explaining the genetic basis of a

the habitat may affect some kinds of organisms more than others. [**Clarification:** Examples of environmental changes could include changes in land characteristics, water distribution, temperature, food, and other organisms.]	relatedness among embryos of different organisms by comparing the macroscopic appearances.] [**Boundary:** Assessment of comparisons is limited to gross appearance of anatomical structures in embryological development.] L8.26: In artificial selection, humans have the capacity to influence certain characteristics of other organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed onto offspring. [**Clarification:** Examples might include the influence of humans on genetic outcomes in other organisms through artificial selection, such as genetic modification, animal husbandry, or gene therapy. One might give such examples as breeds of dogs, horses, and cattle or development of modern maize from teosinte.] L8.27: Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. [**Clarification:** Emphasis is on providing an evidence-based explanation that includes change in environment conditions, advantage of heritable traits for survival and reproduction, and change in traits over time.] [**Boundary:** Assessment requires evidence of heritability but not precise gene-to-protein mechanism. Assessment does not include Hardy-Weinberg calculations.] L8.28: Changes in biodiversity can influence humans' resources and ecosystem services that humans rely on.	factor that led to change in traits in a population.] L12.21: The traits that positively affect survival are more likely to be reproduced and thus are more common in the population. [**Clarification:** Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations about the traits' advantages.] [**Boundary:** Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.] L12.22: Evolution by natural selection results from the interaction of four factors: (a) the potential for a species to increase in number, (b) the genetic variation of individuals in a species due to mutation and sexual reproduction, (c) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (d) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. [**Clarification:** Emphasis is on using evidence to explain the influence each of the four factors has on the number of organisms, behaviors, morphology, or physiology in terms of ability to compete for limited resources and subsequent survival of individuals and adaptation of species. Examples of evidence could include mathematical models such as simple distribution graphs and proportional reasoning.] [**Boundary:** Assessment does not include other mechanisms of evolution, such as genetic drift, gene flow through migration, and coevolution.] L12.23: Natural selection leads to adaptation; that is, it leads to a population dominated by organisms that are anatomically, behaviorally,

	[**Clarification:** Biodiversity includes genetic variation within a species in addition to species variation in different habitats and ecosystem types (e.g., forests, grasslands, wetlands). Examples of humans' resources that can be influenced by changes in biodiversity include food, energy, and medicine. Examples of ecosystem resources that humans rely on could include water purification, nutrient recycling, prevention of soil erosion, and pollination.]	and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms that have an advantageous heritable trait in a population leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. [**Clarification:** Emphasis is on analyzing and using shifts in numerical distribution as evidence to support explanations that tie trait advantage to changes in frequency.] [**Boundary:** Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.] L12.24: Changes in the physical environment, whether naturally occurring or human induced, have contributed to the expansion of some species, and the emergence of new distinct species as populations diverge under different conditions. [**Clarification:** Emphasis is on determining cause-and-effect relationships for how changes to the environment such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of change of the environment affect distribution or disappearance of traits in species.] L12.25: Changes in the physical environment, whether naturally occurring or human induced, have contributed to some species becoming extinct when members can no longer survive and reproduce in their altered environments. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost. [**Clarification:** Emphasis is on explaining how changes to the environment, such as deforestation, fishing, application of fertilizers, drought, flood, and the rate of

		change of the environment, affect the survivability of species.] L12.26: Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also reducing biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem function and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. [**Clarification:** Examples of human activities can include urbanization, the building of dams, and dissemination of invasive species.]
NAEP Earth and Space Sciences Disciplinary Concepts		
Grade 4	Grade 8	Grade 12
Earth's Place in Space *How do we explain Earth's relationship to objects in space?*		
E4.1: Some objects in the solar system can be seen with the naked eye, and some require tools. E4.2: Many objects in the night sky change position and are not always visible due to Earth's rotation. The patterns of motion can be observed, described, and predicted. [**Clarification:** Examples of patterns could include that the sun and moon appear to rise in one part of the sky, move across the sky, and set; and stars other than our sun are visible at night but not during the day.] [**Boundary:** Assessment is limited to relative amounts of daylight, not quantification of the hours or time of daylight.] E4.3: The sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their size and distance from Earth. [**Boundary:** Assessment is limited to relative distances, not sizes, of	E8.1: The orbits of Earth around the sun and of the moon around Earth, together with the rotation of Earth on an axis that runs from its north pole to its south pole, cause observable patterns. These patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models. [**Clarification:** The patterns of motion of the objects in the solar system can be described and predicted based on observations and an understanding of gravity. The patterns can include phases of the moon and different positions of the sun, moon, and stars at different times of the day, month, and year.] [**Boundary:** Assessment is limited to the patterns of motion used to explain seasons, tides, and phases of the moon; assessment does not include the names or shapes of specific constellations.]	E12.1: Orbiting objects can be described in terms of their elliptical paths around the sun as explained by Kepler's laws. [**Clarification:** Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] [**Boundary:** Mathematical representations for the gravitational attraction of bodies and Kepler's laws of orbital motions should not deal with more than two bodies or involve calculus.] E12.2: Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the orientation of the planet's axis of rotation—both occurring over tens to hundreds of thousands of years—have altered the intensity and distribution of sunlight falling on Earth. These changes lead to variations in the energy transfer into and out of Earth's systems,

stars. Assessment does not include other factors that affect apparent brightness (such as stellar masses, age, stage).]	E8.2: The solar system consists of the sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the sun by its gravitational pull on them. E8.3: We can detect properties of objects in the solar system using the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. [**Clarification:** Examples of properties could include size, density, orbital period, and composition (rocky, gaseous, icy).] [**Boundary:** Assessment does not include recalling facts about properties of the planets and other solar system bodies or specific probes.]	resulting in gradual changes in climate. [**Clarification:** Emphasis is on the orbital variation, and one example of the effect of this variation is changes in Earth's climate.] E12.3: The study of stars' light spectra and relative brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
Earth's Systems *What are Earth's systems and how do they change?*		
E4.4: Moving air (wind), moving water, and living organisms change the shape of the land. Rocks making up the land can be broken by natural processes into smaller pieces, such as sand and gravel, which can be moved by wind and water. These pieces can be picked up, transported and deposited, but don't disappear. [**Clarification:** Weathering, erosion, transport, and deposition are separate but interacting processes. The energy driving these processes are driven directly by gravity and less directly by energy from the sun.] E4.5: Maps can be used to make observations of patterns of geological features and phenomena. [**Clarification:** Examples include earthquakes and volcanoes, mountain ranges, and ocean floor structures. The surface of Earth, above and below the ocean surface, can contain mountain ranges, valleys and ocean trenches, and volcanoes. Earthquakes and	E8.4: The transfer of energy and the flow of matter cycling within and between Earth's systems (geosphere, atmosphere, biosphere, hydrosphere) produces chemical and physical changes in Earth's materials and surface. These interactions shape the surface of Earth, the distribution of materials on Earth, and patterns of weather and climate. [**Clarification:** Emphasis is on solid and molten rock, soil and sediments, water and ice, and air as well as living things, including humans.] E8.5: Earth is not a fully solid object. It is divided into multiple layers, including the solid, rigid outer layer of Earth. Earth's outermost layer is broken into pieces, or plates. E8.6: Over long periods of time and at very slow speeds, plates move great distances and interact in multiple ways. Each type of plate interaction produces unique	E12.4: Motions of the mantle and Earth's plates occur primarily through thermal convection, which involves the cycling of matter due to the outward transfer of energy from Earth's interior, and the gravitational movement of denser materials toward the interior. [**Clarification:** Heat generated by the radioactive decay of unstable isotopes provides a source of energy in the Earth system. The thermal differential between Earth's interior and surface provides the primary driver for convection within the mantle.] E12.5: Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding Earth's geologic history and potential future. [**Clarification:** Driven by convection, lithospheric plate motion is divided by slab-pull (where subducted plates sink into Earth), ridge-push (where new crust is created), and lateral shear

volcanoes can occur on land or the ocean floor.] E4.6: Local, regional, and global patterns of rock formations reveal changes over time due to Earth forces, such as the cutting of rock layers by a river, or a change of rocks from those that formed in the ocean to those that formed on land. The presence and location of certain fossil types indicate the order in which rock layers were formed. [**Boundary:** Assessment does not include specific knowledge of the mechanism of rock formation or memorization of specific rock formations, layers, or fossil organisms. The expression of time is limited to sequences that represent relative time.]	geological features and patterns of phenomena. [**Clarification:** Tectonic processes continually generate new ocean seafloor at ridges and destroy old seafloor at trenches by subduction. Plates can move toward one another, apart from one another, or alongside one another. Each type of plate interaction produces unique geological features and patterns of phenomena, such as mountains, basins, earthquakes, and volcanoes. Plate movements are responsible for distribution of rocks and minerals within Earth's crust.] E8.7: The geologic time scale interpreted from rock strata provides a way to organize Earth's history. Analyses of rock strata and the fossil record provide only a relative scale of time, not an absolute age. [**Clarification:** Major historical events include the formation of mountain chains and ocean basins, the evolution and extinction of particular terrestrial and marine organisms, volcanic eruptions, periods of ice cap and ice sheet expansion, and the development of watersheds through glacial and fluvial erosion.] [**Boundary:** Assessment does not include recalling the names of specific periods or epochs and events within them. Major periods in Earth's history can be defined in terms of significant or dominant life-forms.]	(sideways drag under the plates themselves.] E12.6: The distribution of rocks and minerals observed in a given location today is the result of the tectonic activity in the past and present for that location. E12.7: The decay of radioactive isotopes in minerals and rocks provides a way of dating rock formations, thereby placing them within the scale of geological time. Tectonic processes continually generate new ocean seafloor at ridges and destroy old seafloor at trenches, resulting in younger rock on the ocean floor compared to continental rock. [**Boundary:** The use of radioactive decay is most easily expressed in terms of geometric progression only. Items should be matched carefully with Algebra I learning expectations for exponents.]
E4.7: Water is found in oceans, rivers, lakes, and ponds. The downhill movement of water as it flows to the ocean moves soil and rocks from one place to another, shaping the appearance of the land. As the temperature changes, it can change from liquid to solid, or solid to liquid. [**Clarification:** Almost all of Earth's water is found in the oceans and is not freshwater. Most of Earth's freshwater is found frozen in glaciers or as liquid under the	E8.8: Water continually cycles within and among land, ocean, and atmosphere. The complex patterns of the changes and the movement of water in the atmosphere and the oceans are major determinants of local weather patterns. E8.9: Water's movements—both on the land and underground—change the land above and below Earth's surface. [**Clarification:** Ocean currents are the movement of water in the world's oceans. They are driven by	E12.8: Interactions between the hydrosphere and the geosphere are influenced by water's unique properties, including its exceptional capacity to absorb, store, and release large amounts of energy; transmit sunlight; expand upon freezing; dissolve and transport materials; separate different chemical elements, and change the properties of rocks. [**Clarification:** The movement of water causes weathering, erosion, and deposition, all of which can

ground. Phase change discussions are limited to phenomena that are directly observable.] E4.8: Scientists record the patterns of the weather across different times and areas so that they can make predictions about what kind of weather might happen next. [**Boundary:** Assessment focuses on weather, not on climate.]	differences in the density of water from temperature and salinity and by prevailing winds and interactions with land masses.] E8.10: Weather and climate are influenced by interactions involving sunlight, oceans, the atmosphere, ice, landforms, and living things. Because the interactions are so complex, weather patterns in a given location can be predicted only probabilistically. E8.11: Influences on the climate at a given place vary with latitude, altitude, local and regional geography, and oceanic and atmospheric flow patterns.	change the surface of Earth and concentrations of useful materials on a physical level. On a chemical level, the relative enrichment or depletion of one chemical material or another is often expressed as fractionation.] E12.9: The foundation for Earth's global climate system is the electromagnetic radiation from the sun as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems and this energy's reradiation into space. E12.10: Climate change can occur when certain parts of Earth's systems are altered. Geological evidence indicates that past climate changes were either sudden changes caused by alterations in the atmosphere; longer term changes (e.g., ice ages) due to variations in solar output, Earth's orbit, or the orientation of its axis; or even more gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen. The time scales of these changes varied from a few tens of years to millions of years.
Earth and Human Activity *How do Earth's system processes and human activities affect each other?*		
E4.9: Humans use natural resources for everything they do. All living things need water, air, and resources from the land or ocean, and they live in places containing the things they need. [**Clarification:** Examples of human usage could include the use of soil and water to grow food, wood to burn for heat or building shelters, and materials such as iron or copper extracted from Earth to make cooking pans.] E4.10: A variety of natural hazards result from natural processes. Depending on where one lives, some kinds of natural hazards are more likely than others.	E8.12: Humans depend on Earth's geosphere, hydrosphere, atmosphere, and biosphere for many different resources. All materials, energy, and fuels humans use are ultimately derived from naturally occurring sources, and their use affects the environment in multiple ways. E8.13: Natural resources are distributed unevenly around the planet as a result of past geologic processes. Many types of minerals, fresh water, and biosphere resources are limited, and many are not renewable or replaceable over human lifetimes. [**Clarification:** Examples of the	E12.11: Resource availability has guided the development and diversity of human societies. All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors. [**Clarification:** Potential examples of the impact of human resource use and extraction could include fuels, building materials, agricultural products, modes of transportation, and development of new technologies that produce less pollution and waste and that

E4.11: Weather scientists forecast severe weather so that the communities can prepare for and respond to these events. Humans cannot prevent natural hazards but can take precautions to reduce their impacts. [**Clarification:** Examples of weather hazards and responses could include erecting barriers to prevent flooding, planting trees to hold soil and prevent landslides, using strong materials and designs to create wind-resistant roofs, or constructing earthquake-proof structures.] E4.12: Changes to Earth's global average temperature impact the lives of humans and other organisms in many different ways, some of which can be tracked in observable ways. [**Clarification:** Examples include heavy rains, floods, forest fires, extreme temperatures, and drought.] E4.13: Things that people do to live comfortably can affect the world around them. But they can make choices that reduce their impacts on the land, water, air, and other living things. [**Clarification:** Potential examples include recycling and reusing, using energy efficient materials, and using renewable resources.]	natural resources for energy and materials used by humans could be distinguished between renewable and nonrenewable resources.] E8.14: Some natural hazards, such as volcanic eruptions and severe weather, are preceded by observable phenomena. Others, such as earthquakes and tornadoes, occur suddenly and often with very little or no warning. E8.15: Recording the patterns of natural hazards in a region, combined with cultivating an understanding of related geologic forces, can help forecast the locations and likelihoods of future events. [**Clarification:** Examples of natural hazards can be from interior processes (e.g., earthquakes, volcanoes, sinkholes) or from surface processes (e.g., landslides, river flooding/erosion, avalanches) or severe weather (e.g., hurricane storm surges, river overflows.] E8.16: Human activities, such as the release of greenhouse gases from the burning of fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). E8.17: Reducing or mitigating the effects of climate change depends on better understanding of the role of human inputs into climate science models and mechanisms. [**Clarification:** Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Emphasis is placed on the major role that human activities play in causing the rise in global temperatures.] E8.18: Evolution is shaped by Earth's varying geological conditions. Sudden changes in	maintain ecosystem/ecological services.] E12.12: Natural hazards and geologic events have shaped the course of human history; they have significantly altered the sizes of human populations and have driven human migrations. E12.13: Natural hazards can be local, regional, or global in origin, and their risks increase as Earth's population increases. Land use and planning can affect the frequency and intensity of the impacts of some natural hazards. [**Clarification:** Examples of land use and planning could be either positive (e.g., stormwater impoundment, rain gardens, rain barrel storage, weirs on rivers) or negative (extensive paved landscape, absence of tree canopies, reducing the amount of arable land, poor housing designs/zoning).] E12.14: Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year. [**Clarification:** Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (on such things as sea level, glacial ice volumes, or atmosphere and ocean composition).] [**Boundary:** Assessment does not include running computational representations but is limited to using the published results of scientific computational models.] E12.15: The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that

	conditions (e.g., meteor impacts, major volcanic eruptions) have caused mass extinctions, but these changes, as well as more gradual ones, have ultimately allowed other life-forms to flourish in their place. [**Clarification:** The evolution and proliferation of living things over geological time have in turn changed the rates of weathering and erosion of land surfaces, altered the composition of Earth's soils and atmosphere, and affected the distribution of water in the hydrosphere.] E8.19: Changes to Earth's environments can have different impacts (negative or positive) for different living things. Human activities have significantly altered the biosphere and geosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species or creating conditions that favor natural disasters. E8.20: Applying engineering solutions, new technology, and other creative ideas can mitigate negative impacts on Earth's resources and environment, or they could magnify them if not carefully monitored. [**Clarification:** Conditions for preserving and preventing destruction of the environment could include measures to prevent erosion of soil (e.g., build channels, plant trees, shrubs, and grasses); to slow down and disturb rapid flow of water to prevent river bank erosion (e.g., construction of dams to hold and slowly release water, placement of rocks along banks); and to regulate sources of pollution, such as emissions from factories and power plants or the runoff from agricultural activities.]	exists on it. [**Clarification:** Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems. Examples include how life-forms altered the early hydrosphere and atmosphere, how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided new habitats, or how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants.] [**Boundary:** Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.] E12.16: The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. E12.17: When the source of an environmental problem is understood, human activities can be regulated to mitigate global impacts (e.g., ice melting and sea level rising, warming oceans). [**Clarification:** Scientists and engineers can make major contributions by developing technologies and optimizing systems that produce less pollution and waste and that preclude ecosystem degradation. Engineering and technology solutions to reduce or limit amounts of carbon dioxide, methane, and other greenhouse gases in the atmosphere could include reduction/elimination of the use of fossil fuels, increasing use of electrical power with solar panels.]

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NAEP SCIENCE CROSSCUTTING CONCEPTS

Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation and in design. (American Association for the Advancement of Science, 1993)

These crosscutting concepts were selected for their value across the sciences and in engineering. These concepts help provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world. (NRC Framework, 2012)

The crosscutting concepts used in this NAEP framework are based on those defined in the NRC Framework for K–12 Science Education, with some renaming introduced to clarify what is important to stress in each of them. Students who have learned to use these concepts in many contexts as tools for sensemaking (such as a guide to asking productive questions or as a lens to examine a model under development) will be prepared to bring them to bear to address unfamiliar phenomena or problems. These concepts are deeply linked with the practices of science and engineering and are conceptual tools that guide effective and reflective practice. In an assessment context, a student may use one or more of them in developing a successful response but provide no evidence of having done so. Assessments that are intended to elicit student use of these concepts must therefore also explicitly demonstrate such evidence if it is to be required as part of a successful response.

SEVEN CROSSCUTTING CONCEPTS OF THIS FRAMEWORK

The seven crosscutting scientific and engineering concepts for the NAEP Science Assessment are as follows:

1. **Patterns**
2. **Mechanisms and explanation: Cause and effect**
3. **Scale, proportion, and quantity**
4. **Systems and system models/systems thinking**
5. **Conservation, Flows, and Cycles: Tracking Energy and Matter**
6. **Relationships between structure and function**
7. **Conditions for stability and change in systems.**

Descriptions for each of these concepts are given in the NRC Framework for K–12 Science Education and elsewhere. In this document we elaborate the expected learning of students for each of them at Grades 4, 8, and 12 in the tables below.

1. **Patterns:** Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them		
Grade 4	Grade 8	Grade 12
C4.1: Similarities and differences in patterns can be used to sort,	C8.1: Graphs, charts, and images can be used to represent and	C12.1: Classifications or explanations used at one scale may

classify, communicate, and explain, with various representations (such as physical graphs or diagrams) to describe and analyze features of simple natural phenomena and designed products. C4.2: Repeating patterns of change can be used to make predictions.	identify patterns in data and provide estimations of chance events. C8.2: Patterns can be used to identify cause and effect relationships and estimate probabilities of events. C8.3: Many macroscopic patterns are related to the nature of microscopic and atomic-level structure.	fail or need revision when measures and information from smaller or larger scales is introduced, thus requiring improved or new considerations regarding evidence, investigations, and experiments. C12.2: Patterns of performance of designed systems can be analyzed and interpreted to troubleshoot, reengineer, and improve the system. C12.3: Mathematical and statistical/probabilistic representations are needed to identify or describe patterns and to build models and explain mechanisms.
2. Mechanisms and Explanation: Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering		
Grade 4	Grade 8	Grade 12
C4.3: Cause-and-effect relationships are routinely identified, tested, and used to explain changes. C4.4: Events that occur together with regularity might have a cause-and-effect relationship or might have some other explanation.	C8.4: Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation. C8.5: Cause-and-effect relationships may be used to predict phenomena in natural or designed systems. C8.6: Phenomena may have more than one cause, and some cause-and-effect relationships in systems can only be described using probability.	C12.4: Empirical evidence is used to identify patterns and apply them to build models and explain mechanisms for phenomena. C12.5: Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. C12.6: Cause-and-effect relationships can often be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system.
3. Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales and to recognize proportional relationships between different quantities as scales change		
Grade 4	Grade 8	Grade 12
C4.5: Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods. C4.6: Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume.	C8.7: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. C8.8: The observed function of natural and designed systems may change with scale.	C12.7: The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. C12.8: Some systems can only be studied indirectly, as they are too small, too large, too fast, or too slow to observe directly.

	C8.9: Proportional relationships (e.g., speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. C8.10: Scientific relationships can be represented through the use of algebraic expressions and equations. C8.11: Phenomena that can be observed at one scale may not be observable at another scale.	C12.9: Patterns observable at one scale may not be observable or exist at other scales. C12.10: Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. C12.11: Algebraic thinking is used to examine models and scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).
4. Systems and System Models/Systems Thinking: A system is an organized group of related objects or components: System models can be used for understanding and predicting the behavior of systems		
Grade 4	Grade 8	Grade 12
C4.7: A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot. C4.8: To understand a phenomenon it often helps to develop a model of the system in which it occurs. C4.9: A model specifies the important objects or components of the system and the roles that they play in the phenomenon.	C8.12: Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. C8.13: A model that represents a system can be used to help analyze and explain phenomena occurring in that system. C8.14: A model representing a system specifies its essential components and quantities and the relationships or interactions between them. C8.15: Models include representation of both material and conceptual aspects of the system, such as representations of forces between objects or relationships between species. C8.16: Models are limited in that they may only represent those aspects of the system relevant to a particular phenomenon. C8.17: System models are revised and refined based on a cycle of testing and by incorporating new ideas learned from others. C8.18: Engineers design systems to achieve particular functions or do specific tasks.	C12.1: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. C12.13: Flows of matter and transfers of energy into, out of, and within the system are analyzed and described using a system model. C12.14: A system model can be augmented to include a statement of mathematical relationships between quantities in the system. C12.15: Models can be used to simulate and predict the behavior of a system or outcome pattern. Such predictions have limitations on their precision and reliability due to the assumptions and approximations inherent in the model. C12.16: Computational models that include mathematical relationships between quantities can be used to simulate system evolution under varied starting conditions. C12.17: Systems are designed to achieve particular functions. Such systems may be specific objects (e.g., a satellite) or involve large-scale networks of objects (e.g., a transportation system).

	C8.19: An engineering design plan is a form of system model. C8.20: Engineers use system models as a framework for troubleshooting system failures.	C12.18: Computational simulations are often used to test design ideas. C12.19: Changes in systems may have various causes. The scale of the effect is not always comparable to that of the change but may be much larger or smaller depending on conditions and feedback patterns.
5. **Conservation, Flows, and Cycles: Tracking Energy and Matter:** Tracking energy transfers and matter flows, into, out of, and within systems helps one understand their system's behavior		
Grade 4	Grade 8	Grade 12
C4.10: The only way that the total weight of matter in a system can change is by flow of matter into or out of the system. C4.11: To understand the function of a system it is often useful to keep track of the flows and cycles of matter into, out of, and within the system. C4.12: Energy can be transferred between objects in various ways.	C8.21: Matter is conserved because atoms are conserved in physical and chemical processes. C8.22: Within any system, whether natural or designed, transfers of energy are needed to drive any motion or cycling of matter. C8.23: Energy manifests itself to our observation in multiple different ways, including in mechanical, thermal, electrical, and chemical processes. Energy can transfer between these different observed effects and between objects or systems. C8.24: To understand the function of a system it is helpful to track and model the energy transfers and matter flows within it.	C12.20: Flows of matter and transfers of energy into, out of, and within the system are analyzed and described using a system model. C12.21: The amount of any type of matter or of energy in any system changes only by flow of matter or transfer of energy into or out of the system. C12.22: Tracking of matter flows and energy transfers is useful because the availability of matter and/or energy within a system limits what can occur and regulates how the system functions. C12.23: All mechanical systems result in eventual transfer of thermal energy to the surrounding environment. C12.24: In nuclear processes (fission, fusion, and radioactive decays), atoms are not conserved but the sum of the number of protons plus the number of neutrons is unchanged in any process.
6. **Structure and Function:** The way an object is shaped or structured determines many of its properties and functions		
Grade 4	Grade 8	Grade 12
C4.13: Different materials have different substructures, which can sometimes be observed. C4.14: In modeling and seeking to explain the functioning of any system it is often useful to consider how the structures of objects or	C8.25: Complex and microscopic structures within systems can be visualized, modeled, and used to describe how the function of the system depends on the shapes, composition, and relationships among its parts.	C12.25: The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and interconnected, and the molecular substructures of various component materials.

parts of the system relate to their function within the system. C4.15: In designing any object or system it is important to specify details of the shape and structure of the parts that are needed for the function of the system.	C8.26: Structures can be designed to serve particular functions by taking into account properties of different materials and how materials can be shaped and used.	C12.26: Designing new systems or structures requires a detailed examination of the properties of different materials and intentional design of the shapes and structures of different components and of connections between and among components.
7. **Stability and Change:** For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand		
Grade 4	Grade 8	Grade 12
C4.16: In seeking to explain phenomena, it is useful to consider what conditions are needed for it to occur or to continue to function. Student models, explanations, and designs should specify any important conditions for their application. C4.17: Questions about what is changing and what makes it change, as well as about what keeps it unchanged, are useful ways to examine a phenomenon and develop a model for how it occurs. Students should be able to model, describe, or predict the conditions for a stable or ongoing situation (e.g., a growing plant, a healthy body) as well as those for change.	C.8.27: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including both the very large and the very small (e.g., atomic) scale. C8.28: Sudden events can be caused by an accumulation of change over time (e.g., an earthquake) as well as by a sudden change in the conditions of a system (e.g., a switch is turned). C8.29: Small changes in one part of a system might cause large changes in another part. C8.30: In modeling change in a system, it is as important to ask what conditions maintain stability and what causes change. C8.31: Feedback loops are cycles or loops of cause and effect within a system that can either regulate processes to maintain stability or drive them to unstable runaway behavior. Looking for such cycles can help explain both stable and unstable phenomena in a system.	C12.27: Both stability and change require explanation; much of science attends to such issues. Questions about either can help in developing a model and explanation or designing a problem solution. C12.28: Rates of change are quantifiable and are important quantities to consider in modeling any system. C12.29: Feedback mechanisms within a system are important elements for explaining or designing for either the stability or instability of the system.

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NAEP SCIENCE AND ENGINEERING PRACTICES

> *Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.* (NRC Framework 2012, p. 42)

> *Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world, misrepresents science and marginalizes the importance of engineering.* (NRC Framework 2012, p. 43)

The ability to engage in the practices of science and engineering (along with the ability to use Crosscutting Concepts) allows students to apply their disciplinary science knowledge as they develop explanations of phenomena or design solutions to engineering problems. The NAEP Science Assessment will ask students to engage these abilities as part of achieving a successful response to multidimensional tasks.

The goal of science is the construction of theories that can provide explanatory accounts of features of the world. A theory becomes accepted when it has been shown to be superior to other explanations in the breadth of phenomena and conditions it accounts for and in its explanatory coherence and parsimony. Scientific explanations are explicit applications of theory to a specific situation or phenomenon, perhaps with the intermediary of a theory-based model for the system under study. The goal for students is to construct logically coherent explanations of phenomena that incorporate their current understanding of science, or a model that represents it, and are consistent with the available evidence.

In engineering, the goal is a designed solution to a problem rather than an explanation. The term *engineering* applies to any such design, whether it is for an object, a system, or a process. The domain of the problem can be any area of applied science or technology. The problem can arise from individual, community, or global needs or wants. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing, and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. Engineering design focuses on the appropriate use of technology. Appropriate technology refers to using the simplest level of technology that can achieve the intended purpose in each location, using fewer natural resources, emitting less pollution, and costing less. Appropriate technologies are often small-scale and make use of expertise available in the local community.

The practices of science and engineering occur in social contexts and can be used in ways that can benefit or harm individuals, communities, or the environment. As students use these practices, they should do so ethically and recognize the risks and harms that can be caused and have been caused by negligent use, as well as the benefits.

The list of practices developed by the NRC Framework for K–12 Science Education is now used by teachers of science in classrooms across the country, and so the NAEP Science and Engineering Practices reflect this list. The table below defines the expectations of students at Grades 4, 8, and 12 in carrying out these practices.

The eight practices are as follows:

1. **Asking Questions and Defining Problems**
2. **Developing and Using Models**
3. **Planning and Carrying Out Investigations**
4. **Analyzing and Interpreting Data**
5. **Using Mathematics and Computational Thinking**
6. **Constructing Explanations and Designing Solutions**
7. **Engaging in Argument from Evidence**
8. **Obtaining, Evaluating, and Communicating Information**

Scientific work involves all these practices used in an iterative and recursive process to achieve an eventual explanation based on a well-tested model. It further requires honest reporting and critical review to be effective. Engineering work likewise involves an iterative and recursive process using all these practices to design, test, and redesign to achieve a successful problem solution. Individuals and organizations working within science and engineering also consider how their work contributes to ecological and social matters and how to optimize their work, products, and applications to benefit society and minimize harms, including consideration of unintended negative effects. As they engage in the practices, students share these responsibilities, and some of the elements of the tables below are related to this aspect of science and engineering work.

Scientific theories and explanations are empirically based and subject to revision based on new or evolving evidence. The same applies to student-developed models, explanations, and engineering design solutions. Students should be able to reflect on what needs to be revised and whether additional evidence is required to improve the outcome or strengthen the claim. Some elements of the tables below stress this aspect of science and engineering work

1. Asking Questions and Defining Problems

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world; inspired by the predictions of a model, theory, or findings from previous investigations; or driven by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence.

Engineering design work begins with defining a problem to solve. However, engineering may also involve asking questions to help define the problem, such as the following: What is the need or desire that underlies the problem? What are the risks involved if this solution is implemented, and how can they be minimized? What are the criteria for a successful solution? Other questions may arise when generating ideas or testing possible solutions, such as the following: What are the possible trade-offs? What are the constraints impacting this design? What evidence is necessary to determine which solution is best?

Grade 4	Grade 8	Grade 12
S4.1: Ask purposeful questions to help refine observations, develop or revise models, or further define an engineering problem. S4.2: Ask questions to compare various suggested models and find common features or differences. S4.3: Ask questions about patterns found in observations.	S8.1: Ask questions that arise from careful observation of phenomena, models, or data, to clarify and/or seek additional information. S8.2: Ask questions to clarify and/or refine a model, an explanation, or an engineering problem.	S12.1: Ask questions that arise from careful observation of phenomena or data to clarify and/or seek additional information. S12.2: Ask questions that arise from examining a model, an explanation, or a design plan to clarify and/or seek additional information and define tests.
S4.4: Ask questions to reach an understanding of science and engineering ideas, models, and explanations proposed by others.	S8.3: Ask questions to identify and/or clarify evidence and/or the premise(s) of an argument. S8.4: Ask respectful questions that challenge the premise(s) of an argument or the interpretation of a data set.	S12.3: Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of design considerations.
S4.5: Ask "what if" questions about a system or phenomenon being observed, and predict reasonable outcomes based on patterns or expected cause and effect relationships. S4.6: Identify whether questions could be investigated or answered with observations or experiments. S4.7: Ask questions about what would happen if a quantity or condition in the system being observed were changed.	S8.5: Identify whether a question can be answered based on empirical evidence and, if so, what evidence would be needed to answer it. S8.6: Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources, and, when appropriate, frame a hypothesis based on observations and scientific principles. S8.7: Ask questions to determine relationships between variables in a system or system model, experimental plan, or data and to determine which variables can be independently set and which are dependent or output variables determined by those choices.	S12.4: Frame questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources, and, when appropriate, frame a hypothesis that answers the question based on a model or theory. S12.5: Ask questions about data to determine relationships, including quantitative relationships, between independent and dependent variables.
S4.8: Ask questions, make observations, and gather	S8.8: Define the criteria and constraints of a design problem	S12.6: Analyze a major global challenge to specify qualitative and

information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool. S4.9: Define a simple design problem to provide a solution for a need or a want that includes specified criteria for success and constraints on materials, time, or cost. S4.10: Consider possible impacts on different individuals and groups and on the environment as they define an engineering problem.	with sufficient precision to allow a successful solution, considering relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. S8.9: Define a design problem that can be solved through the development of an object, tool, process, or system and that includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. S8.10: Consider the needs and societal norms of both intended users and others possibly affected by a design solution in defining desired outcomes and constraints.	quantitative criteria and constraints for solutions that account for societal needs and wants. S12.7: Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations. S12.8: Discuss and consider ethical issues and impacts on the environment in defining a research question or a problem to be solved.

2. Developing and Using Models

A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Scientists use the term *model* for all these, whereas engineers may talk of a design plan for a diagrammatic representation of a system or a prototype for scaled physical replica. In science, models are used to develop questions and predictions and are repeatedly tested and revised until they can provide successful predictions for tests. They then form the basis of an explanation of the phenomenon of interest. They are likewise a key part of the process of engineering design and of troubleshooting to analyze and identify flaws in designed systems.

Students are expected to develop, test, critique, and apply models as a core feature of their science and engineering assessment. They use models to express, examine, and refine their thinking and support their arguments for a claimed explanation.

Grade 4	Grade 8	Grade 12
S4.11: Distinguish between a model and the actual object, process, and/or events the model represents. S4.12: Identify and describe how the parts of a model and the relationships between them represent a phenomenon. S4.13: Identify limitations of a model for a phenomenon in terms of what the model can or cannot explain.	S8.11: Evaluate limitations of a model for a phenomenon in terms of what the model cannot yet explain. S8.12: Use a physical model to evaluate the limitations of a proposed design solution.	S12.9: Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system to select or revise a model that best fits the evidence or design criteria. S12.10: Design a test of a model to ascertain its reliability.

S4.14: Identify the limitations of a design plan in terms of whether it meets the criteria and constraints of the problem. S4.15: Identify evidence that would be needed to test a model or what revision is needed based on evidence.		
S4.16: Develop and/or revise a model based on evidence that shows the relationships among variables in a phenomenon. S4.17: Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. S4.18: Develop and/or use models to describe and explain phenomena.	S8.13: Develop or modify a model, based on evidence, to reflect relationships between parts of a system. S8.14: Use and/or develop a model of systems with uncertain and less predictable factors. S8.15: Develop, use, and/or revise a model to describe, explain, and/or predict phenomena by identifying relationships among variables, including unobservable mechanisms that explain observable phenomena.	S12.11: Develop, revise, and/or use a model based on evidence to explain and/or predict the relationships between systems or between components of a system. S12.12: Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena and move flexibly between model types based on merits and limitations.
S4.19: Develop a design plan and/or simple physical prototype to convey a proposed object, tool, or process. S4.20: Develop and/or use a model to propose cause-and-effect relationships or interactions concerning the functioning of a natural system or designed solution.	S8.16: Develop and/or use a model to generate data to test ideas about phenomena in natural systems or design solutions, including those representing inputs and outputs and those at unobservable scales. S8.17: Reflect on any new evidence or newly learned science ideas and revise a model based upon that reflection.	S12.13: Develop a complex model that allows for manipulation and testing of a proposed process or system. S12.14: Develop, refine, and/or use a model (including mathematical and computational models) to generate data to support explanations, predict phenomena, analyze systems, and/or design solutions for engineering problems.

3. Planning and Carrying Out Investigations

Scientific investigations may be undertaken to describe a phenomenon or to test a theory or model for how the world works. The purpose of engineering investigations might be to determine conditions under which the design solution needs to function, to find out how to fix or improve the functioning of a technological system, or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena.

Over time, students are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, which should be treated as inputs and intentionally varied from trial to trial, and which should be controlled, or kept the same across trials. In the case of field observations, planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator.

Grade 4	Grade 8	Grade 12
S4.21: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. S4.22: Take appropriate parameters into account when planning how to investigate a scientific question or test a design solution. S4.23: Reflect on what questions still need answering and what test or information could help resolve those questions. S4.24: Consider possible impacts on different individuals and groups and on the environment as they plan investigations. S4.25: Determine what quantities need to be defined and observed or measured and what tools and units of measure would be needed to measure them.	S8.18: Plan an investigation, and in the plan identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to support a claim. S8.19: Consider what impacts the collection of data or the knowledge generated may have on individuals, groups, or the environment, and consider social norms and the opinions of those who may be affected in making planning decisions. S8.20: Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meets the goals of the investigation. S8.21: Plan and carry out tests to evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	S12.15: Plan an investigation or test a design to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. S12.16: Plan and conduct an investigation to produce data to serve as the basis for evidence, and in the plan decide on types, amount, and accuracy of data needed to produce reliable measurements; consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. S12.17: Plan and conduct an investigation or test a design solution in a safe and ethical manner that includes considerations of environmental, social, and personal impacts. S12.18: Plan and carry out tests to evaluate a solution to a complex, real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts. S12.19: Reflect on whether the planned investigation will provide all needed data or whether further tests will be required.
S4.26: Evaluate appropriate methods and/or tools for collecting data.	S8.22: Evaluate the accuracy of various methods for collecting data.	S12.20: Select and use appropriate tools to collect, record, analyze, and evaluate data.
S4.27: Make observations and/or measurements to produce data to serve as the basis for evidence for	S8.23: Collect data to produce data to serve as the basis for evidence to answer scientific questions or test	S12.21: Predict the direction of change of a dependent variable for a given change of independent

an explanation of a phenomenon or test a design solution. S4.28: Make predictions about what would happen if a variable changes. S4.29: Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.	design solutions under a range of conditions. S8.24: Collect data about the performance of a proposed object, tool, process, or system under a range of conditions.	variable and provide an argument to support the prediction. S12.22: Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.
S4.30: Predict the expected outcome of a planned observation, experiment, or test of a design based on their own or a class-consensus model for a phenomenon or on a design plan.	S8.25: Predict the expected outcome of a planned investigation or test of a design plan and give arguments that support that prediction.	S12.23: Predict the expected outcome of a planned investigation or test of a design plan, and give evidence from models, prior experiments, or application of accepted science knowledge to support the prediction.

4. Analyzing and Interpreting Data

Data must be organized in ways that reveal the information it provides in order to serve as the evidence for the claims being made. In the data-rich world of today, this work has even become a discipline, called “data science.” Science classrooms are key places where students can develop their skills in this area.

Students, like scientists and engineers, use a range of tools to display data and identify patterns, sources of error, and degrees of certainty in sets of data. They organize and use data to test model-based predictions, to infer relationships and trends in a system, to provide evidence for argumentation to support or refute a hypothesis or explanation, or to compare different solutions to specific design criteria and determine which design best solves the problem within given constraints.

Grade 4	Grade 8	Grade 12
S4.31: Represent data in tables and/or various graphical displays (bar graphs, pictographs, and/or pie charts) to reveal patterns and/or relationships to explain phenomena or solve problems.	S8.26: Construct, analyze, and/or interpret graphical displays of data and/or large data sets (e.g., maps, charts, graphs, and/or tables) to identify variable relationships, including linear vs. nonlinear relationships, causal vs. correlational relationships, and temporal and spatial relationships.	S12.24: Analyze and/or interpret data using tools, technologies, and/or models (e.g., computational, mathematical) to make valid and reliable scientific claims or determine an optimal design solution.
S4.32: Analyze and interpret data to make sense of phenomena using logical reasoning, mathematics, and/or computation.	S8.27: Analyze and interpret data to provide evidence for phenomena, applying concepts of statistics and probability (limited to mean, median, mode, and variability) and using digital tools when feasible.	S12.25: Analyze and characterize data by applying concepts of statistics and probability to scientific and engineering questions and problems, using digital tools when feasible.
S4.33: Analyze evidence collected for how it fits with or suggests revisions to a prior model and/or explanation.	S8.28: Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better	S12.26: Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.

	technological tools and methods (e.g., multiple trials). S8.29: Evaluate alternative ways of presenting data and its limitations and what each does and does not communicate well.	S12.27: Reflect on whether the data are sufficiently accurate and reliable for the purpose for which they are intended for and how their accuracy or reliability can be improved.
S4.34: Compare and contrast data collected by different groups to discuss similarities and differences in their findings.	S8.30: Analyze and interpret data to determine similarities and differences in findings.	S12.28: Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.
S4.35: Analyze and use data to evaluate and refine a problem statement and/or design solution. S4.36: Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.	S8.31: Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success. S8.32: Analyze test data and draw conclusions for what features of the prior model or design plan they suggest need to be revised. S8.33: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.	S12.29: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success. S12.30: Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

5. Using Mathematics and Computational Thinking

Both science and engineering require mathematics and information technology. Students apply their understanding of mathematics in science and engineering contexts. It is also in these contexts that they are expected to manipulate quantities with physical units, not just pure numbers.

This practice links to student assessment of mathematics and ability to use computational tools, and the progression of expectations across grade levels is therefore closely aligned with the mathematics expected at each grade level.

Grade 4	Grade 8	Grade 12
S4.37: Decide when to use qualitative vs. quantitative data. S4.38: Use quantitative data to compare two alternative solutions to a problem.	S8.34: Break down problems, processes, and/or data into smaller pieces.	S12.31: Design algorithms that provide processes and approaches for accomplishing a task. S12.32: Develop and apply algorithms when designing, programming, testing, and revising scientific models, explanations, and engineering design solutions.
S4.39: Organize simple data sets to reveal patterns that suggest relationships.	S8.35: Use digital tools to gather, record, display, and analyze data sets.	S12.33: Use digital tools to gather, record, display, and analyze data and to present results of

		investigations or tests of design solutions. S12.34: Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
S4.40: Describe, measure, estimate, and/or graph attributes of objects or quantities, such as area, volume, weight, and time, to address scientific and engineering questions and problems.	S8.36: Use mathematical representations of data or system features to describe and/or support scientific explanations and design solutions.	S12.35: Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.
S4.41: Use arithmetic and numbers to identify and describe patterns in the natural and designed world(s). S4.42: Use appropriate units of measure when recording or describing measured quantities involving a single unit of measure.	S8.37: Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems. S8.38: Interpret and use quantities involving ratios based on two different types of units of measure, such as speed, density, and population density.	S12.36: Apply techniques of algebra, functions, statistical reasoning, and computational algorithms to represent and solve scientific and engineering problems. S12.37: Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. S12.38: Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, etc.).
S4.43: Describe the steps needed to address a specific design problem or achieve a particular outcome.	S8.39: Create algorithms (a series of ordered steps) to solve a problem.	S12.39: Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
S4.44: Plan and carry out a series of steps to compare the performance of two design proposals for an engineering problem and decide whether features of each can be combined to provide an improved solution.	S8.40: Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success. S8.41: Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem. S8.42: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.	S12.40: Optimize an engineering design solution considering two or more design criteria.
S4.45: Create and/or use graphs and/or charts generated from simple		

algorithms to compare alternative solutions to an engineering problem.		

6. Constructing Explanations and Designing Solutions

While students at the K–12 level are not expected to develop new scientific theories, they are expected to apply scientific knowledge appropriate to their grade level to explain phenomena or to develop designs that offer a solution to a real-world problem. The process involves a cycle of all eight science and engineering practices, which together allow students to achieve this goal. The elements listed for this practice are those specific to completing the cycle to achieve and present the desired explanation or design.

Each suggested explanation is a claim that must be supported with an argument based on evidence (see the following practice). In science, the argument is most often model-based, and the evidence enters in the process of testing and revising the model. Likewise, engineering design proposals must be supported by tests of the design through prototypes or simulations of the proposed design.

Grade 4	Grade 8	Grade 12
S4.46: Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena.	S8.43: Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. S8.44: Construct and revise an explanation using tested models or representations.	S12.41: Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables.
S4.47: Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.	S8.45: Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. Revise a prior explanation based on new evidence or trusted information. S8.46: Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real world phenomena, examples, or events.	S12.42: Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. S12.43: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, considering possible unintended effects.
S4.48: Apply scientific knowledge to solve design problems.	S8.47: Apply scientific ideas or principles to design, construct,	S12.44: Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated

S4.49: Engage in tinkering to improve a design.	and/or test a design of an object, tool, process, or system. S8.48: Optimize performance of a design by prioritizing criteria, clarifying constraints, making trade-offs, testing, revising, and retesting. S8.49: Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem.	sources of evidence, prioritized criteria, and trade-off considerations. S12.45: Design a solution to a complex problem by breaking it down into smaller, more manageable parts.
S4.50: Try new technologies and generate strategies for improving existing ideas. S4.51: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. S4.52: Reflect on what unexpected results from experiments or tests of design proposals says about needed revisions to their model, explanation, or design plan.	S8.50: Reflect on what revisions to a model change in an explanation, and revise explanations based on the new model. S8.51: Critique technological products and systems to identify areas of improvement.	S12.46: Take into consideration the ideas of others and use empirical evidence together with application of disciplinary ideas as the basis for accepting or rejecting their own or others' explanations or design proposals, or for forming a new version that combines prior suggestions. S12.47: Reflect on how their own backgrounds may influence the claims they put forward and the evidence they use to develop an explanation or solve a design problem.

7. Engaging in Argument from Evidence

Evidence in science and engineering is based on the analysis of empirical data and its comparison with the predictions of a model or the goals and constraints of a design plan.

Scientists argue to critique or defend a model or explanation; engineers likewise argue to support the merits or critique flaws of a design. Students likewise are expected to argue, or critique proposed models, explanations, and designs—both their own and those of others—using evidence from multiple sources as part of the cycle of testing and improving them.

Grade 4	Grade 8	Grade 12
S4.53: Identify arguments that are supported by evidence. S4.54: Select appropriate evidence to support a claim. S4.55: Make a claim from evidence. S4.56: Distinguish between opinion, evidence, and fact.	S8.52: Identify empirical evidence that would support an argument. S8.53: Make a claim from evidence about a phenomenon. S8.54: Select the appropriate science ideas that could be used to support an argument.	S12.48: Identify empirical evidence that would support an argument. S12.49: Construct a claim or counterclaim based on data and evidence. S12.50: Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.
S4.57: Compare and refine arguments based on an evaluation of the evidence presented.	S8.55: Compare and critique two arguments on the same topic and analyze whether they emphasize	S12.51: Compare and evaluate competing arguments or design solutions in light of currently

	similar or different evidence and/or interpretations of facts.	accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.
S4.58: Construct and/or support an argument with evidence, data, and/or a model. S4.59: Use data to evaluate claims about cause and effect.	S8.56: Construct or use an argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. S8.57: Revise an argument when new evidence is presented. S8.58: Identify evidence that could be used to refute an argument.	S12.52: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
S4.60: Explain dilemmas involving technology, such as trade-offs. S4.61: Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence. S4.62: Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.	S8.59: Evaluate competing design solutions based on developed and agreed-upon design criteria. S8.60: Make an argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether the technology meets relevant criteria and constraints.	S12.53: Evaluate competing design solutions to a real-world problem based on scientific ideas and principles. S12.55: Evaluate competing design solutions based on jointly developed and agreed-upon design criteria, empirical evidence, and/or logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

8. Obtaining, Evaluating, and Communicating Information

Reading, interpreting, evaluating, and producing scientific and technical texts, which can include both written and visual information along with data presentation and mathematical relationships, are fundamental practices of science and engineering, as is communicating clearly and persuasively using both verbal and visual resources.

Being a critical consumer of information about science and engineering requires the ability to read or view reports of scientific or technological advances or applications (whether found in the press, the internet, or social media) and to recognize the salient ideas; identify sources of error and methodological flaws; and distinguish observations from inferences, arguments from explanations, and claims from evidence. Scientists and engineers employ multiple sources to obtain information used to evaluate the merit and validity of claims, methods, and designs.

Evaluating information is a critical skill in the world today, where both information and misinformation (even deliberate disinformation) are widely available through digital sources.

Students need to know how to compare information from multiple sources and, where contradictions exist, to use reasonable criteria to determine the most reliable sources and to argue for the merits or unreliability of a source of information.

Communicating information, evidence, and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays, and equations; speaking; writing; and discussing.

Grade 4	Grade 8	Grade 12
S4.63: Read and comprehend grade-appropriate texts and/or other reliable media to summarize and obtain scientific and technical ideas and describe how they are supported by evidence. S4.64: Compare and/or combine across complex texts and/or other reliable media to support the engagement in other scientific and/or engineering practices.	S8.61: Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s). S8.62: Exhibit effective technical writing and graphic abilities.	S12.56: Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
S4.65: Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support the engagement in other scientific and/or engineering practices.	S8.63: Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings.	S12.57: Compare and combine information presented in different media or formats (e.g., visually, quantitatively) as well as in words to address a scientific question or solve a problem.
S4.66: Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem. S4.67: Evaluate whether the information presented is evidence, an opinion, or a story.	S8.64: Gather, read, and synthesize information from multiple sources, and assess the credibility, accuracy, and possible bias of each publication and methods used; describe how the claims made are supported or not supported by evidence. S8.65: Evaluate information from two different sources to determine whether there are conflicts between them. S8.66: Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts. S8.67: Evaluate the reliability of information based on where it is found, and the qualifications of the source and the evidence given to make the claim.	S12.58: Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence used by and the information on qualifications and expertise of each source. S12.59: Evaluate information from multiple sources and discuss what criteria were used for determining their reliability.
S4.68: Communicate scientific and/or technical information, reasoning, and ideas in written formats and various forms of media as well as tables, diagrams, and charts. S4.69: Report work accurately and without leaving anything out.	S8.68: Communicate scientific and/or technical information (e.g., about a proposed object, tool, process, a system) in writing and mixed-format presentations. S8.69: Communicate reasoning about the quality of evidence for a claim and about uncertainties that affect the support for the claim. S8.70: Report investigation results and design considerations accurately and completely.	S12.60: Communicate scientific and/or technical information or ideas (e.g., ideas about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including graphically, textually, and mathematically). S12.61: Convey ideas clearly in constructive, insightful ways, including through written communication and via

		mathematical and diagrammatic models. S12.62: Include information on limitations of and uncertainties in the results and on the context and conditions under which they were obtained in reporting results.

Chapter 3 - Overview of the Assessment Design

Introduction

This chapter provides an overview of the assessment that is proposed for the framework and begins by outlining common definitions used in the framework. It contains a brief description of the NAEP Science Assessment and a discussion of how items can be set in certain contexts based on phenomena to illustrate the three-dimensional components of science content. The types and distribution of items to be included in the assessment are described, and examples are provided where needed.

Science achievement is the ability to use relevant disciplinary concepts (Physical Science, Life Science, Earth and Space Sciences), crosscutting concepts, and science and engineering practices to identify and address problems, make sense of phenomena, and evaluate information to make informed decisions.

An assessment designed to measure science achievement as defined in this framework requires students to demonstrate knowledge in use—that is, sensemaking or problem solving using disciplinary concepts, crosscutting concepts, and science and engineering practices. To do so, all tasks are designed around compelling **phenomena and/or problems**. Without a phenomenon or problem at the center of an assessment task, there is nothing for students to make sense of, problem-solve about, or apply their knowledge to. From the student perspective, they are answering questions about what, why, or how something occurs or what to do about a problem. A phenomenon or problem should be the setting for any assessment task (item, item set, multi-part item, or scenario-based task). The item context provided to the student is based on the phenomenon or problem will then create the conditions by which student understanding of targeted ideas and practices is surfaced.

Phenomena are specific real-world events or processes that provide a setting for a task or set of tasks. They should be chosen to engage student attention and sensemaking effort and to require the target science ideas (disciplinary concepts and crosscutting concepts) and practices tested for their explanation. They should be observable, measurable, or both (through the use of technology, historical records, or direct observation). Further guidance for choosing phenomena is provided later in this chapter.

In this framework, the term *problem* is used to describe a real-world issue that requires a designed solution; as such, it is an engineering problem. However, it is important to note that used in this way, the term *engineering* is broad and covers many areas of application (e.g., medicine, agriculture, infrastructure, environmental management). Engineering solutions may involve the design of an object, a system, a process, or an action plan. While the goal of science is explaining the phenomena, and that of engineering design is producing a solution to the problem, tasks used in the assessment may address any element of that work, namely, engaging in any part of the science and engineering practices, using any of the crosscutting concepts and particular disciplinary concepts to respond to the item.

In this document, the term *context* is used to describe all the information presented to a student in framing a task and the prompt that elicits a student response. However, the same phenomenon or problem can be addressed through many different contexts and thus can frame many tasks. All stimulus information provided to students (e.g., written descriptions, images, videos, simulations, long-form texts, infographics, data tables, graphs, etc.) used to present the phenomenon is considered context, offering background information necessary for students' sensemaking and/or problem-solving.

Phenomena and problems are important for science assessments because they provide access points for students, ensuring that all students can make their thinking visible, and ensure assessments are accessible and provide opportunities for all students to show what they know and can do. High-quality items based on phenomena and/or problems (a) position tasks to be compelling and motivating to students, (b) cue students toward which targeted dimensions they need to demonstrate, and (c) help students from a diversity of prior learning and lived experiences understand what they are being asked to make sense of and provide scaffolds for students to engage and demonstrate their understanding. In this way, high-quality phenomenon-/problem-based tasks are essential to truly surface what all students know and can do and to ensure that scores are trustworthy representations of student understanding in science.

Types of Items

The following definitions are intended to be generally consistent with similar terms in other NAEP frameworks and assessments:

An **item** is the basic scorable part of an assessment, a test question. An item can be selected or constructed response. No item will assess rote content or procedural knowledge, and all items will require some reasoning with the targeted dimensions. To the degree possible, every item will be multidimensional. Each item must include a disciplinary concept as a dimension.

A **multi-part item** is an item with multiple components that are scored together producing a single score.

An **item set** contains multiple questions that are linked to a single phenomenon with multiple items, each scored separately. Item sets typically comprise two to four items built around a common stimulus (e.g., short text, image, data table); students can move back and forth among the items in an item set. Item sets should be three dimensional.

Scenario-based tasks consist of multiple items built around a common problem/situation. These items typically include a storyline and should have interactive or static (but complex) components. Scenario-based tasks will be three-dimensional.

Multidimensional Items

Items elicit evidence that requires students to bring the multiple dimensions together to address the question posed to students. Items should be three-dimensional whenever possible. Each item and each multi-part item should be at least two-dimensional and three-dimensional if appropriate. Item sets and scenario-based tasks should be three-dimensional. No item will be one-dimensional (i.e., require rote content or procedural knowledge or require one dimension to be used to respond to the question). Importantly, disciplinary concepts, crosscutting concepts, and science and engineering practices do not receive separate scores. Each item will receive one score. The score represents an integration of the dimensions.

Distribution of Items

As measured by student response time, the distribution of items by content area should be approximately equal across Physical Science, Life Science, and Earth and Space Sciences at all grades. With respect to crosscutting concepts and science and engineering practices, at all grades, the emphasis should be on meaningful representation rather than a strictly equal distribution. When an authentic query requires only an application of a practice or a crosscutting concept to a disciplinary concept, a two-dimensional item is acceptable.

Distribution of Items by Disciplinary Concept Grouping and Grade			
	Grade 4 (Percentage of student response time)	Grade 8 (Percentage of student response time)	Grade 12 (Percentage of student response time)
Physical Science	33.3	33.3	33.3
Life Science	33.3	33.3	33.3
Earth and Space Sciences	33.3	33.3	33.3

Balance by Response Type

Items include selected response and constructed response types, and these response types may also occur within scenario-based tasks. Selected response items include traditional single-selection multiple choice as well as other response types, such as matching, zone, in-line choice, grid, and limited option responses. These items are machine scored. Constructed response items include short and extended constructed responses. Constructed response items may include item types such as fill-in-the-blank, extended text, digital tool–based, and object-based constructed responses, as well as discourse and collaboration responses. Testing time will be divided evenly between selected response items and constructed response items at all grades, which is generally consistent with most other NAEP assessments.

Percent of Testing Time by Response Type	
Selected Response: 50% of testing time	Constructed response: 50% of testing time

Item Context, Phenomena, and Problems

The presentation of phenomena and problems for science items requires intentionally developed contexts that ground items, multi-part items, item sets, and scenario-based tasks. These contexts should have an appropriate amount of information for both roles: (a) presenting phenomena or problems and (b) supporting items. Some contexts will be short and simple; for example, they will have one or two sentences and one or two images. Other contexts may have more information to present more complex phenomena and problems or to support a broader range of items. These contexts should reflect the nature and scope of intended sensemaking and be sufficient to engage students, and they should not include gratuitous language, information, images, etc. It should be noted that the requirement for contexts does not automatically assume that every context is accompanied by multiple items, an item set, or a task.

General Features of High-Quality Science Phenomenon or Problem-Based Scenarios/Contexts

1. **Criteria.** While the exact nature of contexts will depend on what practice and disciplinary contexts are intended to be elicited, some common features of high-quality contexts for science include the following:
   - a focus on a specific, observable, and/or measurable (including through the use of technology and indirect evidence of their presence) event(s) that drives student sensemaking
   - information that is required for successful student responses (i.e., the scenario/context is not gratuitous)
   - an authentic question related to the phenomenon/problem that requires students to use the targeted disciplinary concepts, crosscutting concept, and science and engineering practices to figure out or make sense of it—**items must require the dimensions to be used by students in service of sensemaking**
   - information that is scientifically accurate
   - scenarios/contexts that are comprehensible and coherent and that position the task to be understandable and motivating to learners
   - scenarios/contexts that are presented in ways that
     - engage students;
     - puzzle/intrigue—this often means presenting an uncertainty up front and providing informational detail only as and when it is needed (i.e., not front-loading content, including unnecessary information)—students;
     - highlight an authentic uncertainty that students are motivated to figure out;
     - use multiple modalities to convey important information;
     - attend to language considerations appropriately (see below), including using as many words as needed to convey the context appropriately, but no more; and
     - are authentic—a real stakeholder group (other than generic scientists) could realistically be invested in the outcome.

2. Additional guidance

- **Focus on specific phenomena and conceptual understanding.** While specific phenomena/problems are important to ensure that science assessments elicit students' knowledge-in-use, it is important that science assessment items focus on requiring the targeted conceptual understanding and do not inadvertently require knowledge of highly specific topics/phenomena/problems that were not required by standards.
- **Avoid gratuitous information.** In developing science content that will engage students, scenarios should only present necessary information, limit the reading burden on students, and avoid an additional (unnecessary and usually unintentional) dimension of cognitive burden on learners by **not** asking them to (a) hold a lot of contextual information in working memory and (b) sort through which pieces are relevant/necessary for each item. While there may be some instances (e.g., asking students to evaluate information to identify relevant evidence) where this is needed, contexts/scenarios should limit up-front overloading of unnecessary contextual information to the degree possible.
- **Do not give away the punchline.** In developing useful and interesting contexts, scenarios/contexts should avoid inadvertently including information that students should have been expected to bring to the table (e.g., about a science idea), preserving opportunities for sensemaking and assessing knowledge-in-use. It is important that task contexts leave space for students to bring their understanding to the table and do not solely assess reading or logical reasoning.

Specific Features of High-Quality Phenomenon-Based Scenarios and Contexts

Language considerations in scenarios/contexts. Assessments that present phenomena and problems to enable knowledge-in-use often require more language use (reading, writing) than do traditional assessments focused on recall and memorization. While this is necessary both to better engage learners and to elicit the student thinking targeted by the assessment, attending to some specific considerations for language use can ensure that all learners can successfully engage with the assessment task. Some of these features are described here; for more detailed guidance, please see this document. Please note that this section focuses on the use of language as part of scenario/context information. Productive language (language produced by students in response to open-ended questions) will be addressed separately in guidance for item specifications.

- Use as many words as needed to convey a compelling and necessary context and no more.
- Leverage a variety of modalities (e.g., text, images, video) and types of text (e.g., graphs, charts, bulleted lists, different kinds of written sources) to convey information such that students have multiple access points to the contexts.
- Avoid ambiguous use of words (e.g., those that have different scientific and colloquial meaning).

- Use similar language conventions within and across domains to the extent possible—and clarify what should *not* be assumed as convention.
- Ensure that observations are not limited to information presented in certain forms of text alone.
- Ensure that the language used itself is accessible to a wide range of learners:
    - appropriate (defined from both developmental and disciplinary lenses) balance of narrative, expository, scientific, and everyday language
    - use of active voice
    - appropriate qualitative and quantitative reading levels for texts

Reflecting a Wide Range of Learners. The NAEP Science Assessment is administered to a wide range of learners with rich and diverse cultural and linguistic backgrounds, identities, and learning environments. This diversity influences how students experience the assessment as well as how they make their thinking visible—ultimately impacting how we interpret and use the resulting scores. While it may be unreasonable to expect this large-scale measure to be responsive to each student taking the assessment, it is important that the assessment be designed in such a way that it is responsive and relevant to this diversity—that a wide range of specific groups of students see themselves and their communities represented in the tasks and that the range of assets and funds of knowledge diverse learners bring to the table are acknowledged as important elements of science achievement. The selection and presentation of phenomena and problems is one key way that assessment tasks and instruments can be positioned to be more directly culturally responsive.

Below are definitions and general principles for culturally relevant scenarios and contexts for NAEP science followed by a list of particular features of these scenarios/contexts.

- **General principles and definitions**
    - All students have culture, and when we think about diverse cultural representation, we mean to be inclusive of cultural and linguistic experiences across a range of geographies, cultural practices, disabilities, genders, and languages.
    - In order to avoid stereotyping, exclusion of students who do not have average or majority experiences, etc., assessment scenarios/contexts should be relevant and specific to a range of specific communities rather than trying to represent an average. The expectation is that all students could see themselves and their peers represented in some phenomena/problems, not in every phenomenon/problem.
    - Developers and users understand that this means that some phenomena will be more relevant to some students than others. By varying the range of who the phenomena/problems are relevant to, we ensure that there is authentic relevance to multiple student groups and that all students are engaged in addressing scenarios/contexts and problems that are culturally novel (in contrast to this being

    a burden placed specifically on students whose cultural identities fall outside of the average experience).
    - When scenarios/contexts focus on legitimate interests of communities, it is more likely that students will be engaged with the items. While traditional sensitivity reviews might flag all such contexts as problematic, a culturally relevant lens asks that if the item elicits a productive response.

- **Specific features of culturally relevant scenarios/contexts and task design**
    - Scenarios/contexts focus on real, specific phenomena and problems particular communities care about (as evidenced through surveys, focus groups, voices of community members, etc.).
    - Solutions/explanations generated by students through the assessment items improve lives and livelihoods.
    - Item contexts consider geographic, demographic, and time-related factors to create enough distance between students and the phenomenon to limit any negative affective responses.
    - Scenarios/contexts include diverse representations of who is considered a scientist and engineer.
    - Scenarios/contexts position non-White people as (a) more than a stereotyped experience and (b) powerful doers and contributors to science and the broader world.
    - Scenarios/contexts do not include (or limit) gratuitous or superficial representation of diverse races, ethnicities, genders, etc.

Use of Scenario-Based Tasks

As NAEP moves toward reduced contact assessment administration, we recommend replacing HOTs with computer-administered scenario-based tasks that include interactive components. Some aspects of authentic knowledge-in-use that integrate science and engineering practices, crosscutting concepts, and disciplinary concepts can be difficult to assess through discrete items and or a single stimulus. Scenario-based tasks should be used to probe student thinking in ways that cannot be easily supported through selected and constructed response items. Scenario-based tasks can focus on interdisciplinary activities, authentic modeling, extended investigation design, and evaluation of design solutions.

Some phenomena lead to contexts that include more complexity than students can make sense of at once. By interweaving context and items, scenario-based tasks scaffold students' interactions with the phenomena and context. By following a narrative arc, scenario-based tasks scaffold students' efforts to build a conceptual model of the phenomenon and interpret the provided context, allowing students to make sense of the relationships more easily among the components of the phenomena, layers of context, and nested systems.

Interactivity can provide opportunities for students to demonstrate particular science and engineering practices and disciplinary concepts. For example, interactive items may allow students opportunities to collect data, design, and test solutions, and carry out investigations. These interactive items elicit evidence that cannot be collected in static environments. However, the task does not have to be interactive to be a scenario-based task.

Sampling Across the Full Range of Student Performance

It is important that NAEP provide a complete picture of student performance. Although there have been concerns that that creating a test consisting largely of multidimensional items, item sets, and scenario-based tasks might prove too difficult for students who have not been provided the opportunity to develop proficiency in science, research from the learning sciences, including research on how students learn and develop three-dimensional science understanding, suggests otherwise. While traditional approaches to assessment often assume that rote understanding or simple procedural skills (e.g., definitions, facts, lab skills) are less cognitively complex and therefore more likely to be doable by students who are still developing their science understanding, this is not borne out in practice. Students do not learn by mastering one dimension at a time before integrating the dimensions—they learn by using the dimensions together in increasingly sophisticated ways. Likewise, assessments intended to surface what students who have not yet mastered grade-level expectations know and can do may do so more effectively by varying the sophistication of multidimensional performances rather than focusing on one-dimensional items.

This is particularly important for multilingual learners and other students who may have conceptual understanding without having yet mastered vocabulary or rote facts and procedures. Students at all grade levels and all performance levels can and do find success with multidimensional performances if students are presented with items and tasks that (a) use appropriately complex contexts, (b) sufficiently scaffold and support learners in engaging with the task, and (c) use the dimensions in appropriate combinations to right-size the complexity. By focusing on multidimensional tasks that range in complexity, NAEP can better capture student thinking along progressions that mirror how student thinking develops.

The cognitive complexity framework that will be applied to NAEP item development will reflect how cognitive complexity specifically scales within and across multidimensional science items, including

- the complexity of the phenomenon or problem-based context,
- the degree and nature of scaffolding and guidance provided, and
- the nature of the intersections of dimensions within items.

Sample Items

The sample items included here are intended to illustrate how large-scale assessment items can measure the concepts and practices described in this framework while still operating within NAEP's parameters for test design. All items below leverage standard item technologies while prioritizing a move away from rote content and procedural knowledge. While these items are **not all necessarily exemplary of all aspects of multidimensional items**, they have been adapted to highlight specific important features and are intended to be a helpful guide to operationalizing this framework. The sample items below were adapted from the Disruptions in Ecosystems Chapter 5 Assessment Task (pp. 59–63). Please note that these are all for Grade 8 and use the same context. Our goal is to show how different item types can be developed to assess science achievement in various ways.

Example 1: Stand-alone Multiple-Choice Item (2D)

Disciplinary Concepts: L8.11; L8.16
Science and Engineering Practice: Developing and Using Models

Many animals and plants live in the sea near Seaside City. Recently, people who live in Seaside City have noticed that the beaches used to have a lot of seaweed, but they rarely see seaweed anymore. Seaweed is very important to the local ecosystem because it is a major food source and safe environment for many animals living in the region.

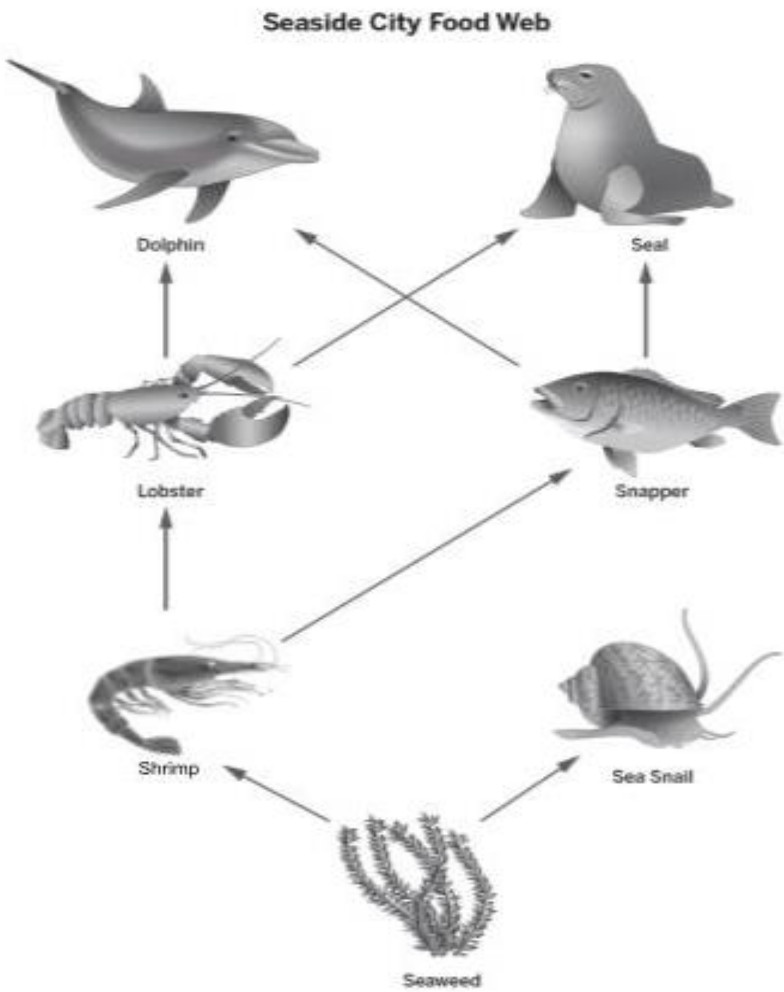
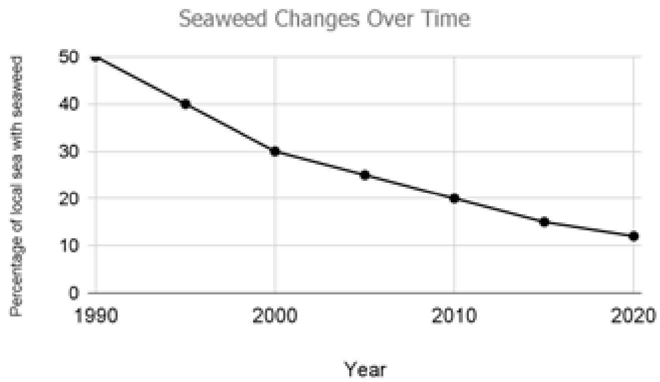


Figure 1: A diagram showing feeding relationships in the sea near Seaside City. Not all living things in this ecosystem are represented.

Data confirm that seaweed has been declining in the area over the last 30 years. This is shown in the graph below.



Item 1:
Based on the information provided, which observation would you expect to be true in this ecosystem?

a) the total number of dolphins was higher in 2020 than in 1990
b) individual seals were larger in 2020 than in 1990
c) **there was more competition among sea snails and shrimp in 2020 than in 1990**
d) Lobsters ate more seals in 2020 than in 1990

Example 2: Stand-alone Selected Response Item (2D)

Disciplinary Concepts: L8.11; L8.16
Science and Engineering Practice: Engaging in Argument from Evidence

Many animals and plants live in the sea near Seaside City. Recently, people who live in Seaside City have noticed that the beaches used to have a lot of seaweed, but they rarely see seaweed anymore. Seaweed is very important to the local ecosystem because it is a major food source and safe environment for many animals living in the region.

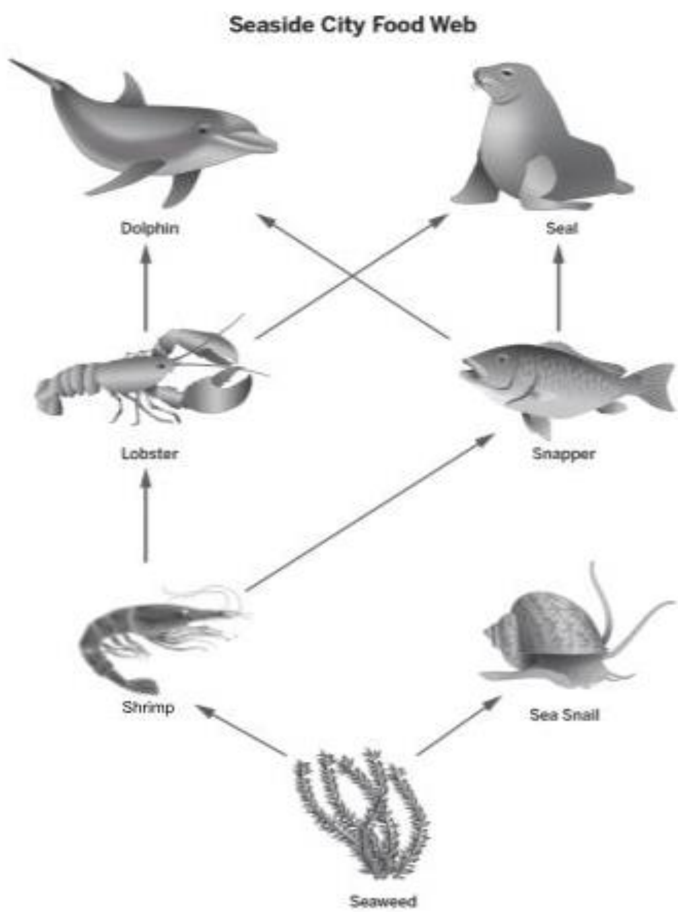
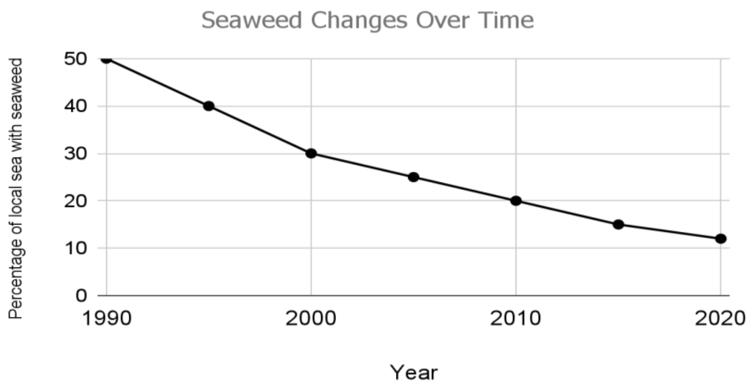


Figure 1: A diagram showing feeding relationships in the sea near Seaside City. Not all living things in this ecosystem are represented.

Data confirm that seaweed has been declining in the area over the last 30 years. This is shown in the graph below.



Some people claim that **the amount of seaweed near Seaside City is declining because people are eating more lobsters and snappers**.

The people investigating the decline in seaweed have made the following observations. Use your understanding of how organisms interact in ecosystems and the information provided to select three (3) statements to support the claim and three (3) statements that do not support the claim.

Evidence	SUPPORTS	DOES NOT SUPPORT
Both snapper and lobster populations have decreased from 1990 to 2020.	x	
Lobsters and snappers both eat many organisms (including shrimp) that feed on seaweed.	x	
At a similar area nearby, the shrimp population is staying constant while seaweed is declining at a similar rate.		x
The number of shrimp is higher in 2020 than in 1990.	x	
The shrimp population increases initially but then declines.		x
As the number of human-made buildings on the coast increases, the amount of seaweed decreases.		x

Example 3: Multi-part Item (3D)

Disciplinary Concepts: L8.11; L8.16
Crosscutting Concept: Mechanisms and explanation: Cause and effect
Science and Engineering Practice: Engaging in Argument from Evidence

Seaside City is a popular vacation spot. Each year, more tourists visit, and more people come to live there.

Observations of human impacts
• Increased fishing to provide food for people • Disruptions to the local environment (land and sea) while building homes and businesses for people • Decline of some species as human activities impact the resources they need to survive and reproduce

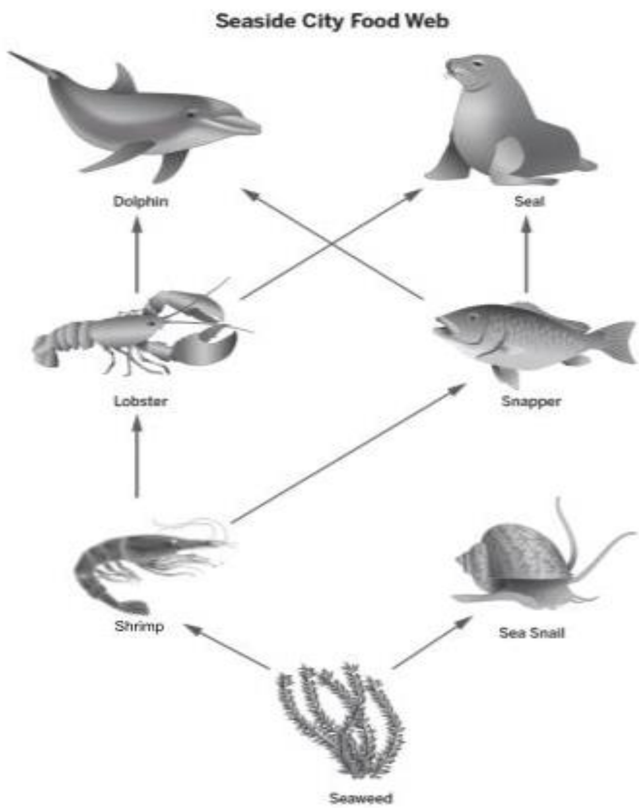
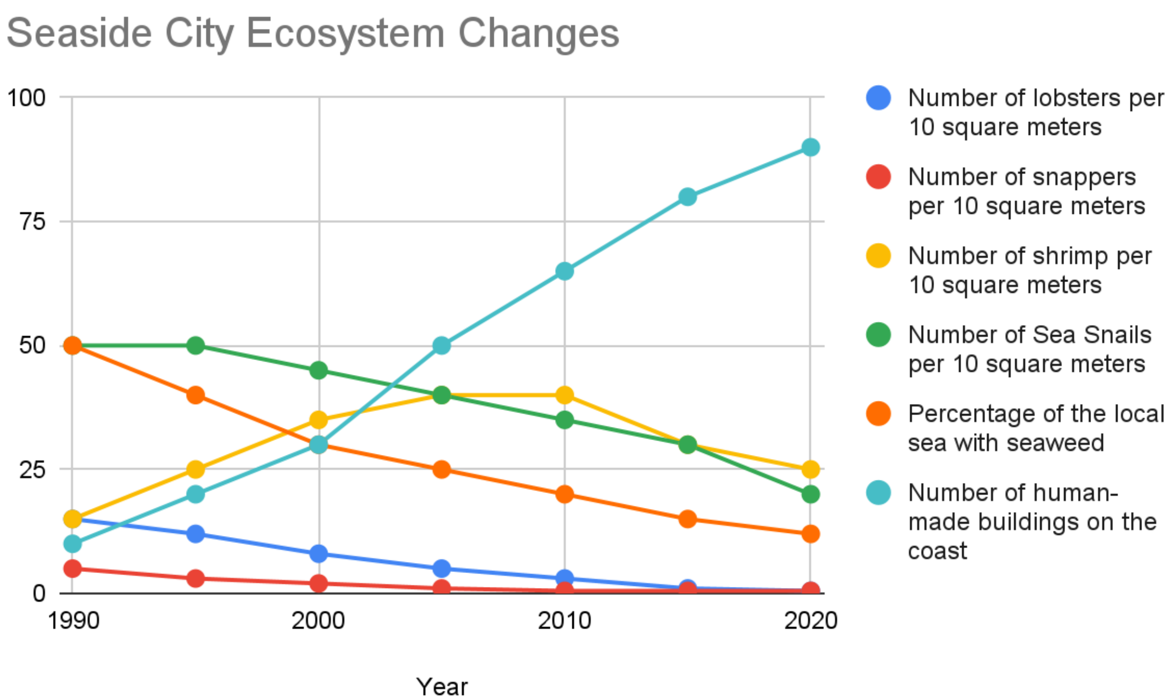


Figure 1: A diagram showing feeding relationships in the sea near Seaside City. Not all living things in this ecosystem are represented.

A wide range of animals and plants live in the sea near the city. Recently, people who live in Seaside City have noticed that the beaches used to have a lot of seaweed, but they rarely see seaweed anymore.

Seaweed is very important to the local ecosystem because it is a major food source and safe environment for many animals living in the region. The data below show how living and nonliving factors in this area have changed over the last 30 years.



Some people claim that **the amount of seaweed near Seaside City is declining because people are eating more lobsters and snappers**.

Part A: The people investigating the decline in seaweed have made the following observations. Use your understanding of how organisms interact in ecosystems and the information provided to select three (3) statements to support the idea and three (3) statements that do not support the idea.

Evidence	SUPPORTS	DOES NOT SUPPORT
Both snapper and lobster populations have decreased from 1990 to 2020	x	
The shrimp population increases initially but then declines.		x
The number of shrimp is higher in 2020 than in 1990	x	
At a similar area nearby, the shrimp population is staying constant while seaweed is declining at a similar rate.		x
Lobsters and snappers both eat many organisms (including shrimp) that feed on seaweed.	x	
As the number of human-made buildings on the coast increases, the amount of seaweed decreases.		x

Part B (option 1): What is one different claim that could explain the seaweed decline? Base your answer on the evidence provided, the ecosystem model, and your understanding of interactions in ecosystems.

Part B (option 2): What is one different idea that could explain the seaweed decline? Select a possible alternative claim, based on the evidence provided, the ecosystem model, and your understanding of interactions in ecosystems.

a. Changes in the sea snail population are leading to declines in the amount of seaweed.
b. Increased human construction along the coast is destroying seaweed in the area.
c. There is a disease killing seaweed.

Part C: What additional information would you need to know to determine whether your new claim provides the best explanation for what is causing seaweed decline near Seaside City? Provide at least 2 additional pieces of information and describe why they would be needed.

Example 4: Item Set (3D)

Disciplinary Concepts: L8.11; L8.16
Crosscutting Concept: Mechanisms and explanation: Cause and effect
Science and Engineering Practice: Engaging in Argument from Evidence

Many animals and plants live in the sea near Seaside City. Recently, people who live in Seaside City have noticed that the beaches used to have a lot of seaweed, but they rarely see seaweed anymore. Seaweed is very important to the local ecosystem because it is a major food source and safe environment for many animals living in the region.

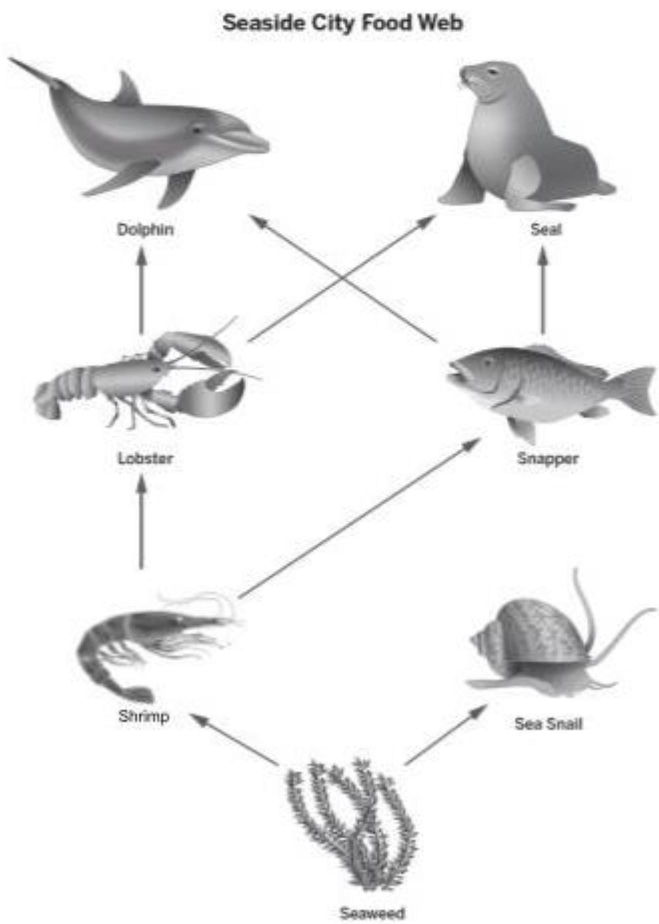
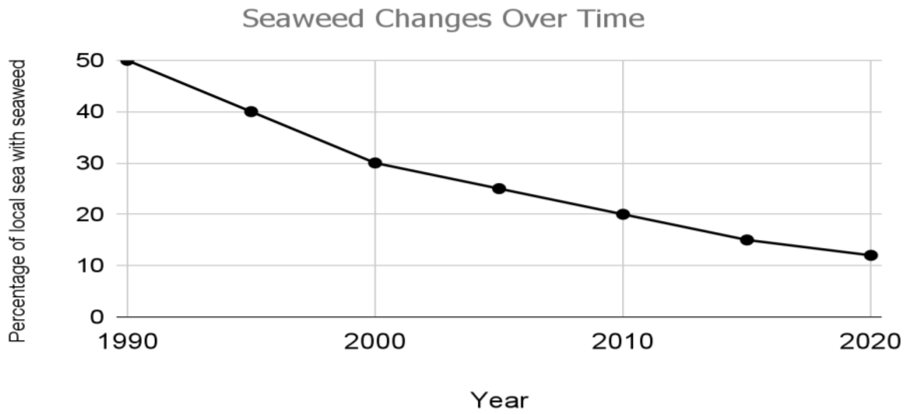


Figure 1: A diagram showing feeding relationships in the sea near Seaside City. Not all living things in this ecosystem are represented.

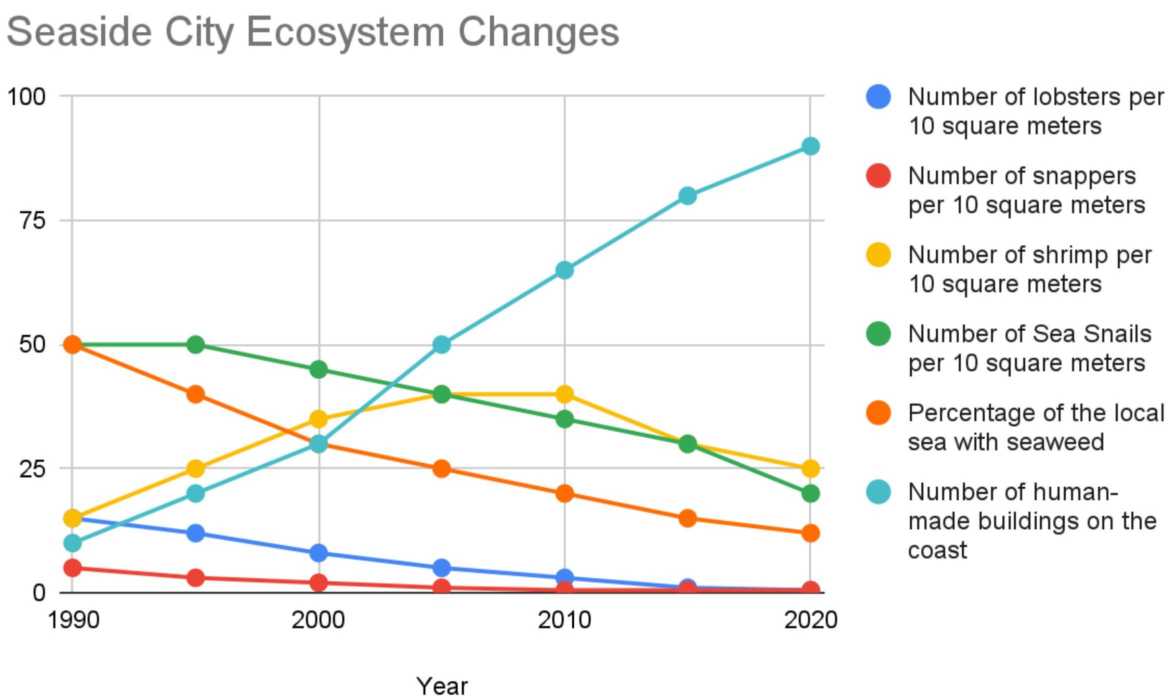
Data confirm that seaweed has been declining in the area over the last 30 years. This is shown in the graph below.



Item 1:
Based on the information provided, which observation would you expect to be true in this ecosystem?

a. the total number of dolphins was higher in 2020 than in 1990
b. individual seals were larger in 2020 than in 1990
c. there was more competition among sea snails and shrimp in 2020 than in 1990
d. lobsters ate more seals in 2020 than in 1990

Item 2:
Some people claim that **the amount of seaweed near Seaside City is declining because people are eating more lobsters and snappers**. Scientists and community members examined how living and nonliving factors in this area have changed over the last 30 years.



Observations of human impacts
• Increased fishing to provide food for people • Disruptions to the local environment (land and sea) while building homes and businesses for people • Decline of some species as human activities impact the resources they need to survive and reproduce

Part A: The people investigating the decline in seaweed have made the following observations. Use your understanding of how organisms interact in ecosystems and the information provided to select three (3) statements to support the idea and three (3) statements that do not support the claim.

Evidence	SUPPORTS	DOES NOT SUPPORT
Both snapper and lobster populations have decreased from 1990 to 2020	x	
Lobsters and snappers both eat many organisms (including shrimp) that feed on seaweed.	x	
The number of shrimp is higher in 2020 than in 1990.	x	
At a similar area nearby, the shrimp population is staying constant while seaweed is declining at a similar rate.		x
The shrimp population increases initially but then declines.		x
As the number of human-made buildings increases, the amount of seaweed decreases.		x

Part B, Constructed Response Option: What is one different claim that could explain the seaweed decline? Base your answer on the evidence provided, the ecosystem model, and your understanding of interactions in ecosystems.

Part B, Selected Response Option: What is one different idea that could explain the seaweed decline? Select a possible alternative claim, based on the evidence provided, the ecosystem model, and your understanding of interactions in ecosystems.

a. Changes in the sea snail population are leading to declines in the amount of seaweed.
b. Increased human construction along the coast is destroying seaweed in the area.
c. There is a disease killing seaweed.

Part C: What additional information would you need to know to determine whether your new claim provides the best explanation for what is causing seaweed decline near Seaside City? Provide at least 2 additional pieces of information and describe why they would be needed.

Part D: If your claim is correct, how do you account for the relationship between snappers, lobsters, and seaweed?

Item 3:
In 2021, Seaside City banned new construction to prevent further damage to the marine ecosystem off its coast. Students at the local middle school have developed a model to predict what the organism populations might look like over time. Based on the model, students make two predictions about the shrimp population in 2030:

Option A: The shrimp population will remain about the same in 2030 compared to 2020.
Option B: The shrimp population will increase by 2030, compared to 2020.

Choose one option and complete the statement below. (Note: Both options could be correct under the right conditions.)

The model predicts that the shrimp population will remain about the same if the seaweed present will [remain the same, increase]. This is because how much the shrimp population grows will [be limited, increase, decrease] if competition for resources [stays the same, increases, decreases] compared to 2020.

Chapter 4 - Reporting Results of the NAEP Science Assessment

The NAEP Science Assessment provides the nation with a snapshot of what U.S. students know and can do in science. Results of the NAEP Science Assessment administrations are reported in terms of average scores for groups of students on the NAEP 0–300 scale and as percentages of students who attain each of the three achievement levels (*NAEP Basic*, *NAEP Proficient*, and *NAEP Advanced*). This is an assessment of overall achievement, not a tool for diagnosing the needs of individuals or groups of students. Reported scores are always at the aggregate level; by law, scores are not produced for individual schools or students. Results are reported for the nation as a whole, for regions of the nation, and sometimes for states and large districts that volunteer to participate. The NAEP results are published in an interactive version online as *The Nation's Report Card*.

The Nation's Report Card allows for examination of results by school characteristics (urban, suburban, rural; public and nonpublic) and other student characteristics (race/ethnicity, gender, English learner status, socioeconomic status, and disability status [i.e., supported by an Individualized Education Program]), as required by law. The NAEP Data Explorer is a publicly accessible tool that allows users to customize reports and to investigate specific aspects of student science achievement, such as performance by disciplinary area or by selected contextual variables. Also, reports of the results of survey questionnaires are produced each year on various topics (e.g., students' internet access and digital technology at home, instructional emphasis on science activities, confidence in science knowledge and skills, teachers' satisfaction, and views of school resources).

In 2002, NAEP initiated the TUDA in five large urban school districts that are members of the Council of the Great City Schools (the Atlanta City, City of Chicago, Houston Independent, Los Angeles Unified, and New York City Public Schools districts). In 2003, additional large urban districts began to participate in these assessments, growing to a total of 27 districts by 2017. Sampled students in TUDA districts are assessed in the same subjects and use the same NAEP field materials as students selected as part of national or state samples. TUDA results are reported separately from the state in which the TUDA is located, but results are not reported for individual students or schools. With student performance results reported by district, participating TUDA districts can use results for evaluating their achievement trends and for comparative purposes.

Reporting Scale Scores

NAEP reports average results on a scale of 0–300 in science. In the past, the average scores have also been reported on three disciplinary groupings: Life Science, Physical Science, and Earth and Space Sciences. The new framework intends to report average scores on the same three disciplinary groupings, although a slight renaming may be applied, such as "Sensemaking in Life Science." The renaming indicates that the score is an integration of the three dimensions of science: disciplinary concepts, crosscutting concepts, and science and engineering practices rather than a score that only reflects knowledge of the disciplinary concepts.

Reporting Achievement Levels

Since 1990, the Governing Board has used achievement levels for reporting results on NAEP assessments. Generic policy definitions for achievement at the *NAEP Basic*, *NAEP Proficient*, and *NAEP Advanced* levels describe in very general terms what students at each grade level should know and be able to do on the assessment (see Exhibit 2). Achievement level descriptions specific to the 2028 NAEP Science Framework are still under development and will be included in the final framework. These will be used to guide item development and initial stages of standard setting for the 2028 NAEP Science Assessment if it is necessary to conduct a new standard setting.

Reporting on achievement levels is one way that the Nation's Report Card uses to help the general public and policymakers interpret the results. Results are reported as percentages of students within each achievement level range as well as the percentage of students at or above *NAEP Basic* and at or above *NAEP Proficient*. Students performing at or above the *NAEP Proficient* level on NAEP assessments demonstrate solid academic performance and competency over challenging subject matter. Following the first administration of the science assessment based on the updated framework, new Reporting ALDs will be created to specify certain skills in which students are likely to have demonstrated competency at each achievement level. Results for students not reaching the *NAEP Basic* achievement level are reported as below *NAEP Basic*. As noted, individual student performance cannot be reported based on NAEP results.

Note that the *NAEP Proficient* achievement level does not represent grade-level proficiency as determined by other assessment standards (e.g., state or district assessments), and there are significant differences between achievement in the context of NAEP as compared to the context of state-level annual tests. For one, teachers and students are not expected to have studied the NAEP framework or systematically aligned state standards or local curricula with it, nor are students expected to study for the assessment. Furthermore, the NAEP assessment is broader than a typical state grade-level test, for NAEP covers multiple years of study and does not focus on specific instructional units and school years.

All achievement level setting activities for NAEP are performed in accordance with current best practices in standard setting and the Governing Board's *Developing Student Achievement Levels for the National Assessment of Educational Progress Policy Statement* (2018). The Governing Board policy does not extend to creating achievement level descriptions for performance below the *NAEP Basic* level.

Exhibit 2. Generic Achievement Level Policy Definitions for NAEP

Achievement level	Definition
NAEP Advanced	This level signifies superior performance beyond *NAEP Proficient*.
NAEP Proficient	This level represents solid academic performance for each NAEP assessment. 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.
NAEP Basic	This level denotes partial mastery of prerequisite knowledge and skills that are fundamental for performance at the *NAEP Proficient* level.

Contextual Variables

NAEP legislation requires reporting according to various student populations (see section 303[b][2][G]), including

- gender,
- race/ethnicity,
- eligibility for free/reduced-price lunch,
- students with disabilities, and
- English language learners.

NAEP users mistakenly may presume that the categories used to report data are related to causal explanations for observed differences (e.g., that gender predicts or explains performance differences or "achievement gaps"). However, scholars find that these differences also reflect gaps in students' opportunities to learn. When results are interpreted in ways that emphasize achievement gaps without attending to opportunity gaps, score differences across subgroups of students can be misinterpreted as differences in student ability rather than as differences due to unequal and inadequate educational opportunities.

The *Standards for Educational and Psychological Testing* (AERA, APA, & NCME, 2014) recommend that reports of group differences in assessment performance be accompanied by relevant contextual information, where possible, to both discourage erroneous interpretation and enable meaningful analysis of the differences. That standard reads as follows:

> Reports of group differences in test performance should be accompanied by relevant contextual information, where possible, to enable meaningful interpretation of the differences. If appropriate contextual information is not available, users should be cautioned against misinterpretation. (Standard 13.6)

Contextual data about students, teachers, and schools are needed to fulfill the statutory requirement that NAEP include information, whenever feasible, that promotes meaningful interpretation of NAEP results. Contextual variables are selected to be of topical interest, timely, and directly related to academic achievement and current trends and issues in science. In the past, a range of information has been collected as part of NAEP.

Science-Specific Contextual Variables

Science-specific contextual data about students, teachers, and schools are also collected from questionnaires. The science-specific questionnaires are intended to be updated to reflect recommended changes in the framework, such as student exposure to technology and engineering, the amount that science is taught by Grade 4, and exposure to crosscutting concepts and science and engineering practices in instruction. At the time of public comment, the science-specific questionnaires are still under review. Additional recommendations will be developed based on future panel deliberations, including consideration of the suggestions made during public comment.

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