

THE NEXT GENERATION SCIENCE STANDARDS AND THE EARTH AND SPACE SCIENCES

The important features of Earth and space science standards for elementary, middle, and high school levels

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The *Next Generation Science Standards (NGSS)*, due to be released this spring, represents a revolutionary step toward establishing modern, national K-12 science education standards. Based on the recommendations of the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), these performance expectations present a progressive approach to developing students' understanding of science. The writing of the *NGSS* has been supervised by Achieve, Inc., the bipartisan not-for-profit organization that also supervised the writing of the math and English language arts Common Core (NGACBP/CCSSO 2010). The *NGSS* involves significant changes from traditional standards at all levels for all of the sciences, integrating three dimensions of science content, science practices, and the crosscutting, big-picture themes of science. Nowhere are these changes more apparent than for the Earth and space sciences (ESS), which now require a year of upper-level high school coursework.

Emphasis on Earth and space sciences

Earth and space sciences have a strong presence within the *NGSS*, especially in high school. Earth and space sciences traditionally occupy about a third of the middle school science curriculum, on par with life and physical science. This parity often breaks down in high school with science curricula dominated by physics, chemistry, and biology. The *NGSS* represent a major departure from this, with the number of performance expectations in Earth and space sciences roughly equal to that of both life and physical sciences. At a high school level, the amount of content in Earth and space sciences is roughly equal to the amount of chemistry and physics combined.

For Earth and space sciences, within both the *Framework* and *NGSS*, there is a significant change toward a systems-approach that draws upon the wealth of Earth systems science research in both content and pedagogy (e.g., Ireton, Mogk, and Manduca 1996). Within the *Framework*, Earth and space science content is parsed into three Big Ideas, each of which is subdivided into components (Figure 1, p. 32). ESS1 examines the space and solar *systems*; ESS2 examines the interconnections among Earth's many different *systems* of the geosphere, hydrosphere, atmosphere, cryosphere, and biosphere; and ESS3 focuses on the anthroposphere *system*, the important role that human civilization plays in affecting Earth's other systems.



The geosphere is Earth's rock and metal; the hydrosphere is Earth's water; the atmosphere is Earth's air; the cryosphere is Earth's ice; and the biosphere is Earth's life. These overlap significantly. For example, the atmosphere contains parts of all the other spheres in the form of dust, ice, water, and living organisms.

Motivation for Earth and space sciences

The third Big Idea—human interactions—is the primary reason for the increased attention given to Earth and space sciences in the NGSS. This Big Idea contains many of the most newsworthy topics in science: natural hazards, energy sources, water and mineral availability, climate change, environmental impacts, and human sustainability.

Perhaps the greatest change in Earth and space science content from the influential *National Science Education Standards* (NRC 1996) comes from the increased awareness of the enormous magnitude of the effects of human activities on our planet. Humans now use almost 40% of Earth's land surface to produce food. The land area devoted to roads and parking lots in the United States is larger than the state of Georgia. Americans use roughly 4 billion metric tons of non-energy-related rocks and minerals each year (~10× the total material carried by the entire

Mississippi River system) to construct all the material objects of our lives, roughly 25,000 pounds per person. The release of acidic aerosols in the atmosphere have increased global land erosion rates and have increased ocean acidity by 30% in just a few centuries.

Human impacts are no longer an asterisk in Earth science: Our activities are changing the composition of the atmosphere, hydrosphere, biosphere, and cryosphere and altering land surfaces faster than any other natural process. In fact, the sphere of human impact on Earth systems—the *anthroposphere*—is now the greatest agent of geologic change on our planet's surface, and this needs to be reflected in our curricula. The NGSS pass no moral judgment on these human activities. The impacts are simply the reality of the immense power of our species and need to be recognized as such in our educational standards.

Connections across and between standards

The NGSS strive for a greater integration among the sciences and engineering, as well as with the Common Core. This integration reinforces concepts across fields to enrich and deepen students' understanding. The divisions among scientific fields is entirely arbitrary; nature knows or cares nothing about biology, chemistry, geology, or physics; there is only nature. Earth

FIGURE 1

The Big Ideas and subtopics of *A Framework for K–12 Science Education* (NRC 2012) are shown at left below. The standard topics for high school and middle school from the January 2013 public draft of the *Next Generation Science Standards* (Achieve, Inc., forthcoming) are at right. The numbers of standard topics differ for middle and high school because the middle school standards for *Interior Systems* and *Surface Systems* are merged into a single high school *Earth's Systems*. Elementary is not shown because of the high level of integration of science content among all of the sciences in grades K–5.

Framework for K–12 Science Education

ESS1: Earth's Place in the Universe
 ESS1.A: The Universe and Its Stars
 ESS1.B: Earth and the Solar System
 ESS1.C: The History of Planet Earth
 ESS2: Earth's Systems
 ESS2.A: Earth Materials and Systems
 ESS2.B: Plate Tectonics and Large-Scale System interactions
 ESS2.C: The Roles of Water in Earth's Surface Processes
 ESS2.D: Weather and Climate
 ESS2.E: Biogeology
 ESS3: Earth and Human Activity
 ESS3.A: Natural Resources
 ESS3.B: Natural Hazards
 ESS3.C: Human Impacts on Earth Systems
 ESS3.D: Global Climate Change

Next Generation Science Standards: Middle School – Earth and Space Science Topics (Draft, January 2013)

MS.Space Systems
 MS.History of Earth
 MS.Earth's Interior Systems
 MS.Earth's Surface Systems
 MS.Weather and Climate
 MS.Human Impacts

Next Generation Science Standards: High School – Earth and Space Science Topics (Draft, January 2013)

HS.Space Systems
 HS.History of Earth
 HS.Earth's Systems
 HS.Climate Change
 HS.Human Sustainability

and space sciences, in particular, are the most integrated of all the sciences; most faculty members in university Earth science departments would not identify themselves as geologists but rather as geochemists, geophysicists, or geobiologists. Better integration among the sciences is required for the optimal teaching of Earth and space sciences.

One way the NGSS better integrate the sciences is with crosscutting concepts, which are universal principles (e.g., *cause and effect*, *structure and function*) that apply to all sciences. Each performance expectation of each standard topic is tied to the most closely related crosscutting concept. Standard topics often have strong connections with one particular crosscutting concept. For example, the middle school *Space Systems* topic connects well with the crosscutting concept of *scale, proportion, and quantity*, and the high school *Earth's Systems* topic

connects well with the crosscutting concept of *matter and energy: flows and cycles*. The NGSS performance expectations are also aligned with concepts of the *nature of science* (Appendix H of the January, 2013, release), which are integrated with both the science and engineering practices and the crosscutting concepts and therefore can appear in either one of the associated foundation boxes.

There is a greater connection within the NGSS between the basic sciences and the fields of engineering and technology, recognizing that a continuum rather than a sharp line exists between science and engineering. Wherever possible, the standards have incorporated aspects of Engineering, Technology, and the Applications of Science (ETS). This has been easy for Earth and space sciences because of the emphasis on human-related areas of natural resources, hazards, and human impacts.

Essentials of A Framework for K–12 Science Education

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2012) presents fundamental concepts and practices for the new standards and implied changes in K–12 science programs. The *Framework* describes three essential dimensions: science and engineering practices, crosscutting concepts, and core ideas in science disciplines. In this article, the core disciplinary ideas are from the Earth and space sciences.

The scientific and engineering practices have been discussed in earlier NSTA publications and are summarized below.

Practices for K–12 science curriculum

1. Asking questions (for science) and defining problems (for engineering)
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 (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

The second dimension described in the NRC *Framework* is crosscutting concepts. These too have been discussed in earlier articles and are summarized here.

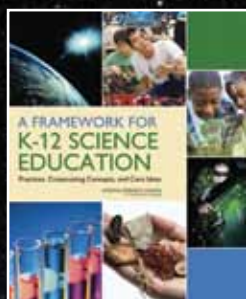
Crosscutting concepts for K–12 science education

1. *Patterns*. Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying the patterns.
2. *Cause and effect: Mechanism and explanation*. Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships and the mechanisms by which they are mediated is a major activity of science.
3. *Scale, proportion, and quantity*. In considering phenomena, it is critical to recognize what is relevant at different sizes, times, and energy scales and to recognize proportional relationships between different quantities as scales change.
4. *Systems and system models*. Delimiting and defining the system under study and making a model of it are tools for developing understanding used throughout science and engineering.
5. *Energy and matter: Flows, cycles, and conservation*. Tracking energy and matter flows, into, out of, and within systems, helps one understand a system's behavior.
6. *Structure and function*. The way an object is shaped or structured determines many of its properties and functions.
7. *Stability and change*. For both designed and natural systems, conditions of stability and what controls rates of change are critical elements to understand.

FIGURE 2

The Framework.

The *Framework for K–12 Science Education* (NRC 2012), funded by the Carnegie Foundation of New York, provides the blueprint for a comprehensive set of K–12 science standards for life, physical, and Earth and space sciences. The *Framework*, publicly available (www.nap.edu), draws upon the best practices of pedagogy and methods for K–12 science education (NRC 2007, 2008) and advocates construction of science standards by interweaving three distinct aspects, or dimensions: (1) the practices of science, (2) the disciplinary core ideas of science, and (3) the broad crosscutting concepts of science. The ideas of this blueprint were integrated into performance expectations for the *Next Generation Science Standards*.



The NGSS Earth and space science topics of *Human Impacts* in middle school and *Human Sustainability* in high school are primarily focused on how human technology is affecting Earth's other systems and how that same technology can also be used to monitor, understand, and minimize these impacts. However, engineering and technology connections play important roles throughout the Earth and space sciences. For example, NASA technology provides the basis for our understanding of the space and solar systems, and weather predictions such as the path and timing of Hurricane Sandy are only possible because of the complex monitoring systems that continuously gather weather data and the computer models that analyze them.

The NGSS are also correlated with grade-appropriate Common Core State Standards in both mathematics and English language arts (ELA). Reading and writing in the sciences pose unique ELA challenges. The Earth and space sciences involve concepts and vocabularies that are often new and unfamiliar to students, and both the science and language education benefit from the coordination of their progressions. ELA standards are especially connected to the NGSS through the practice of "Obtaining, Evaluating, and Communicating Information."

At a research level, the Earth and space sciences are as mathematical, quantitative, and computational as any other field of study, but that has not been adequately represented in K–12 education, where geoscience is often still presented as a field of qualitative categorization. For example, identifying minerals or types of rock has little value by itself but is important in understanding complex quantitative processes

in the cycling of matter among Earth systems. Weather and climate are often taught as exercises in memorizing categories of cloud or climate types; in the NGSS, however, weather, climate, and climate change are presented as dynamic sciences that are mathematically and computationally complex, and inasmuch as climate incorporates all of Earth's systems (including the solar system) and requires significant understanding of physical and life sciences, it can be seen as a capstone high school experience that integrates all of the sciences in a quantitative and societally relevant experience.

Elementary school

At the elementary level, the NGSS present performance expectations that are integrated across sciences and organized into broad topics that could be used to organize a curriculum. The specific identifications of life, physical, or Earth and space sciences are not made at these levels, though the topics are usually based primarily in one of these areas. The disciplinary core ideas in the *Framework* were organized into K–2 and 3–5 grade-band endpoints, though the NGSS present them as grade-level standards. Students are introduced to all of the practices and crosscutting concepts starting in kindergarten and will experience these through a progression of sophistication, as with the core ideas and crosscutting concepts, building through to the end of high school. This is an important aspect, particularly for the practices. It is not the case that some categories of practices are more sophisticated than others. For example, "Using Mathematics and Computational Thinking" is not inherently more advanced than "Planning and Carrying Out Investigations;" both are done at all levels but vary depending on grade.

The elementary grades contain three Earth and space science standard topics, which each appear more than once: *Space Systems* (grades 1 and 5), *Earth's Surface Systems* (grades 2, 4, and 5), and *Weather and Climate* (grades K and 3). There is a greater integration of performance expectations at the elementary level. Performance expectations from those middle school Earth and space science topics not represented at the elementary level (*History of Earth*, *Earth's Interior Systems*, and *Human Impacts*) are incorporated into other standard topics in Earth and space sciences, life, or physical science. The goal is not to turn the 3–4 grade-level topics into broad umbrellas to cover all performance expectations, but rather the disciplinary core ideas for each module are interpreted so as to produce coherent storylines that provide sufficient depth into the content.

It is important that a well-connected progression of story lines continue through elementary and into middle school. For example, when *Space Systems* appears in grade 1, there is a focus on the patterns and cycles that students can observe in the sky. The patterns of the Sun, Moon, and stars provide observations by which students begin to understand foundational aspects of nature such as the passing of time, the cyclic aspect of some

phenomena such as seasons, and the generation of light by stars. Students also encounter a significant role of engineering by recognizing that objects in the night sky can be seen in much greater detail with the help of telescopes. Students could record observations of natural phenomena (e.g., sunrise/sunset times) to identify patterns that allow for future predictions.

When *Space Systems* is revisited in grade 5, observational data concerning the day/night sky are expanded into more sophisticated practices. Students analyze data to develop an explanation for the relative brightness of the Sun and stars, providing the basis for understanding the scale of the universe. Students use observations to begin to explain the role of gravity in holding the Earth together. Students make the leap to developing models of the motions of the Sun, Moon, and Earth that will explain observations of repeating cycles of day and night, the length and direction of shadows, and the seasonal appearance of certain stars in the night sky. Corresponding engineering/technology concepts now investigate how telescope lenses operate. The story line now includes core ideas not only from the *Framework's* Big Idea of *Earth's Place in the Universe*, but also from the physical science Big Ideas of *Motion and Stability: Forces and Interactions* and *Waves and Their Interactions* and from the engineering concept of *Interdependence of Science, Engineering, and Technology*.

Middle school

Middle school Earth and space science standards are not broken out by grade but are presented in a 6–8 grade band in recognition of the wide array of curricular arrangements

that may be practiced at this level. The six standard topics (Figure 1, p. 32) represent roughly a year's worth of instruction. These could be taught in a single year but could also be broken out into a more integrated middle school curriculum. The performance expectations push students to more advanced levels, and the added complexity is addressed by the regular addition of “clarification statements” and “assessment boundaries,” which help define their scope.

The middle school Earth and space science topics do not always align in a one-to-one manner with the Big Ideas from the *Framework*. This realignment allows for the performance expectations of the middle school topics to be presented in a structure that provides coherent story lines. For example, the story of Earth's history is best told by combining the history of plate motions and landform evolution with the paleontological record of biological evolution, which is why *History of Earth* contains *Framework* core ideas from both ESS1 and ESS2. Within the *Framework*, the subjects of natural resources and natural hazards are grouped together as part of the anthropospheric Big Idea ESS3.

However, in constructing story lines, the relevant parts of resources and hazards are better grouped with their appropriate topics. So, resources play an important role in *Human Impacts*, but the interior-related resources (e.g., minerals, energy sources) and hazards (e.g., earthquakes and volcanoes) appear in *Earth's Interior Systems*; the surface-related resources (e.g., soils, evaporates) and hazards (e.g., avalanches, landslides) appear in *Earth's Surface Systems*; and weather-system hazards (e.g., tornadoes, floods, hurricanes) appear in *Weather and*

FIGURE 3

Earth and space science content sources

These four literacy documents were used in constructing the Earth and space science content of the *Framework* (from Wysession 2011). These documents of essential concepts were produced by joint research and education community efforts that included the Earth Science Literacy Principles (ESLPs) (www.earthscienceliteracy.org), Essential Principles of Ocean Literacy (www.coexploration.org/oceanliteracy/documents/OceanLitChart.pdf), Essential Principles and Fundamental Concepts for Atmospheric Science Literacy (<http://eo.ucar.edu/asl/index.html>), and Essential Principles of Climate Science (<http://cleanet.org/cln/index.html>). Of particular relevance were the ESLPs (Wysession et al. 2012), which were written with direct input from 350 Earth scientists and educators and reviewed by many hundreds more and consist of the nine “Big Ideas” and 75 “Supporting Concepts” that every citizen should know about Earth science.



Climate. Again, the *NGSS* are not a structured curriculum, and there are many different possible ways of organizing instruction around these performance expectations.

There is a clear progression from elementary school into middle school: The elementary school *Space Systems* lead into both *Space Systems* and *History of Earth* at the middle school level; the elementary school *Earth's Surface Systems* leads to both *Earth's Interior Systems* and *Earth's Surface Systems*, and the elementary school *Weather and Climate* becomes both *Weather and Climate* and *Human Impacts* at the middle school level.

Continuing with the example of *Space Systems*, the performance expectations in middle school take this topic to its natural progressions. For example, models of the Earth-Moon-Sun system are now used to construct explanations for more complex phenomena such as seasons, eclipses, and tides. The concept of gravity is now expanded from its role on Earth to address the motions of orbits within the solar system, and students are no longer just observing but are using models to explain the relative motions of the Sun, Moon, and Earth (seasons, lunar phases, eclipses). Students now examine the scale of both the solar system and galaxy. The contributions of engineering and technology to these topics are prominent in space and planetary science, particularly in acquiring the data that students analyze to examine the geologic processes of other objects in the solar system.

High school

The *NGSS* present high school Earth and space sciences at a high level of complexity that progresses well beyond the middle school level. The structure of the U.S. secondary school science curriculum is largely based on recommendations made 120 years ago in a report by the “Committee of Ten,” which suggested that “physical geography” be taught in middle school, and that biology, physics, and chemistry be taught in high school [NEA 1893]. Unfortunately for the Earth and space sciences, the emergence of modern geosciences in the 1960s and 1970s was not able to break into this construction, and the relegation of Earth and space sciences to middle school classrooms has only served to perpetuate the misconception that the geosciences are low-level sciences of categorization and classification.

This is no longer the case with the *NGSS*. For example, the high school *Space Systems* builds upon middle school *Space Systems* to include the physical science concepts of nuclear fusion and electromagnetic radiation in order to construct explanations for the big bang and formation of the universe, the creation of larger atomic nuclei during stellar nucleosynthesis processes, and the formation of the solar system based on analyses of observable data. Students mathematically and computationally apply Newtonian gravitational laws to the orbital motions of the solar system and analyze evidence to

explain how changes in Earth’s orbital parameters affect cyclic climate changes on Earth such as the repeating Ice Ages. This is not simplistic stuff.

Other high school Earth and space science standards also show a high level of sophistication and integration with other fields. The middle school *Human Impacts* progresses into the high school *Human Sustainability*, which provides students with complex, open-ended investigations that explore possible solutions to conflicts between increasing human populations, the development of dwindling resources, and the need to minimize the resulting impacts. *Weather and Climate* focuses on weather in middle school but on climate and climate change in high school. Climate change occurs over many time scales that span at least eight orders of magnitude (years to hundreds of millions of years) and include solar dynamics, the gravitational perturbations of other planets to Earth’s orbital parameters, atmospheric and oceanic chemistry, radiation physics, oceanic and atmospheric circulation dynamics, biogeochemical cycles, volcanic eruptions, plate tectonics and mountain building, human activity, and the feedbacks between many of these. Student understanding of climate systems requires preexisting understandings in biology, chemistry, and physics.

Model course maps

In fact, it turns out that most of the Earth and space science content needs to be taught following instruction in physics, chemistry, and biology, both for middle school and high school. An important part of the *NGSS* is a set of model course maps (Appendix J of the January, 2013, release) that provide guidance on how to construct curricula around the *NGSS* performance expectations. Course Map 1, the most efficient in instruction and the most sensible in content progress, is a three-course integrated science curriculum for both middle and high school. It orders the science content by identifying the prerequisites needed for students to understand each core idea. The first year is largely physical science, with some Earth and space science; the second year is largely life science, with some physical and Earth and space science; the third year is mostly Earth and space science, with a large amount of life science as well. This holds for both middle and high school. This is similar to the “physics first” curriculum but with Earth and space science as the capstone.

The *NGSS* includes two additional model course maps. Course Map 2 would be the easiest way to align a curriculum with the *NGSS*: It consists of three courses each for middle and high school: Physical Science, Life Science, and Earth and Space Science. In theory, these could be taught in any order, but following the findings of Course Map 1, the ideal way to teach them would be in this exact order, again with Earth and Space Science as the capstone course for both middle and high school.

The last model, Course Map 3, is clearly the least acceptable; it tries to fit the Earth and space sciences into high school physics, chemistry, and biology courses. Because a significant amount of content would be taught out of order in terms of the needed progression of prerequisites, this model would be very inefficient as teachers would have to introduce concepts before they appear in the curriculum and then reteach them later. While most states now require three years of high school science, adding a fourth year would make Course Map 3 workable: a year of Earth and space science would follow courses in physics, chemistry, and biology.

Ironically, it is historically appropriate that Earth and space science should provide a natural capstone experience for the life and physical sciences. Nearly all sciences largely began in the form of Earth and space sciences through early attempts to explain the natural world. Sir Isaac Newton developed the theory of gravity (and calculus along with it) to explain the concept of objects orbiting Earth. Theories of magnetism began with studies of Earth's magnetic field. The field of chemistry began with alchemical studies of minerals and other Earth materials. Even theories of the history of life began with examinations of the paleontological rock record.

Earth and space sciences, in a modern curriculum, can provide students with concrete, understandable, and extremely societally relevant demonstrations of many of the concepts of biology, chemistry, and physics that are sometimes presented in those classes in more general and abstract ways.

Challenges

The NGSS performance expectations, and Earth and space sciences in particular, will pose special challenges to their implementation. Most current science assessments test memorized facts. Shifting toward testing what students can do, instead, will require new approaches to assessment. Teachers may find many challenges: They may be unfamiliar with the aspects of engineering and technology newly integrated into the science curriculum; they may be unaccustomed to teaching from a practice-based approach as opposed to a concept-focused approach; and they may be unused to connecting science content with overarching crosscutting concepts, with aspects of the nature of science, and with Common Core concepts of math and English language arts. This will all require significant professional development.

The prominent role of the Earth and space sciences within the NGSS will also pose significant challenges to implementation. There aren't enough high school Earth and space science teachers in the United States to handle a significant increase in high school Earth and space science content, and a state's implementation of a curriculum based on the NGSS would need to provide for this. None of these challenges is

insurmountable, however, and many efforts are underway to help address them. However they are ultimately organized, structured, taught, and assessed in all of the states that adopt them, the NGSS provide a remarkable opportunity to realize the long-identified potential for Earth and space sciences to be taught in exciting, engaging, encompassing, and relevant manners from kindergarten through 12th grade. ■

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