APPENDIX A

# Methods, Criteria, and Grading Metric

## Methods

This review examined the current K-12 science standards for every state plus the District of Columbia, as well as the NAEP *Science Framework*. We sought to determine how clearly, specifically, and rigorously they cover important content in four areas: physical science, life science, earth and space science, and scientific inquiry and methodology. As with other Fordham Institute reviews of state standards, this analysis focused solely on the quality of the standards themselves. We did not look at whether they are linked to a robust accountability system, whether they are being effectively implemented by a given state, or whether a state's students are achieving at high levels in the subject. Those are all crucial issues, of course, but they are also affected by many factors that go well beyond a state's expectations as expressed in its academic standards.

This is our third review of state science standards. We published the first in 1998 and the second in 2005. Our approach to this review matches that of our previous reports: We gathered the most recent version of each state's science standards from its department of education website, contacted the science standards coordinator(s) for each state to confirm the accuracy of the documents we were to review, and asked a team of trusted and top-notch content experts to apply a set of criteria to them.

For this set of reviews, Lawrence S. Lerner served as lead reviewer, while also reviewing states' K-12 physical science and high school physics standards. Ursula Goodenough reviewed states' K-12 life science standards (including those for high school biology); John Lynch, the K-12 scientific inquiry and methodology standards; Martha Schwartz, the K-12 earth and space science standards; and Richard Schwartz, the K-12 physical science and high school chemistry standards. Adam Marcus helped cobble these reviews into one cohesive document. (For further biographical information about our authors, see About the Authors, page 216.)

Between November 2010 and May 2011, Fordham staff searched the websites of state education departments and communicated with states' science experts. We sought to evaluate the most recently adopted standards. Supplemental materials, including assessment frameworks and curriculum guides, were included in this review only when they were both (a) characterized by the state department of education as a key standards document, and (b) determined by our expert reviewers to be an integral part of the state's standards.

The documents identified at the beginning of each state's profile show (and provide links to) the materials we reviewed. Fordham staff rechecked these materials in the winter of 2011 to ensure that nothing had changed. To the best of our knowledge, all standards were current as of December 2011.

In order to evaluate the quality of states' science standards, our expert reviewers devised content-specific criteria (see page 205). State standards were evaluated against the content-specific grading criteria and were judged against a common grading metric (see page 209). To increase inter-discipline comparability, the common grading metric used for this set of reviews is the same as was used in Fordham's 2010 review of mathematics and English language arts standards, *The State of State Standards—and the Common Core—in 2010*, as well as our 2011 review of U.S. history standards, *The State of State U.S. History Standards 2011*.[1]

[1] Note that the criteria used for this report differ from the criteria our experts used in both our 1998 and 2005 reviews of state science standards. Therefore, comparisons of the grades states received in each review are imperfect. Grade differences could be due to changes in a state's standards, changes in our criteria, or both.

Each state's final score is a composite based on how well the state's standards fared in two categories: (1) content and rigor, and (2) clarity and specificity. Content and rigor were scored on a zero-to-seven point scale, and clarity and specificity on a zero-to-three point scale. Reviewers scored each state's content and rigor for the reviewer's given discipline of expertise. In addition, all reviewers offered clarity and specificity scores for each state. Final content and rigor scores are the average of reviewers' individual discipline-specific scores. Final clarity and specificity scores are averages of all the reviewers' responses. The sum of these two sub-scores determined each state's final score. Final grades were converted into letter grades according to the following scale:

| Grade | Points |
|---|---|
| A | 10 |
| A- | 9 |
| B+ | 8 |
| B | 7 |
| C | 5 or 6 |
| D | 3 or 4 |
| F | 0, 1, or 2 |

# Content-Specific Criteria

As described above, our experts developed criteria that delineated the essential content that should be included in rigorous K-12 science standards. Following is a list of the content-specific criteria used to evaluate the state standards.

## Introduction to the K-12 Science Criteria

In an effective standards document for K-12 science, instruction in the proposed content for Kindergarten through eighth grade should proceed with increasing sophistication and abstraction, as appropriate to each grade. This progression is suggested in the staged content expectations below.

Science cannot be taught effectively without carefully designed and content-matched laboratory and field activities to augment textual materials. Students' understanding of science processes and scientific discourse depends in an essential way on such activities. Laboratory work—with instruments and tools that are already available or are thoughtfully crafted for tasks that students can readily understand—is also an indispensable path to understanding relationships between science and technology and the value of good design. But standards themselves need not name specific laboratory work related to each idea; this may be done in related curriculum documents.

It is impossible to specify an absolute, minimal, "must-have" set of content items in K-12 for all modern science. Physics, chemistry, biology, geology, astronomy, and other sciences are intellectually distinct in important ways, but they are interdependent and overlapping in other ways. Quantitative thinking and problem solving are critical to all. Science content choices for elementary and middle school should include basic and unique topics from all three of the now-standard domains: physical science, life science, and earth and space science. The sequence of presentation may vary, and some areas may be omitted in some years, but this essentially arbitrary tripartite division has come into near-universal use.

For these reviews, we scored criteria against the following disciplines in the following grade spans: scientific inquiry and methodology, K-12; physical science, K-12; physics, grades 9-12; chemistry, grades 9-12; earth and space science, K-12; and life science (including high school biology), K-12.

## Science Content: General Expectations for Learning through Grade Eight

### *Physical Science*

- Know and be able to describe the common forms and states of matter, including solids, liquids, and gases, elements, compounds, and mixtures.
- Know how to use the standard units of measurement (SI).
- Understand time, rate of change, and the relationships among displacement, velocity, and acceleration.
- Understand the relationship between force and motion and be able to solve elementary problems in mechanics.
- Know how to define "gravity."
- Understand kinetic and potential energy, and their transformations.
- Know that matter is made of atoms, which are made of still smaller particles, and that atoms interact to form molecules and crystals.
- Know that heat is a mode of molecular motion. Understand temperature and explain how a thermometer works.

- Know some of the evidence that electricity and magnetism are closely related.
- Know the parts of a simple electric circuit and be able to build one.
- Recognize that light interacts with matter, as in such phenomena as emission and absorption.

### *Earth and Space Science*

- Describe the organization of matter in the universe into stars and galaxies.
- Describe the motions of planets in the solar system and recognize our star as one of a multitude in the Milky Way.
- Recognize Earth as one planet among its solar system neighbors.
- Describe the internal layering of Earth by composition and density.
- Identify the sun as the major source of energy for processes on Earth's surface.
- Describe the main features of the theory of plate tectonics, and cite evidence supporting it.
- Understand how plate tectonics contributes to re-shaping Earth's surface and produces phenomena such as earthquakes, volcanism, and mountain building.
- Identify common minerals by their observable properties.
- Know the major rock types and how the rock cycle describes their formation.
- Understand weather in terms of such basic concepts as temperature and air pressure differences, humidity, and weather fronts.
- Distinguish between weather and climate, and describe changes in Earth's climate over time.
- Describe the hydrologic (water) cycle.
- Recognize that sedimentary rocks—and the fossils they may contain—preserve a record of conditions at the time and place in which they formed.
- Explain that the Earth environment supplies indispensable resources for humans (e.g., soil), but also creates hazards (e.g., earthquakes, volcanic eruptions, floods). Understand that human activity can protect the environment or degrade it.

### *Life Science*

- Know requirements for the maintenance of life, both short-term and long-term, including food, appropriate environment, and efficient reproduction.
- Know how to identify, describe clearly, and name some plant and animal species, including our own.
- Identify the broadest physical and chemical characteristics of Earth's biota.
- Show familiarity with structure and function in prokaryotic and eukaryotic cells and in the tissues of multicellular organisms.
- Know the elements of biological energetics, including cellular respiration and photosynthesis.
- Trace major events in the history of life on earth, and understand that the diversity of life (including human life) results from biological evolution.
- Identify and describe the basic stages of gamete formation and embryogenesis in animals.
- Understand Mendel's laws, phenotype, and genotype.
- Recognize that genes are made of nucleic acids and encode the structure of proteins.
- Recognize the significance of differential gene expression in the processes of development.
- Know the operations of some biochemical and physiological systems (e.g., digestive, sensory, circulatory) in microbes, plants, and animals—including humans.
- Be able to offer examples of cooperation and competition among plants and animals in groups, in populations, and in ecosystems.

## Science Content: General Expectations for Learning for Grades Nine through Twelve[2]

Between ninth grade and high school graduation, many (but not all) students take only one full, two-semester science course. Others may take an "integrated" science course or courses. Elective opportunities, including AP courses, are widespread. The expectations shown here must, therefore, be read selectively and with care. The physics content shown, for example, is primarily, but not necessarily, limited to students who have taken high school physics.

### *High School Physics*

- Use Newton's laws quantitatively to describe falling bodies, linear and curvilinear motion, simple harmonic motion, and fixed-axis rotation.

[2] Note that in the K-8 standards, physics and chemistry content is combined under the heading "physical science." At the high school level, standards for physics and chemistry should be broken out and presented separately. Our criteria reflect this difference.

- Describe planetary motion using Kepler's laws and explain how those laws derive from Newton's laws of motion.
- Use momentum and energy conservation laws to describe one-dimensional elastic collisions.
- Use the work-energy theorem to explain the constancy of total mechanical energy in a frictionless system (e.g., a bouncing Super Ball).
- Understand and describe the absolute temperature scale, the Celsius and Fahrenheit scales, and be able to convert from one to another.
- Explain the first law of thermodynamics in terms of the concepts of heat flow, work, and internal energy.
- Use the operation of an idealized heat engine/heat pump to explain the concepts of thermodynamic efficiency and coefficient of performance. Evaluate the efficiency of heat engines and the performance of refrigerators.
- Understand and be able to apply basic electromagnetic quantities, including charge, polarity, field, potential, current, resistance, capacitance, inductance, and impedance.
- Understand simple electric and electronic circuits quantitatively, in terms of currents and voltage drops.
- Understand how electromagnetic radiation results from the interaction of changing electric and magnetic fields. Analyze refraction and reflection at an optical interface.
- Recognize the basics and some applications of spectrometry.
- Describe the photoelectric effect and the production of X-rays.
- Describe elementary particles and distinguish matter and radiation.

### High School Chemistry

- Outline the Bohr and quantum mechanical models of the atom, and relate them to spectral lines and electron transitions. Understand and give examples of the role of ionic, metallic, covalent, and hydrogen bonding in chemical and biochemical processes.
- Be able to use Lewis dot structures to predict the shapes and polarities of simple molecules.
- Use kinetic theory to describe the behavior of gases (i.e., the ideal gas law) and phase changes.
- Understand and apply the basic principles of acid-base and oxidation-reduction chemistry.
- Understand the common factors that affect the rate of a chemical reaction (e.g., catalysis).
- Describe dynamic equilibrium processes as ones in which forward and reverse reactions occur at the same rates and how a system at equilibrium reacts when stressed.
- Write and balance equations for chemical reactions; solve stoichiometric problems using moles and mole relationships.
- Understand the role of carbon in organic chemistry; write structural formulas for simple aliphatic and aromatic compounds, and name them correctly.
- Calculate the concentration of solutions (as molarity and percent) and discuss factors that affect solubility.
- Use the periodic table to discern and predict properties of atoms and ions, and the likelihood of chemical reactions taking place among them.

### Earth and Space Science

- Cite and explain evidence that the universe has been evolving over some fourteen billion years.
- Describe important events in Earth and solar system evolution over the past four billion years.
- Explain the main events in the evolution of stars and how a star's initial mass determines its eventual fate.
- Know the main physical characteristics of solar system planets and their major satellites.
- Understand and use correctly the basic units of astronomical distance.
- Explain methods of relative and absolute dating of rocks.
- Explain why earthquakes occur, how their sizes are reported as intensity and magnitude, and how scientists use data to locate an earthquake's epicenter.
- Summarize the main lines of evidence for the existence and motion of tectonic plates.
- Describe the movement of continents in terms of mantle convection, lateral motion, seafloor spreading, and subduction at the boundaries between plates.
- Show where Hawaiian-style and Vesuvian-style volcanoes are located in relation to plate boundaries and mantle hot spots, and compare their eruption styles and the structures they build.
- Describe climate and weather patterns in terms of latitude, elevation, oceans (with reference to special properties of water, such as specific heat), land, heat, evaporation, condensation, and rotation of the planet.

- Describe the greenhouse effect and how a planet's atmosphere can affect its climate.
- Describe the solar cycle; be aware of possible effects of solar activity variation on Earth.
- Describe how nutrients, such as carbon, cycle through the atmosphere, hydrosphere, and solid earth.

### Life Science

- Describe the differences between prokaryotes and eukaryotes and probable evolutionary relationships between them.
- Describe ultrastructure and functions of the principal subcellular organelles.
- Understand the distinctions between asexual and sexual reproduction.
- Identify landmark stages of mitosis and meiosis, the purpose of meiosis, and key stages of early development and morphogenesis in animals.
- Be able to state and apply Mendel's laws and to recognize their operation in genetic crosses.
- Know the basic structures of chromosomes and genes down to the molecular level.
- Know the principal steps in photosynthesis, its contribution to the evolution of Earth's atmosphere, and its effect on the forms and chemistry of green plants.
- Understand the genetic code and the steps by which it is expressed in protein synthesis.
- Provide evidence to support the central role of differential gene expression in cellular differentiation and development (e.g., the role of Hox genes).
- Compare and contrast the structure and function of basic physiological systems in animals and higher plants (e.g., digestive, circulatory, sensory, reproductive).
- Define natural selection and speciation in terms of population and evolutionary genetics.
- Understand how evolutionary relationships are inferred with the help of gene/genome sequencing.
- Define genetic drift and explain its effect on the probability of survival of mutations.
- Recognize and give examples of the main classes of ecosystem and their structures.
- Give examples of ecological change that can drive evolutionary change.

## *Sample* Content Expectations at Specific Stages (Points of Assessment)

### Fourth Grade

- Distinguish among solids, liquids, and gases.
- Recognize sizes and scales; know measuring tools and techniques (e.g., rulers, balances, thermometers); make and interpret elementary bar and line graphs to display data.
- Be able to discuss motion and its causes: pushes and pulls (i.e., forces).
- Know how to observe and record operations of levers, pulleys, objects on inclined planes, spring-mass systems, and simple pendulums.
- Recognize that energy has several forms and that they can be inter-converted.
- Observe and describe some material transformations (e.g., phase changes, hydration, dehydration, solution, chemical reaction).
- Recognize such basic life processes as breathing, feeding, and reproducing.
- Know the basic structure of higher plants; observe plant growth and its requirements.
- Recognize animal structures and behaviors and the groupings of animals and plants in communities.
- Observe and be able to describe similarities and differences between parents and offspring.
- Observe Earth, the sun, and the moon and discuss their motions and directly visible properties.
- Recognize rocks, soil, and fossils in rocks; land and water; mountains and plains; oceans and continents.
- Recognize some conditions and processes that cause weathering and erosion, stream formation, and sedimentation.

### Eighth Grade

- Make measurements and perform calculations, paying attention to precision and accuracy.
- Make and interpret graphical displays of data.
- Understand and make simple calculations involving displacement, time, and average velocity.
- Define volume, weight, mass, density, and chemical and physical change.
- Demonstrate addition of forces in one dimension and explain the relationship between net force and acceleration.

- Describe mechanical work as the effect of a force acting over a distance, and explain that the work done in lifting a mass or compressing a spring is stored as potential energy.
- Demonstrate basic familiarity with heat, light, sound, and electricity.
- Distinguish between, and give examples of, elements and chemical compounds.
- Describe directly observable properties of acids and bases and use of the pH scale.
- Describe accurately key differences between prokaryotic and eukaryotic cells.
- Recognize photosynthesis as a primary energy-capture process of life, and the sun as the indispensable source of that energy.
- Recognize and be able to express in simple taxonomic terms the vast range of plant and animal diversity.
- Identify structure/function relationships in physiological systems (e.g., reproductive, digestive, nervous, circulatory).
- Know the elements of Mendelian inheritance.
- Be aware of the history of Earth's biosphere and some of the basic evidence for its evolution.
- Understand that Earth is geologically active, with building and breakdown processes in continual operation.
- Know the rock cycle.
- Describe the solar system and know some relative orbit radii, periods, and planet and satellite sizes.
- Recognize the existence of myriad galaxies, their sizes, and intergalactic distances.

# Common Grading Metric

As explained above, once a state's standards are evaluated against the science content criteria, the standards are judged against a grading metric (shown below). States can earn up to seven points for content and rigor, and up to three points for clarity and specificity.

## Content and Rigor

### *7 points – Standards meet all of the following criteria:*

- Standards are reasonably comprehensive in terms of content. Coverage for each of the three core scientific disciplines is adequate, and good decisions have been made about what topics to include under each heading.
- Not only is appropriate content covered by the standards, but it is also articulated in a readily understood way.
- Sound decisions have been made about what content can be left out. Excellent standards can neither cover everything in science nor include superfluous or distracting material.
- The standards distinguish between more important and less important content and skills, either directly (by stating which are more and less important) or via the number of standards and amount of discussion devoted to particular topics. The standards neither overemphasize topics of small importance nor underemphasize topics of great importance.
- The level of rigor is appropriate for targeted grade level(s). Students are expected to learn the content and skills in a rational order and at appropriately increasing levels of difficulty. The standards, taken as a whole, define science literacy for all students; at the same time, standards that run through twelfth grade are sufficiently challenging to ensure that students who do achieve proficiency by the final year will be ready for college or career.
- The standards do not overemphasize "life experiences" or "real world" problems. They do not embrace fads or display political or cultural biases. They do not imply that all interpretations of natural phenomena are equally valid. While these standards may not be uniformly perfect, any defects are marginal.

### *6 points – Standards fall short in one of the following ways:*

- Some important content (as identified in our content criteria) is missing.
- Content is covered satisfactorily but the presentation is not of uniformly high quality.
- Some proposed content in the standards is unnecessary and distracting.
- Standards do not always differentiate between more and less important content (i.e., importance is neither articulated explicitly nor conveyed via the number of standards dedicated to a particular topic). In other words, these standards overemphasize a few topics of little importance or underemphasize a few topics of great importance.
- Some of the expectations at particular grade levels are set either unrealistically high or too low.
- There are small problems or errors in the presentation of important subjects, such as those listed among our content criteria.

***5 points – Standards fall short in at least two of the following ways:***

- Some important content (as identified in our content criteria) is missing.
- Content is covered satisfactorily but the presentation is not of uniformly high quality.
- Some proposed content in the standards is unnecessary and distracting.
- Standards do not always differentiate between more and less important content (i.e., importance is neither articulated explicitly nor conveyed via the number of standards dedicated to a particular topic). In other words, these standards overemphasize a few topics of little importance or underemphasize a few topics of great importance.
- Some of the expectations at particular grade levels are set either unrealistically high or too low.
- There are a few problems or errors in the presentation of important subjects, such as those listed among our content criteria.

***4 points – Standards fall short in one or both of the following ways:***

- Although there are no grossly misleading or mistaken standards, about half of the important content (as listed among our content criteria) is missing.
- There are errors or failures to set learning expectations high enough and appropriate to grade level.

***3 points – Standards fall short in one or both of the following ways:***

- Although there are no grossly misleading or mistaken standards, considerably more than half of the important content (as listed among our content criteria) is missing.
- There are frequent errors or failures to set learning expectations high enough and appropriate to grade level.

***2 points – Standards fall short in one of the following ways:***

- Most, but not necessarily all, of the important science content (as represented in our content criteria) is missing.
- Some of the content offered is superfluous or distracting; even if not in error, it often fails to reach levels of sophistication that are grade-appropriate.

***1 point – Standards fall short in both of the following ways:***

- Most, but not necessarily all, of the important science content (as represented in our content criteria) is missing.
- The content offered is frequently superfluous, distracting, or poorly chosen; even if not in error, it generally fails to reach levels of sophistication that are grade-appropriate.

***0 points: Standards fall short in the following way:***

- No effort has been made to represent the state and content of modern science; that is, the character and content of modern science are not recognizable in these standards.

## Clarity and Specificity

***3 points – Standards are clear, coherent, and well organized.***

Both scope and sequencing of the material are apparent and reasonable. The standards provide practical guidance to users (students, parents, teachers, curriculum directors, test developers, textbook writers, etc.) on the science content knowledge and skills required. The level of detail is appropriate for expectations covering all K-12 science.

The document(s) is (are) written in prose that the general public can understand and that is free of jargon. (Necessary technical terms and mathematical notation may appear; they are not considered jargon.) The standards describe measurable achievements—performance levels comparable across students and schools. The standards as a whole make clear the intellectual growth expected through the grades.

***2 points – The standards are somewhat lacking in clarity, coherence, or organization.***

Scope and sequencing of the material are not completely apparent or are not always useful for curriculum planning. The standards do not quite provide a complete guide for users as to the content knowledge and skills required. (That is, as a guide for users, these standards have shortcomings not addressed directly in the content and rigor review.) The standards provide insufficient detail. The prose is generally comprehensible but there is some jargon or vague language. Some of the standards do not imply measurable expectations.

***1 point – The standards fail frequently to be clear, coherent, or well organized.***

The standards offer only limited guidance to users (students, parents, teachers, curriculum directors, textbook writers, etc.) on the content knowledge and skills required, and there are shortcomings (regarding guidance for users) that are not addressed directly in the content and rigor review. The standards are seriously lacking in detail, and the language is sometimes too vague to make clear what is really being asked of students and teachers.

### *0 points – The standards are incoherent and/or disorganized.*

The standards will not be helpful to users. They are sorely lacking in detail. Scope and sequence are a mystery.