SCIENCE

Pennsylvania

GRADE	SCORES		TOTAL SCORE
D	Content and Rigor	2/7	3/10
	Clarity and Specificity	1/3	

REPORT CARD

Content & Rigor	**2.3**
Scientific Inquiry & Methodology	0
Physical Science	4
Physics	2
Chemistry	3
Earth & Space Science	3
Life Science	2
Clarity & Specificity	**1.4**

Average numerical evaluations

Document(s) Reviewed

- *Academic Standards for Science and Technology and Engineering Education: Elementary Standards*. June 2009. Accessed from: http://www.pdesas.org/main/fileview/Academic_Standards_for_Science_and_Technology_and_Engineering_Education_(Elementary).pdf
- *Academic Standards for Science and Technology and Engineering Education: Secondary Standards*. January 2010. Accessed from: http://www.pdesas.org/main/fileview/Academic_Standards_for_Science_and_Technology_and_Engineering_Education_(Secondary).pdf

Overview

The Pennsylvania science standards are generally poor. If a bright spot exists, it's in the earlier grades, where the coverage does occasionally earn reasonable marks for rigor. In high school, however, the material generally descends into flabbiness and disorder. By no means could these standards serve as the foundation for a sound science curriculum for students in the Keystone State.

Organization of the Standards

The Pennsylvania standards for grades 3-8 are first divided into four "standard categories": biological sciences; physical sciences; earth and space sciences; and science, technology, and engineering. (The inquiry and methodology standards are embedded in the science, technology, and engineering strand.) For each standard category the state provides "organizing categories," and then strands. For example, under "biological sciences," the first organizing category is "organisms and cells." Beneath that, the first strand is "common characteristics of life."

Finally, grade-specific "standard statements" are provided.

The high school standards are organized similarly—with the same standard categories, organizing categories, and strands—with one big caveat: Standards are not presented by grade level, but by course (physics, chemistry, biology) and by tenth- and twelfth-grade "targets for instruction and student learning." In other words, each of the three high school courses (physics, chemistry, and biology), as well as the tenth- and twelfth-grade expectations, addresses the material in each of the four standard categories listed above: biological sciences, physical sciences, earth and space sciences, and science, technology, and engineering. This presentation renders the high school material wildly confusing. Biology material, for example, appears within the biology course, within the chemistry course under the biological sciences standard category, and within the tenth- and twelfth-grade expectations.

No standards are provided for grades K-2, except within a broad K-4 inquiry grade band.

Content and Rigor

The Pennsylvania science standards have many shortcomings, from a lack of grade-appropriate content across all disciplines to the inclusion of baffling and, at times, downright risible material.

Scientific Inquiry and Methodology

The Pennsylvania standards assert that "*Science as Inquiry* is logically embedded in the Science and Technology and Engineering Education standards [*sic*] as inquiry is the process through which students develop a key understanding of sciences." While this may be true, the document offers scant guidance as to how this is to be achieved. Process content is featured on a single page, organized into four grade bands (K-4, 5-7, 8-10, 11-12). Within each grade band, the state presents a series of bullet points (e.g., "compare and contrast scientific theories" [grades 8-10]) and then cross-references specific content-area strands to be examined. Yet, once identified among the content standards, those content strands merely direct the reader *back* to the single page overview, telling the reader to "See *Science as Inquiry* in the Introduction for grade level indicators." Thus, the inquiry standards, such as they are, include no link to real content, give no indication of just how these goals are embedded within the curriculum, and are functionally useless.

Also, missing entirely from the bulleted lists is any mention of the historical development of science.

Physical Science

The physical science standards suffer from two main problems. First, the expectations too often change very little from year to year, resulting in little progression of content or rigor as the grades advance. Take, for example, the following fourth- and fifth-grade standards:

> **Identify types of energy and their ability to be stored and changed from one form to another. (grade 4)**
>
> **Examine how energy can be transferred from one form to another. (grade 5)**

Here, the fifth-grade standard requires essentially the same level of understanding of energy transfer as the fourth.

There are some notable exceptions to this inertia of grade-to-grade development. A fine example is the treatment of dynamics:

> **Explain how movement can be described in many ways. (grade 3)**
>
> **Explain how an object's change in motion can be observed and measured. (grade 4)**
>
> **Explain how mass of an object resists change to motion. (grade 5)**
>
> **Explain how changes in motion require a force. (grade 6)**
>
> **Describe how unbalanced forces acting on an object change its velocity.**
>
> - **Analyze how observations of displacement, velocity, and acceleration provide necessary and sufficient evidence for the existence of forces. (grade 7)**
>
> **Explain how inertia is a measure of an object's mass.**
>
> **Explain how momentum is related to the forces acting on an object. (grade 8)**

Now, one may carp about the impracticality of teaching resistance to change in motion in fifth grade while deferring the discussion of force—the very thing that is being resisted—to sixth grade. But in the give-and-take of a real classroom, that will not be a problem. A more serious criticism is the final statement in eighth grade, which can lead to confusion between *impulse*, which is directly related to momentum, and *force*, which is related only indirectly. But overall, the development is refreshingly clear and pedagogically sound.

The second problem with the physical science standards is the way that some topics jump around from year to year, making it difficult to track the scope and sequence of content. Take waves as an example: Students study light in third grade, sound in fourth and fifth grades, nothing in sixth grade, light again in seventh grade, and nothing in eighth grade. Arbitrarily dividing this related content makes little sense. It would be better to study sound and light together year after year, which would help the student acquire insight into the nature of waves in general while at the same time deepening his or her understanding of the specific properties of sound and light.

High School Physics

The standards for high school physics are problematic. For starters, the ordering of items is bewildering. For example, the following mechanics content appears in the tenth-grade expectations—presumably before students will have taken high school physics (which typically happens in the eleventh grade):

> **Analyze the relationships among the net forces acting on a body, the mass of the body, and the resulting acceleration using Newton's Second Law of Motion.**

- **Apply Newton's Law of Universal Gravitation to the forces between two objects.**
- **Use Newton's Third Law to explain forces as interactions between bodies.**
- **Describe how interactions between objects conserve momentum. (grade 10)**

This detailed content belongs in the physics course itself, which in turn speaks to Newton's laws in only one standard:

> **Use Newton's laws of motion and gravitation to describe and predict the motion of objects ranging from atoms to the galaxies. (high school physics)**

What's more, the physics standards are devoted to a hodgepodge of applications that do violence to the natural logic and order of the subject. Take, for example, the following:

> **Differentiate among translational motion, simple harmonic motion, and rotational motion in terms of position, velocity, and acceleration.**

- **Use force and mass to explain translational motion or simple harmonic motion of objects.**
- **Relate torque and rotational inertia to explain rotational motion. (high school physics)**

This is a jumble of prerequisite material students will need for the study of kinematics and some applications of mechanics that follow on the essential introductory matters of Newton's laws.

And that's all there is of mechanics.

Sadly, equally chaotic and meaningless standards cover other important topics as well. For instance, students are asked to "explain how stationary and moving particles result in electricity and magnetism," or to "explain how electrical induction is applied in technology" (high school physics). Here, doubtless, the intent was to present electromagnetic induction. Electrical (or more properly electrostatic) induction has to do with the process of charging a dielectric object without touching it to a source of charge.

High School Chemistry

Chemistry, like physics, is confusing at the high school level. Aspects of the science are found in the chemistry course as well as in the tenth- and twelfth-grade expectations, leaving little confidence that students will learn the essentials.

What's more, standards that are included under the chemistry-course banner are sometimes overbroad and wildly ambitious, with students being asked to "explain the chemistry of metabolism" (high school chemistry). The chemistry of metabolism is a complex and wide-ranging subject; including this expectation adds little value. Other standards are simply hollow and represent failed attempts to link disciplines. For example, in a section devoted to photosynthesis and metabolism, the chemistry sub-strand includes the following:

> **Describe how changes in energy affect the rate of chemical reactions. (high school chemistry)**

This is meaningless; changes in the energy of what? Unfortunately, such entries are typical.

Oftentimes, content is too broad to be useful—or is missing entirely. And the list of material that fits this bill is entirely too long. It includes: gas law relationships; acid/base definitions and properties; neutralization reactions; pH scale; molarity; equilibrium; Le Châtelier's principle and stresses; equilibrium expressions and constants; organic chemistry, including types of bonding; names, shapes, and formulas of simple molecules; and solutions including preparation and dilutions. Phew!

Earth and Space Science

The earth and space science standards for elementary and middle school include some critical content. Stars and galaxies, for example, are well covered, as is the solar system:

> **Compare and contrast the size, composition, and surface features of the planets that comprise the solar system as well as the objects orbiting them. (grade 6)**

Unfortunately, lack of specificity often masks the intended scope. For example, in fourth grade, students are asked to "identify the layers of the earth." In seventh grade, this grows to "describe the layers of the earth." But it is unclear how "deep" the standards should go in either grade.

Further, some critical content is missing. The rock cycle is mentioned but not explained, and the major rock types—igneous, metamorphic, and sedimentary—are barely mentioned. Plate tectonics receives no more than a passing nod.

The high school standards are worse. For starters, there is no designated earth science course. Related standards are scattered between the tenth- and twelfth-grade expectations, but without a specific earth science course, it is unclear how such material would be presented to students. Even then, much is either glossed over or missing entirely. For example, astronomical units are not mentioned, nor are volcanism, climate and weather factors, or earthquakes. ("Seismic activity" is murkily defined in the glossary.) Plate tectonics is mentioned once each in fifth and tenth grades (and is incorrectly defined in the glossary), but never developed. Tenth-grade students are only asked to “relate plate tectonics to slow and rapid changes in the earth’s surface.” And the history of the universe is barely mentioned in tenth grade, when students are asked only to “provide evidence to suggest the Big Bang Theory.”

Life Science

The life science standards are woefully inadequate. First of all, while some important content is included, there is no clear progression of content or rigor through the grades. For example, in fifth grade, students are asked to “explain the concept of the cell as the basic unit of life.” Then, in seventh grade, they are asked to “explain how the cell is the basic structural and functional unit of living things.” There is little difference between the two standards.

Second, too many expectations are nonsensical or so broad that they are essentially meaningless. For instance, seventh graders are asked to “explain why the life cycles of different organisms have varied lengths”—a question that may only have a theological answer!

Similarly, in eighth grade, students are asked to “explain mechanisms organisms use to adapt to their environment,” a broad expectation that includes virtually no content.

In addition, much of the high school content simply demands too little of students. For instance, biology standards scattered among the tenth-grade expectations are pitched at such a low level that they do not merit discussion.

On the positive side, the high school biology course itself is far better, and much of the important content is covered with impressive depth and rigor. For example, students are asked to:

> **Describe how Mendel’s laws of segregation and independent assortment can be observed through patterns of inheritance.**
>
> **Distinguish among observed inheritance patterns caused by several types of genetic traits (dominant, recessive, codominant, sex-linked, polygenic, incomplete dominance, multiple alleles). (high school biology)**

And later, students will:

> **Explain how the processes of replication, transcription, and translation are similar in all organisms.**
>
> **Explain how gene actions, patterns of heredity, and reproduction of cells and organisms account for the continuity of life. (high school biology)**

Unfortunately, these glimpses of excellence are rare, and some critical topics are missing even here. For instance, the standards contain no physiology at all, across all grades, so students will have no idea how their muscles and guts and brains work.

The treatment of evolution is nearly complete, with one notable omission. The previous version of Pennsylvania’s science standards from 2002 laudably covered human evolution. Yet human evolution has been removed from this 2009 version of the Pennsylvania standards. Virtually no states cover human evolution; with this removal, Pennsylvania transitioned from being a pioneer to just another in the pack.

Overall, the Pennsylvania science standards are inadequate and earn a dismal average score of two out of seven for content and rigor. (See Appendix A: Methods, Criteria, and Grading Metric.)

Clarity and Specificity

There are two significant problems with the Pennsylvania standards, both of which detract greatly from the clarity of the material. First, as noted above, the presentation of the high school content is wildly confusing. Physics, chemistry, and biology material appears scattered across three courses of the same names and across the tenth- and twelfth-grade expectations. The introduction to the *Secondary Standards* states:

> **In addition to course standards, the standards for grades 10 and 12 are shown to clarify the targets for instruction and student learning. Although the standards are not a curriculum or a prescribed series of activities, school entities will use them to develop a local school curriculum that will meet local students’ needs.**

Unfortunately, this does little to clarify how the tenth- and twelfth-grade standards should be fitted into actual courses, and the scope and sequence of essential content is difficult to track.

In addition, the way some standards are written renders them meaningless. Some are far too broad: For instance, in fifth through seventh grades (but not at any higher level), students are asked to “use mathematics in all aspects of scientific inquiry.” *All?* In eleventh and twelfth grades, they must “examine the status of existing theories,” whatever that means. Other items in the standards are written in such vague language as to be incomprehensible, as in the glossary definition of the rock cycle: “The process by which rocks are formed, altered, destroyed, and reformed by geological processes and which is recurrent, returning to a starting point." It is a "process" made up of "processes" and returns to a starting point?

Other standards foster the insinuation of pseudoscience into science content by inviting teachers to "teach the controversy" about evolution and global warming, when delineating the specific scientific content they should learn would obviously be preferable.

In all, these drawbacks are significant and earn Pennsylvania an average score of one out of three for clarity and specificity. (See Appendix A: Methods, Criteria, and Grading Metric.)