# Update on the Next Generation Science Standards

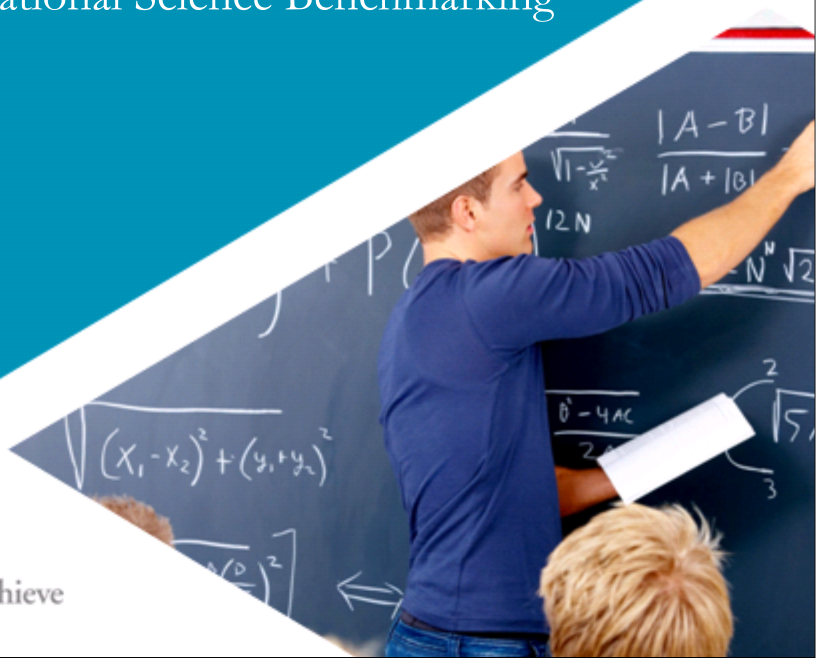
*Stephen Pruitt, Ph.D., Vice President, Content, Research and Development*

Achieve

## Agenda

- International Science Benchmarking Study
- Overview of the Next Generation Science Standards Development Process

# International Science Benchmarking Study



Achieve

## New Science Standards will be Internationally Benchmarked

**Achieve examined standards from 10 countries to determine emphases in foundational science–-standards for *all* students (grade spans 1-6 and 7-10) versus emphases in discipline-based standards in Upper Secondary**

*Science Standards*

1. *Canada (Ontario)*
2. *Chinese Taipei*
3. *England*
4. *Finland*
5. *Hong Kong*
6. *Hungary*
7. *Ireland*
8. *Japan*
9. *Singapore*
10. *South Korea*

**Three Research Questions:**

- What knowledge and skills do countries expect all students to learn prior to taking discipline-specific high school courses?
- What knowledge and skills do countries expect students to learn in Upper Secondary courses in Biology, Chemistry, Physics, and Earth and Space Science?
- What are exemplary features of countries' standards that should be considered in developing NRC framework & new science standards?

# Achieve International Benchmarking: Two-Part Study Design

**Quantitative Analysis**

- Modeled on methodology (framework and codes) developed by Michigan State University for 1997 study of standards and textbooks
- Content experts coded standard statements of 10 countries to permit analysis of content and performances for 3 grade spans: Primary (~grades 1-6; Lower Secondary (~7-9/10) and Upper Secondary (discipline-specific courses)
- Framework is a neutral tool; coding allowed Achieve to aggregate content and performances to determine overall patterns

**Qualitative Analysis**

- Conducted preliminary review of 10 countries standards to identify most promising for informing development of draft framework and standards
- Conducted in-depth qualitative review of 5 countries: Canada, England, Hong Kong, Japan and Singapore by content experts

# International Study: Quantitative Analysis Findings

## Overall findings: Grade span 1-6 and 7-9/10

- **Integrated science instruction** - 7/10 countries require general science through grade 9/10 prior to students taking discipline-specific courses
- **Physical sciences** are emphasized – on average physics and chemistry content, taken together, receive the most attention (43%)
- **Biology** content on average receives significant attention (28%)
- **Earth and Space Sciences** on average receive the least attention (9%)
- **Cross-cutting content** (nature of science, nature of technology/ engineering, interactions of science, technology and society and sustainability) on average receives significant attention (20%)

## International Study:
## Quantitative Analysis Findings

### Overall findings: Upper Secondary Levels

- **Physics** - on average, emphasis is on Newtonian mechanics, science, technology & society and electricity; atomic structure receives significant emphasis in both physics and chemistry
- **Chemistry** - organic chemistry and stoichiometry on average receive unexpected attention
- **Biology** - on average the categories receiving the most emphasis are Cells-structure and function; Reproduction, development & heredity; Systems, organs and tissues)
- **Earth and space science** - only 3/10 countries have E/ss courses at upper secondary; these courses included the most interdisciplinary and cross-cutting content –on average 40%

## International Study:
## Qualitative Analysis Findings

### Exemplary Features:

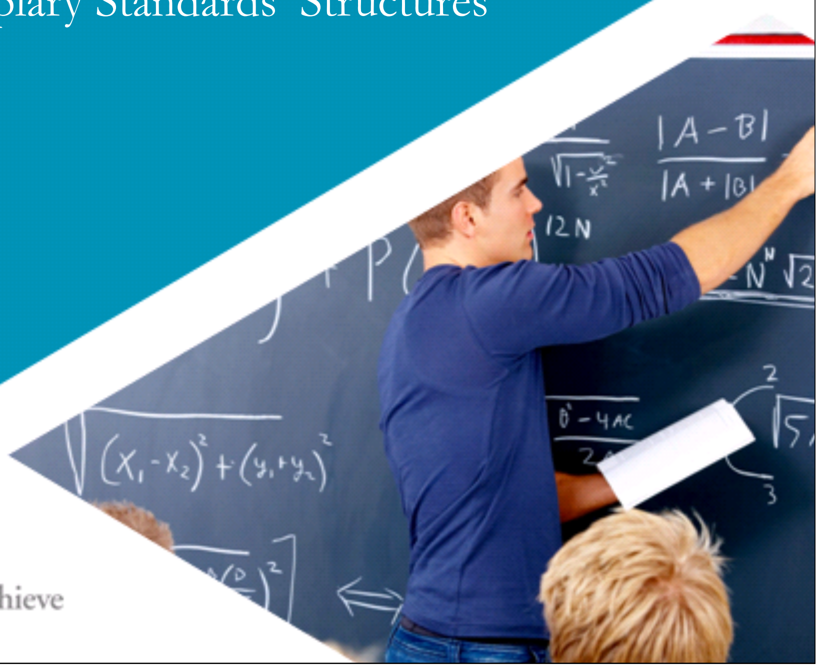
- Framework based on "Big Ideas" seems to lead to more coherent and focused standards (Canada, Singapore)
- Incorporation of *multiple* examples clarifies level of rigor and helps learners connect concepts with applications (Canada)
- Connecting standards to assessment keeps focus on raising student achievement (Canada, England, Hong Kong)
- Choice of organization and format has enormous effect on clarity (Canada, Singapore)
- Parallel development of inquiry and design processes supports project work that cultivates scientific habits of mind and stimulates student interest (Canada)

## New Opportunities and New Directions

**Shortcomings in Current Standards = Opportunities for the U.S. to Take the Lead in Science Education Reform**

- Incorporation of mathematics
- Evidence-based inquiry
- Model-building
- Use of engineering design
- Foundations for concepts in modern biology
- Interdisciplinary connections

## Exemplary Standards' Structures



Achieve

# College Board

*Standards* represent the core, overarching ideas of each discipline. Each standard has its own unique code or letter/ number combination with the letter(s) representing the relevant discipline. A key word or phrase accompanies each standard to indicate the content covered. A more in-depth description follow each standard.

*Objectives* describe the target understanding for college readiness; they explain specific learning goals that relate to the corresponding standard. Like the standards, each objective has a unique code as well as a unique code as well as a corresponding key word or phrase.

*Suggested connections* are provided to show how the content of a given objective links to the content of other objectives with a discipline and across disciplines.

*Performance expectations* (PEs) specify what students should know, understand and be able to do in order to be successful in college. They also illustrate how students engage in science practices to develop a better understanding of the essential knowledge statements and the objectives.

## Standard C.2
## Matter and Change

The properties of matter and the changes that matter undergoes result from its atomic–molecular level structure. For any chemical or physical change, matter is conserved.

Students understand that the properties of materials are determined by the elements present in the substance; the arrangement of the atoms, ions or molecules in the compound; and the forces between atoms, ions or molecules in the compound. Conversely, if the properties of a material are known, then predictions about the type of bonding and the type of intermolecular attractions present at the atomic–molecular level can be made.

Clarification: In chemical systems, mass–energy conservation is not considered.

### Objective C.2.1
### Periodic Table

Students understand that the periodic table is an organizational tool that can be used for the prediction and classification of the trends and properties of elements.

**Suggested Connections**
*Within Chemistry:* Electrons (C.1.2); Bonding (C.1.3)

*Between Chemistry and Other Disciplines:* Carbon Cycle (ES.4.2); Energy Transfer (LS.4.2); Nuclear Interactions and the Conservation of Mass–Energy (P.2.3)

*Prepares students for the following AP Enduring Understandings:* AP Chemistry 1C

**PERFORMANCE EXPECTATIONS**

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

**C-PE.2.1.1** Predict, based on its position in the periodic table, the properties of a given main group element. Properties include appearance, electronegativity, type of bond formed, and ionic charge. Make a claim about the type (metal, nonmetal, metalloid) of the given element. Give examples of other elements that would have similar properties, and explain why they would have similar properties.
*[**BOUNDARY:** Elements are restricted to adjacent elements in the s-block and p-block only.]*

**C-PE.2.1.2** Given a data table of atomic properties (e.g., atomic radius, ionization energy or electronegativity) for elements in a period and/ or elements in a group:
*[**BOUNDARY:** Atomic properties do not include electron affinity and only address first ionization energy. It is not necessary to explain changes in size across a period.]*

- **C-PE.2.1.2a** Select the appropriate method of data representation.
- **C-PE.2.1.2b** Analyze data for trends of a property across a period and down a group.
- **C-PE.2.1.2c** Explain, using knowledge of atomic structure, the trend in that property across a period or down a group.
- **C-PE.2.1.2d** Predict, based on the previous explanation, the trend in that property for a different set of elements. Gather data from print and electronic resources, and confirm the prediction.

**C-PE.2.1.3** Predict, using the periodic table, trends in properties for groups (i.e., families) of elements. Predicted trends should include atomic radius, electronegativity, ionic charge (if formed), type of bond formed with metal and/or nonmetal, and type of substance (metal, nonmetal, metalloid).

**C-PE.2.1.4** Explain, in terms of attractions and repulsions between the electrons and the nucleus, why the radius of an atom changes when the atom becomes an ion.

---

*Essential knowledge* (EK) statements describe conceptual targets for student learning that support the corresponding objective. They provide language and boundaries of the performance expectations.

### *Objective C.2.1: Periodic Table*

**ESSENTIAL KNOWLEDGE**

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The modern version of the periodic table is organized in order of increasing atomic number (number of protons).
- Elements were originally placed in the periodic table based on their repeating properties, which are a result of the number and type of valence electrons.
- Properties of an element can be predicted based on its placement in the periodic table. Groups of elements exhibit similar properties with predictable variations; rows of elements have predictable trends.
- Elements are often classified as metals, nonmetals and metalloids.
- There are a number of elements — such as nitrogen, oxygen, phosphorus, sulfur, hydrogen and carbon — that are important for living systems. Carbon, the most important of these elements, is central to the chemistry of biological systems because of its unique bonding characteristics. Carbon compounds are usually classified as organic compounds.
*[**BOUNDARY:** Organic nomenclature is beyond the scope of these standards.]*
- Another way to use the periodic table is to consider the elements as arranged in "blocks" based on the elements' outermost electrons. The elements in these blocks (s-block, transition metals, p-block, lanthanides and actinides) in the modern periodic table also have similar properties of predictable variability.
*[**BOUNDARY:** Only the s-block and the p-block should be discussed in detail.]*

# Canada (Ontario)

The *overall expectations* describe in general terms the knowledge and skills students are expected to demonstrate by the end of each course. Two or three overall expectations are provided for each stand in every course. The numbering of overall expectations indicates the strand to which they belong.

The *specific expectations* describe the expected knowledge and skills in greater detail. The expectation number identifies the strand to which the expectation belongs and the overall expectation to which it relates.

The *examples* are meant to illustrate the kind of knowledge or skills, the specific area of learning, the depth of learning, and/or the level of complexity that the expectation entails. The examples are illustrations only, not requirements.

The *sample issues* provide a broader context for expectations in the strand Relating Science to Technology, Science, and the Environment. They are examples of relevant topics of open-ended issues or problems related to the expectations.

The *samples questions* are intended to help teachers initiate open discussions on a range of current issues related to the topic of the expectations.

The *abbreviations in square brackets* following many specific expectations link the expectation to one or more of the *four broad areas of scientific investigation skills*: initiating and planning; performing and recording; analysing and interpreting; and communicating.

## B. MATTER, CHEMICAL TRENDS, AND CHEMICAL BONDING

### OVERALL EXPECTATIONS

By the end of this course, students will:

**B1.** analyse the properties of commonly used chemical substances and their effects on human health and the environment, and propose ways to lessen their impact;

**B2.** investigate physical and chemical properties of elements and compounds, and use various methods to visually represent them;

**B3.** demonstrate an understanding of periodic trends in the periodic table and how elements combine to form chemical bonds.

### SPECIFIC EXPECTATIONS

#### B1. Relating Science to Technology, Society, and the Environment

By the end of this course, students will:

**B1.1** analyse, on the basis of research, the properties of a commonly used but potentially harmful chemical substance (e.g., fertilizer, pesticide, a household cleaning product, materials used in electronics and batteries) and how that substance affects the environment, and propose ways to lessen the harmfulness of the substance (e.g., by reducing the amount used, by modifying one of its chemical components) or identify alternative substances that could be used for the same purpose [IP, PR, AI, C]

*Sample issue:* Many commercial household cleaning products contain corrosive substances that can accumulate in the environment. There are now many "green" cleaners that do not contain these substances, although some of these products may not be as environmentally friendly as claimed.

*Sample questions:* Why is it more environmentally friendly to use latex rather than oil-based paint? Why should paint never be poured down a drain? What properties of some common pharmaceuticals allow them to stay in water systems and influence the growth and development of organisms? What are some ways in which this impact can be reduced?

**B1.2** evaluate the risks and benefits to human health of some commonly used chemical substances (e.g., chemical additives in foods; pharmaceuticals; cosmetics and perfumes; household cleaning products) [AI, C]

*Sample issue:* Artificial sweeteners, such as aspartame, are used as sugar substitutes to reduce calories in processed foods and beverages. Although such sweeteners may benefit people who are watching their weight, or those with diabetes, some experts say that their harmful effects on human health may outweigh their benefits.

*Sample questions:* How can the use of non-stick cookware help reduce the amount of fat in our diet? What risks are associated with the use of such cookware? What are the risks and benefits of using sunscreens that contain PABA? What are the risks and benefits of using insect repellents that contain DEET?

#### B2. Developing Skills of Investigation and Communication

By the end of this course, students will:

**B2.1** use appropriate terminology related to chemical trends and chemical bonding, including, but not limited to: *atomic radius, effective nuclear charge, electronegativity, ionization energy,* and *electron affinity* [C]

# Ontario (continued)

**B2.2** analyse data related to the properties of elements within a period (e.g., ionization energy, atomic radius) to identify general trends in the periodic table [AI]

**B2.3** use an inquiry process to investigate the chemical reactions of elements (e.g., metals, non-metals) with other substances (e.g., oxygen, acids, water), and produce an activity series using the resulting data [PR, AI]

**B2.4** draw Lewis structures to represent the bonds in ionic and molecular compounds [PR, C]

**B2.5** predict the nature of a bond (e.g., non-polar covalent, polar covalent, ionic), using electronegativity values of atoms [AI]

**B2.6** build molecular models, and write structural formulae, for molecular compounds containing single and multiple bonds (e.g., $CO_2$, $H_2O$, $C_2H_4$), and for ionic crystalline structures (e.g., NaCl) [PR, AI, C]

**B2.7** write chemical formulae of binary and polyatomic compounds, including those with multiple valences, and name the compounds using the International Union of Pure and Applied Chemistry (IUPAC) nomenclature system [AI, C]

#### B3. Understanding Basic Concepts

By the end of this course, students will:

**B3.1** explain the relationship between the atomic number and the mass number of an element, and the difference between isotopes and radioisotopes of an element

**B3.2** explain the relationship between isotopic abundance of an element's isotopes and the relative atomic mass of the element

**B3.3** state the periodic law, and explain how patterns in the electron arrangement and forces in atoms result in periodic trends (e.g., in atomic radius, ionization energy, electron affinity, electronegativity) in the periodic table

**B3.4** explain the differences between the formation of ionic bonds and the formation of covalent bonds

**B3.5** compare and contrast the physical properties of ionic and molecular compounds (e.g., NaCl and $CH_4$; NaOH and $H_2O$)

# Singapore

**THE PERIODIC TABLE: CHEMICAL PERIODICITY**

**Content**

- Periodicity of physical properties of the elements: variation with proton number across the third period (sodium to argon) of:
  - (i) Atomic radius and ionic radius
  - (ii) Melting point
  - (iii) Electrical conductivity
  - (iv) Ionisation energy
- Periodicity of chemical properties of the elements in the third period
  - (i) Reaction of the elements with oxygen and chlorine
  - (ii) Variation in oxidation number of the oxides (sodium to sulfur only) and of the chlorides (sodium to phosphorus only)
  - (iii) Reactions of these oxides and chlorides with water

**Learning Outcomes**

Candidates should, for the third period (sodium to argon), be able to:

(a) describe qualitatively (and indicate the periodicity in) the variations in atomic radius, ionic radius, melting point and electrical conductivity of the elements (see the *Data Booklet*);

(b) explain qualitatively the variation in atomic radius and ionic radius;

(c) interpret the variation in melting point and in electrical conductivity in terms of the presence of simple molecular, giant molecular or metallic bonding in the elements;

(d) explain the variation in first ionisation energy;

(e) describe the reactions, if any, of the elements with oxygen (to give $Na_2O$; $MgO$; $Al_2O_3$; $P_4O_6$; $P_4O_{10}$; $SO_2$; $SO_3$), and chlorine (to give $NaCl$; $MgCl_2$; $Al_2Cl_6$; $SiCl_4$; $PCl_3$; $PCl_5$);

(f) state and explain the variation in oxidation number of the oxides and chlorides;

(g) describe the reactions of the oxides with water;

[treatment of peroxides and superoxides is **not** required]

# Singapore (continued)

(h) describe and explain the acid/base behaviour of oxides and hydroxides, including, where relevant, amphoteric behaviour in reaction with sodium hydroxide (only) and acids;

(i) describe and explain the reactions of the chlorides with water;

(j) interpret the variations and trends in (f), (g), (h), and (i) in terms of bonding and electronegativity;

(k) suggest the types of chemical bonding present in chlorides and oxides from observations of their chemical and physical properties;

In addition, candidates should be able to:

(l) predict the characteristic properties of an element in a given Group by using knowledge of chemical periodicity;

(m) deduce the nature, possible position in the Periodic Table, and identity of unknown elements from given information of physical and chemical properties.

## Hong Kong

Topic II Microscopic World I (24 hours)

**Overview**

The study of chemistry involves the linkage between phenomena in the macroscopic world and the interaction of atoms, molecules and ions in the microscopic world. Through studying the structures of atoms, molecules and ions, and the bonding in elements and compounds, students will acquire knowledge of some basic chemical principles. These can serve to further illustrate the macroscopic level of chemistry, such as patterns of change, observations in various chemical reactions, the rates of reactions and chemical equilibria. In addition, students should be able to perform calculations related to chemical formulae, which are the basis of mole calculations to be studied in later topics.

Students should also be able to appreciate the interrelation between bonding, structures and properties of substances by learning the properties of metals, giant ionic substances, simple molecular substances and giant covalent substances. With the knowledge of various structures, students should be able to differentiate the properties of substances with different structures, and to appreciate that knowing the structure of a substance can help us decide its applications. While materials chemistry is becoming more important in applied chemistry, this topic provides the basic knowledge for further study of the development of new materials in modern society.

Through activities such as gathering and analysing information about atomic structure and the Periodic Table, students should appreciate the impact of the discoveries of atomic structure and the development of the Periodic Table on modern chemistry. Students should also be able to appreciate that symbols and chemical formulae constitute part of the common language used by scientists to communicate chemical concepts.

*Content Expectations*

*Performance Expectations*

| Students should learn | Students should be able to |
|---|---|
| b. The Periodic Table<br>• the position of the elements in the Periodic Table related to their electronic arrangements<br>• similarities in chemical properties among elements in Groups I, II, VII and 0 | • understand that elements in the Periodic Table are arranged in order of ascending atomic number<br>• appreciate the Periodic Table as a systematic way to arrange elements<br>• define the group number and period number of an element in the Periodic Table<br>• relate the position of an element in the Periodic Table to its electronic structure and vice versa<br>• relate the electronic arrangements to the chemical properties of the Group I, II, VII and 0 elements<br>• describe differences in reactivity of Group I, II and VII elements<br>• predict chemical properties of unfamiliar elements in a group of the Periodic Table |

## Hong Kong (continued)

**Suggested Learning and Teaching Activities**

Students are expected to develop the learning outcomes using a variety of learning experiences. Some related examples are:

- searching for and presenting information on the discoveries related to the structure of an atom.
- searching for and presenting information on elements and the development of the Periodic Table.
- performing calculations related to relative atomic masses, formula masses and relative molecular masses.
- drawing electron diagrams to represent atoms, ions and molecules.
- investigating chemical similarities of elements in the same group of the Periodic Table (e.g. reactions of group I elements with water, group II elements with dilute hydrochloric acid, and group VII elements with sodium sulphite solution).
- predicting chemical properties of unfamiliar elements in a group of the Periodic Table.
- writing chemical formulae for ionic and covalent compounds.
- naming ionic and covalent compounds.
- exploring relationship of colour and composition of some gem stones.
- predicting colours of ions from a group of aqueous solutions (e.g. predicting colour of $K^+(aq)$, $Cr_2O_7^{2-}(aq)$ and $Cl^-(aq)$ from aqueous solutions of potassium chloride and potassium dichromate).
- investigating the migration of ions of aqueous solutions, e.g. copper(II) dichromate and potassium permanganate, towards oppositely charged electrodes.
- building models of three-dimensional ionic crystals and covalent molecules.
- using computer programs to study three-dimensional images of ionic crystals, simple molecular substances and giant covalent substances.
- building models of diamond, graphite, quartz and iodine.
- predicting the structures of substances from their properties, and vice versa.
- justifying some particular applications of substances in terms of their structures.
- reading articles or writing essays on the applications of materials such as graphite and aluminium in relation to their structures.

## Hong Kong (continued)

**Values and Attitudes**

Students are expected to develop, in particular, the following *values and attitudes*:

- to appreciate that scientific evidence is the foundation for generalisations and explanations about matter.
- to appreciate the usefulness of models and theories in helping to explain the structures and behaviours of matter.
- to appreciate the perseverance of scientists in developing the Periodic Table and hence to envisage that scientific knowledge changes and accumulates over time.
- to appreciate the restrictive nature of evidence when interpreting observed phenomena.
- to appreciate the usefulness of the concepts of bonding and structures in understanding phenomena in the macroscopic world, such as the physical properties of substances.

## Overview of Next Generation Science Standards Development Process

Achieve

## Phase II – Achieve Process for Development of Next Generation Science Standards

After the final Conceptual Framework for Science is released by the NRC in 2011, Achieve will engage states and other key stakeholders in the development and review of the new standards

- Writing Teams
- Critical Stakeholder Team
- Strategic Advisory Team
- Comprehensive Feedback Loops
- State Involvement

Revision of multiple standards' drafts based on stakeholder and public input

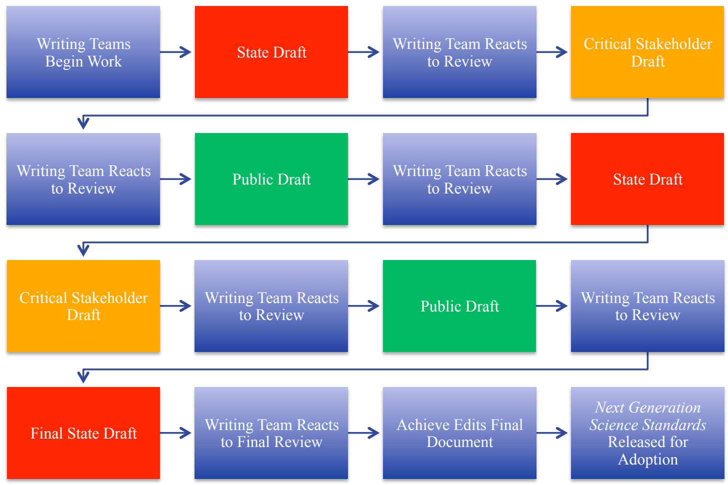
NRC Study Committee members to check the fidelity of standards based on framework



## Writing Team

- The Writing Team is comprised of approximately 30 members who will write the standards based on the NRC's Conceptual Framework for Science Education.
- The Writing Team includes members that have expertise in elementary school science, middle school science, and high school science, students with disabilities, English language acquisition, state level standards/ assessment and business experience and includes prominent scientists and academics that have working knowledge of science standards.
- Individuals were selected based on recommendations from various groups including NSTA and the Council of State Science Supervisors as well as interested parties who contacted Achieve.
- Educators will play a central role in the development, since in the end they will be responsible for implementation.

# Current Writing and Review Timeline






# Development Considerations for Next Generation Science Standards

- Organization
  - Grade levels versus grade bands
  - High school standards versus courses
  - Middle school content
  - Inquiry and design
- Grain size and format
- Inclusion of examples for content and performance expectations
- NGSS-Common Core State Standards in ELA and math connection
- Vocabulary and accessibility
- Learning progressions
- Exemplary features identified in int'l benchmarking study

# Contact Information

**Stephen Pruitt, Ph.D.**

**Vice President, Content, Research and Development**

**spruitt@achieve.org**

**www.achieve.org**