Achieve

International Science Benchmarking Report

Taking the Lead in Science Education: Forging Next-Generation Science Standards

Executive Summary

U.S. students have consistently lagged behind their peers in other nations on international science assessments – a performance increasingly at odds with the challenge of being able to live and compete in a global environment, powered by innovations in science, engineering and technology. A strong foundation in science is clearly critical if today's students are to have the option of pursuing careers in STEM-related fields where employment opportunities are expanding. But the ability to compete in a world economy is not the only issue. More than ever, participating as an informed citizen in a democracy, and making personal decisions, requires the ability to digest current events and make judgments based upon scientific evidence. National efforts in science education are focusing on two key issues: scientific literacy for all students and STEM preparedness to increase the STEM pipeline. From a standards and learning progression perspective, these issues exist on a continuum and are not mutually exclusive. A sound foundation to scientific literacy allows students to pursue Upper Secondary and post-secondary options based on their interests and occupational goals.

In response to concerns over the need for a scientifically literate workforce, increasing the STEM pipeline, and aging science standards documents, the scientific and science education communities are embarking on the development of a new conceptual framework for science, led by the National Research Council (NRC), and aligned next generation science standards, led by Achieve. The American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA) are also key partners in this effort.

Leaders have called for U.S. standards to be internationally benchmarked – reflective of the expectations that other leading nations have set for their students. To that end, Achieve examined 10 sets of international standards with the intent of informing the development of both the conceptual framework and new U.S. science standards. Achieve selected countries based on their strong performance on international assessments and/or their economic, political, or cultural importance to the United States.

All of the countries selected require their students to learn science from Primary through Lower Secondary, which ends at either grade 9 (three countries) or grade 10 (seven countries). In Upper Secondary, countries expect students to pursue further science study by taking courses in biology, chemistry, physics and/or (where available) Earth and space science. The way in which countries structure their standards prompted researchers to think about findings from three perspectives that framed the analysis:

1. Science Through Lower Secondary School: *What knowledge and skills do countries expect all students to learn in primary through lower secondary grades prior to taking discipline-specific high school courses in science?*
2. Upper Secondary Science: *What knowledge and skills do countries expect students to learn in upper secondary courses in Biology, Chemistry, Physics, and Earth and Space Science that prepare them for postsecondary study in science, engineering and technology?*
3. Exemplars: *What are exemplary features of the standards reviewed in this study that should be considered by developers of next-generation science standards in the United States? What are common shortcomings – and how might they be overcome?*

Achieve's study was limited by design to standards. It did not take into account the broader country context, i.e., how the education system functions as a whole and differences in economic, social, and

cultural norms. Where one country may have several standards dedicated to a topic or concept, the actual instructional time may be less than the expectation of another country that had few standards, but required more dedicated instructional time. Other limitations were a dearth of information on student course-taking patterns and pathways that limited Achieve's ability to have an "all students" versus a "stem-capable" view, and the availability of adequate English translations. In addition, the overall coherence of the education system (e.g., teacher education and development, assessments, instructional tools, and supplementary curriculum materials) was not taken into account which creates an incomplete picture. These are all areas for future study.

Achieve's analysis has both a quantitative and qualitative component. The quantitative analysis identifies the specific content and performance expectations the ten high-performing countries have established for each science discipline for Primary through Lower Secondary and for Upper Secondary (subject-specific courses). The qualitative examination complements the quantitative analysis by identifying noteworthy practices and weaknesses among the countries' standards. The table below shows the countries selected for the study and how their standards were analyzed.

Country	Preliminary Qualitative Review	In-Depth Qualitative Review		Quantitative Analysis
		Biology, Chemistry & Physics	Earth and Space Science	
Canada [Ontario]	✓	✓	✓	✓
Chinese Taipei	✓		✓	✓
England	✓	✓		✓
Finland	✓			✓
Hong Kong	✓	✓		✓
Hungary	✓			✓
Ireland	✓			✓
Japan	✓	✓	✓	✓
Singapore	✓	✓		✓
South Korea	✓			✓

Major Findings of the International Benchmarking Study

The overall goal of Achieve's study on international standards is to inform the development of the NRC framework and next-generation science standards. Through a quantitative analysis of international standards, Achieve's reviewers discovered four key findings.

Finding #1 - All countries require participation in integrated science instruction through Lower Secondary and seven of 10 countries continue that instruction through Grade 10, providing a strong foundation in scientific literacy.

Finding #2 –Physical science content standards (physics and chemistry content taken together) receive far more attention in lower primary through lower secondary. Other countries dedicate the greatest proportion of their standards to biology and physics content and the least to Earth and space science.

Finding #3 – Other countries' standards focus life science instruction strongly on human biology, and relationships among living things in a way that highlights the personal and social significance of life science for students and citizens. However, in the U.S., virtually all states also have a requirement for health and physical education from lower primary to lower secondary which could explain the difference in focus.

Finding #4 – Cross-cutting content common to all of the sciences such as the nature of science, nature of technology and engineering receives considerable attention. Inquiry skills in Primary are stressed more than in Lower Secondary. However, advanced inquiry skills receive increasing attention in Lower Secondary.

Exemplary Features

Achieve charged its reviewers to qualitatively review five countries' standards documents to determine exemplary features. Achieve's reviewers submitted six exemplary features for the Conceptual Framework for Science Education committee to consider.

Feature #1 – Standards based around "unifying ideas" for Primary through Lower Secondary seem to confer more benefits than a discipline-based structure. Achieve's reviewers found that developing standards around unifying ideas provided greater coherence and focus within the standards. In addition, this structure provides a more focused perspective in development by providing a method to determine what content should be included.

Feature #2 – Providing multiple examples of performance into content and performance standards makes expectations for student performances specific and transparent. Achieve's reviewers found Canada's use of multiple examples within their standards an excellent method to communicate the level of rigor expected from students. Multiple examples help learners connect concepts with applications in the real world, help them to explain everyday phenomena, and enhance the clarity and accessibility of standards. Incorporating multiple examples (rather than relying on a single example) is important because multiple examples show a range of applications, rather than a single point that can quickly become a limiting factor.

Feature #3 – Making meaningful connections to assessment helps to focus attention on the ultimate goal of raising student achievement. Achieve found three countries, Canada, England, and Hong Kong, make a special effort to show how their standards and assessments are aligned. While the approaches vary considerably, all three countries make solid links between the content they expect students to learn and how that learning will be evaluated. States, districts, and teachers would benefit greatly from understanding the connections and performance expectations required by the statewide assessment.

Feature #4 – Organization and format has an enormous effect on the clarity and accessibility of a country's standards. Achieve found Canada, Singapore, and Hong Kong have user-friendly standards, and their approaches are similar. England's standards are structured differently but are also accessible. Great care was taken on the part of these countries to ensure they were clear and communicated the level of rigor and intent of the standards.

Feature #5 – Developing students' ability to use inquiry, engineering design, and modeling supports student participation in structured projects that nurture scientific habits of mind and stimulates student interest. Developing students' capacity to understand, design and apply physical, conceptual, and mathematical models is a key ability that should be interwoven in the standards. Achieve found that Canada's parallel development of inquiry and design stands out as a quality example. It makes fundamental connections between conducting investigations in the natural world and problem solving in the designed world. It describes a progression of performances from beginning to proficient in four key areas for both inquiry and design: Initiating and Planning; Performing, and Recording; Analyzing and Interpreting; Communicating.

Feature #6 – All student populations should have accessibility to science and guidance should be provided to support this philosophy. Achieve's reviewers found countries who had clearly made accessibility of science to all populations a priority. For instance, England includes guidelines for teaching science to all students that are an important part of a standards document. Hong Kong also includes curriculum adaptations for a diversity of learners including accelerated learners.

Shortcomings

Clearly, the five countries' standards have much to recommend them. However, Achieve also found weaknesses in several areas as described below. These present opportunities for the developers of the NRC framework and new science standards to carve out a fresh vision for science education.

- *Incorporation of Mathematics*: The importance of integrating mathematics with science standards has long been raised as a central issue by both AAAS and the NRC. Recent research has revealed, "*High-school mathematics carries significant cross-subject benefit (e.g., students who take high-school calculus average better grades in college science than those who stop at pre-calculus).*"[1] This is an area in which none of the countries has been completely successful.
- *Evidence-based Inquiry*: The five countries do not generally call for students to consistently focus on evidence. This area is an instance of where an exemplar is found in U.S. standards. The recently revised College Board Standards call attention to and consistently incorporate science practices that focus on *establishing lines of evidence, using the evidence to substantiate claims, to develop and refine testable explanations, and to make predictions about natural phenomena*.[2]
- *Chemistry Foundation for Concepts in Modern Biology*: The five countries' Primary and Lower Secondary standards in Biology do not appear to provide a sufficient foundation in chemical bonding, reactions, and some aspects of organic chemistry for students to comprehend essential concepts in modern biology.
- *Interdisciplinary Connections*: With the exception of Earth and Space Science, standards at the Upper Secondary level generally do not highlight fundamental connections between disciplines that would reinforce student understanding of how a concept in one discipline has explanatory power in another.
- *Learning Progressions*: As noted earlier, no individual country's standards were able to serve as an overall exemplar from the Primary through the Upper Secondary levels. A noticeable gap between Lower and Upper Secondary standards in terms of the complexity of content and performance expectations, including the application of mathematics in a number of countries, suggest this is an area that will require close attention as the next-generation U.S. science standards are developed.

Conclusion

Conditions are right for the United States to take the lead internationally in forging a new conceptual framework for science, and next generation science standards. The NRC framework and aligned science standards will create a fresh vision for science education and new directions for teaching, learning, and assessment that could contribute significantly to improving student understanding and achievement. Seizing the opportunity that this moment presents will bring us a step closer to moving the United States into the vanguard of international science education reform.

[1] Philip M. Sadler and Robert H. Tai, "TRANSITIONS: The Two High-School Pillars Supporting College Science," *Science* 27 July 2007 317: [DOI: 10.1126/science.1144214], 457.

[2] The College Board, SCIENCE College Board Standards for College Success, (The College Board, 2009).