CBE—Life Sciences Education
Vol. 5, 204–209, Fall 2006

Feature
From the Academies

National and State Standards in Science and Their Potential Influence on Undergraduate Science Education[1]

Jay B. Labov

Center for Education, National Research Council of the National Academies, Washington, DC 20001

INTRODUCTION

Standards in science and other subjects are a recent phenomenon in education, with most of them having been developed within the past 15 years. In 2002, Kimberly Tanner and Deborah Allen published in the first volume of *Cell Biology Education* (*CBE*) an important article about national science education standards for Grades K–12. That article likely provided for many readers of *CBE* their first glimpse of the standards movement in K–12 education and the potential impact of standards on higher education. The article focused on the two national science standards documents, *Benchmarks for Science Literacy*, published by the American Association for the Advancement of Science (AAAS; 1993), and the *National Science Education Standards*, published by the National Research Council (NRC; 1996), and what those standards specify about what students should know and be able to do at various grade levels in cell biology. Tanner and Allen (2002) also provided what have turned out to be some prescient ideas and questions about the more general roles of science standards in education in the United States.

Much has happened in K–12 education during the past four years and, for the following reasons, an update on the standards movement is warranted.

- Tanner and Allen reported how the national documents were designed to serve as guidelines for the development of state standards and pointed out some of the issues involved in translating the national standards to state frameworks. In the four years since Tanner and Allen published their article, all states except Iowa have developed their own standards. Indeed, some states are now in a cycle of revising their standards documents.
- During the past five years, the federal No Child Left Behind Act (NCLB) has become much more a part of the fabric of K–12 education. Most people who are familiar with this legislation identify it with new expectations for testing and accountability. What is less known is that states are also required to align standardized assessments and classroom instruction with their standards documents.
- To date, students have been tested only in reading and mathematics as part of NCLB. Science will be tested for the first time during the 2007–2008 school year. Thus, science will take on a much greater level of importance in public education in the ensuing years, and this increased attention could have important ramifications for higher education in the sciences.

This article addresses all of these issues and also provides readers who may not remember the details from Tanner and Allen with a more general and updated introduction to national and state science standards. It also provides a brief overview of the science content standards movement in the United States, insights into the forces that have caused the adoption of science standards to be contentious in some states, discussion of why college faculty need to learn more about their own state's standards, and the roles that professional scientists might play in shaping those standards in the future. For a more comprehensive recent review of national and state K–12 science standards, see Sunal and Wright (2006).

A BRIEF HISTORY

Beginning with a historic conference of the National Governors Association and continuing into the early 1990s, President George H.W. Bush and the nation's governors developed the National Education Goals (sometimes referred to

DOI: 10.1187/cbe.06–05–0162
Address correspondence to: Jay B. Labov (jlabov@nas.edu).

[1] Adapted with permission from an article published in *Marine Technology Society Journal*, Winter 2005/2006, Vol. 39, No. 4, pp. 15–19. The Marine Technology Society is a not-for-profit, international, professional association. Founded in 1963, the society believes that the advancement of marine technology and the productive, sustainable use of the oceans depend upon the active exchange of ideas between government, industry, and academia. See http://www.mtsociety.org.

as "Goals 2000").[2] Eight goals were articulated; goal 4 declared that by the year 2000, "U.S. Students will be first in the world in mathematics and science achievement." To achieve this goal, the governors decided that national standards for science and other subjects should be developed.[3] For science, the governors declared the following objectives.

> Students in Grades K–12 will
> Use scientific principles and processes appropriately in making personal decisions.
> Experience the richness and excitement of knowing about and understanding the natural world.
> Increase their economic productivity.
> Engage intelligently in public discourse and debate about matters of scientific and technological concern.
> Be aware of careers in science, technology, and the medical sciences.

These principles suggested approaches to science education that were very different from the prevailing teaching methods in several fundamental ways. First, instead of focusing almost exclusively on facts, these objectives also called for educating students to understand the connections between science and other types of knowledge and how science is relevant to their lives and their communities. Second, rather than emphasizing science education primarily for those students who were most likely to pursue careers in science or engineering (as had been promulgated in the post-Sputnik era), these objectives emphasized science education and scientific literacy for all students. Last, science was to be introduced to students much earlier in their academic preparation than was typical.

All of these changes had clear implications for the education and ongoing professional development of teachers, the numbers of teachers able to teach science, curriculum development and implementation, and even the physical spaces in which science would be taught. Clearly, some guidance was needed to help state education departments as well as local school districts and school personnel implement such sweeping changes in precollege science education.

This new perspective on science education was influenced greatly by the publication of *Science for All Americans* (Rutherford and Ahlgren, 1990) by AAAS. In response to both this publication and the directives of the National Governors Association, both AAAS and the NRC began work on producing national standards for science. AAAS' *Benchmarks for Science Literacy* (Figure 1) were published in 1993 (AAAS, 1993) and focused on content standards.

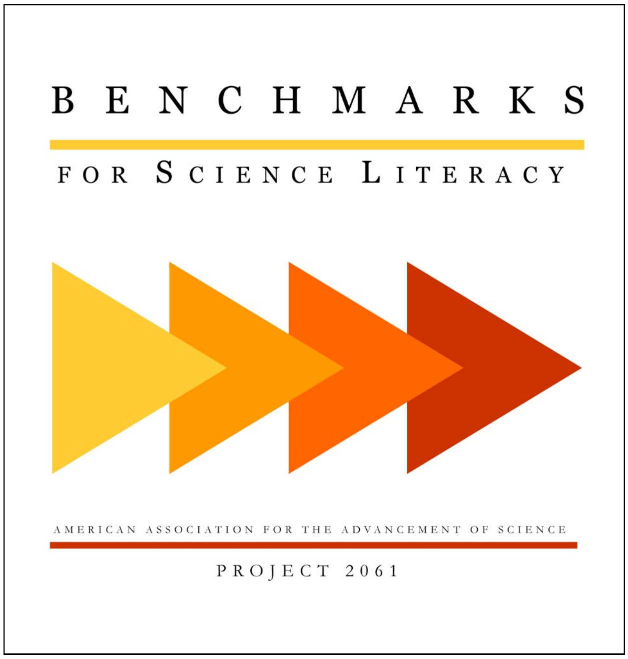

Figure 1. Cover of *Benchmarks*.

The NRC released the *National Science Education Standards* (*NSES*) in 1996 (Figure 2). These standards deliberately embedded science content standards within a larger system of science education, thereby emphasizing that gains in student performance are dependent upon improvements in the entire system of science education and not solely on enhancements in content standards. Consequently, the *NSES* called for changes in six sectors of the education system that would be required to realize sustained improvements in student performance:

- Teaching
- Professional development for teachers
- Assessment
- Content
- Science education programs
- Science education systems

Both the *Benchmarks* and the *NSES* offer their content standards by grade bands rather than by individual grade levels; this gives schools, districts, and states flexibility in deciding when specific topics might be taught.[4] Although the content standards in the *Benchmarks* and the *NSES* differ to some degree in emphasis (Table 1), an analysis by AAAS (1997) indicates that the *Benchmarks* and the *NSES* content standards are 90–95% congruent in their focus and subject matter. Thus, as individual states have adopted and adapted

[2] For additional information on Goals 2000, see http://www.ed.gov/G2K/index.html.

[3] Standards for mathematics had already been developed by the National Council of Teachers of Mathematics and released in 1989. These mathematics standards were revised and updated in 2000. For more information, see National Council of Teachers of Mathematics (1989, 2000). In 2000, the International Technology Education Association also published the *Standards for Technological Literacy: Content for the Study of Technology*. See References for additional information.

[4] The *Benchmarks* specify four grade bands: Grades K–2, 3–5, 6–8, and 9–12. The *NSES* specify three grade bands: Grades K–3, 4–8, and 9–12.

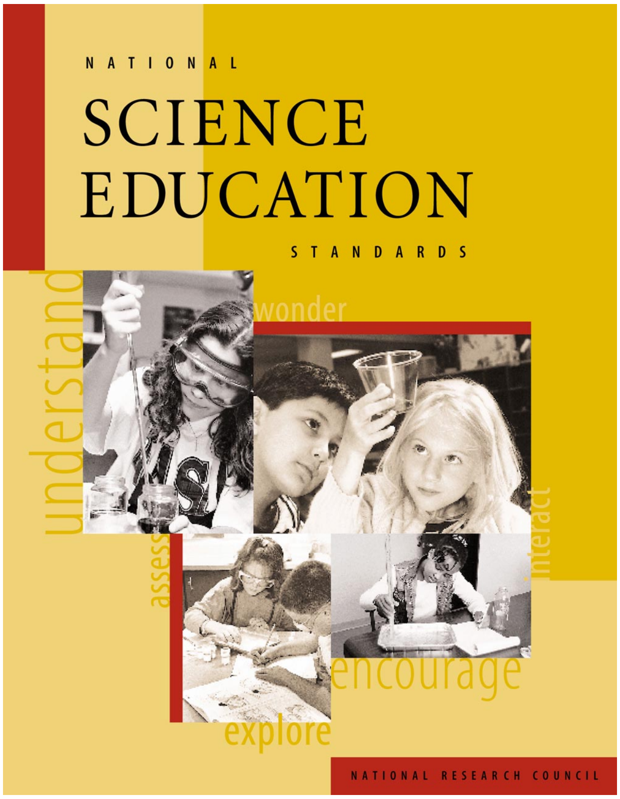

Figure 2. Cover of *NSES*.

these national guidelines for their own, some have based their standards on one of these sets of national standards guidelines, whereas others have used aspects of both.

The *NSES* call for a very different way of presenting content and assessing students' knowledge of science (Tables 2 and 3). The *NSES* view science education as something that students "do," rather than something that is "done to them." There is greater emphasis on integrating the processes and nature of science with content knowledge in

Table 1. Content topics in the *Benchmarks* and the *NSES*

AAAS *Benchmarks*	*NSES*
The Nature of Science	
The Nature of Mathematics	
The Nature of Technology	Science and Technology
The Physical Setting	Physical/Earth/Space Sciences
The Living Environment	Life Sciences
The Human Organism	Science in Personal/Social Perspectives
Human Society	
The Designed World	
The Mathematical World	
Historical Perspectives	History and Nature of Science
Common Themes	Unifying Concepts and Processes
Habits of Mind	Science as Inquiry

Topics are organized such that similar topics in each column are displayed on the same row.

the various scientific disciplines as a student progresses from the elementary through the secondary grades.

Not all content is of equal importance. Consequently, both the *NSES* and the *Benchmarks* stress that students will gain a deeper understanding and appreciation of science if they cover fewer topics and instead uncover some in greater depth, i.e., "less is more."

The *NSES* also call for fundamental changes in what teachers should know and be able to do (Table 4), especially for elementary and middle school teachers who increasingly are becoming teachers of science. These recommendations suggest that new and very different approaches to teacher preparation and ongoing professional development are needed.

Since the publication of the *Benchmarks* and the *NSES*, both the AAAS and the NRC have published supplements to their original documents. AAAS has released several publications that focus on how to use the *Benchmarks* and the implications of their use in schools. An especially useful supplement is AAAS' *Atlas of Science Literacy* (AAAS, 2001)[5] that helps educators identify prerequisite knowledge and understanding in the content disciplines addressed by the *Benchmarks* that students need to study grade-level-appropriate material and to be prepared to progress to more advanced materials. The *Benchmarks* and all of these supplemental publications are available at http://www.project2061.org/.

Supplements to the *NSES* have focused on broader systems issues, including helping teachers understand the nature of inquiry (NRC, 2000), classroom assessment (NRC, 2001a), designing standards-based mathematics or science curricula (NRC, 1999), a framework for research efforts to investigate the efficacy of standards (NRC, 2001b), and a publication to help parents of school-age children and the general public understand the changes being promoted by the *NSES* (NRC, 1997).

STATE-BASED IMPLEMENTATION OF NATIONAL STANDARDS

National Standards Are Not Federal Standards

There are no mandated national standards for any subject in Grades K–12 in the United States. The responsibility for precollege education is vested constitutionally with state and local authorities. The Federal Government contributes approximately 8% of the total budget for K–12 education. Thus, the *Benchmarks*, *NSES*, and other national standards documents that were produced at the same time as, and subsequent to, these documents[6] are intended to serve as guides that states can use to voluntarily develop and implement their own standards. However, when published the *NSES* represented a national consensus of the scientific and science education communities of what constitutes quality

[5] AAAS is currently preparing a second volume of the *Atlas*. Additional information and samples from the new volume are available at http://www.project2061.org/publications/atlas/vol2/default.htm.

[6] For example, in 2000 the International Technology Education Association published *Standards for Technological Literacy* (International Technology Education Association, 2000). See http://www.iteaconnect.org/TAA/TAA.html.

Table 2. The *NSES* stress a changing emphasis on scientific content and process

Less emphasis on	More emphasis on
Knowing scientific facts and information	Understanding science processes and developing abilities of inquiry
Studying subject matter disciplines (e.g., physics, earth sciences) for their own sake	Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science
Separating science knowledge and science process	Integrating all aspects of science content
Covering many science topics	Studying a few fundamental science concepts
Implementing inquiry as a set of processes	Implementing inquiry as instructional strategies, abilities, and ideas to be learned

This information is from NRC (1996), p. 113.

Table 3. The *NSES* stress a changing emphasis on assessment of scientific knowledge and understanding

Less emphasis on	More emphasis on
Assessing what is easily measured	Assessing what is most highly valued
Assessing discrete knowledge	Assessing rich, well-structured knowledge
Assessing scientific knowledge	Assessing scientific understanding and reasoning
Assessing to learn what students do not know	Assessing to learn what students do understand
Assessing only achievement	Assessing achievement and opportunity to learn
End-of-term assessments by teachers	Students engaged in ongoing assessment of their work and that of others
Development of external assessments by measurement experts alone	Teachers involved in the development of external assessments

This information is from NRC (1996), p. 100.

science education and the educational systems needed to support that education. They were reviewed by thousands of scientists and science educators and by dozens of professional societies before their release.

State standards are now the predominant influence on K–12 education, and there is considerable variation from state to state in their use of the *NSES* and the *Benchmarks* and in their adjudged quality (e.g., Gross *et al*., 2005). As a specific example, evolution is a subject that has received considerable attention by the media, policy makers, and the public in both national standards documents. Some states have adopted these recommended standards faithfully, whereas others have eliminated selected components or do not mention evolution at all (Lerner, 2000; Gross *et al*., 2005). In other cases, there has been great controversy about the amount of content that students should be required to know and at what grade levels they are expected to know it. Political and other considerations continue to influence the state-based adoption process as individual states revise their standards every five to seven years.[7]

The proliferation of state standards has resulted in some unintended consequences. For example, science textbook publishers and curriculum developers who previously only had to show that their products were consistent with one or both national standards documents to be adopted now have to tailor their products to the many different state standards to be considered. Such pressures can lead to fragmentation of content or production of textbooks that respond to the "lowest common denominator."

During the past few years, state standards also have taken on increasing prominence because of NCLB, which mandates that students be tested on content that is tied to a state's standards in a particular discipline. Each state must administer tests aligned to those standards. However, since

Table 4. Excerpts from *NSES* of standards for the professional development of teachers of science

Standard	Excerpt
A	The professional development of teachers of science requires learning science content through the perspectives and methods of inquiry . . .
B	Professional development of teachers of science requires integrating knowledge of science, learning, pedagogy and students, applying that understanding to science teaching . . .
C	The professional development of teachers of science enables them to build the knowledge, skills, and attitudes needed to engage in lifelong learning . . .
D	Pre-service and in-service professional development programs for teachers are coherent and integrated . . .

This information is excerpted and modified from NRC (1996).

[7] See, for example, the controversy that has arisen in California at http://www.sci-ed-ga.org/standards/analysis.html.

the law's inception, schools have only been held accountable for testing and demonstrating adequate yearly progress[8] in reading and mathematics, and only for Grades 3–8 in these subjects. Science will be tested beginning in the 2007–2008 school year and then only in each grade band corresponding to the elementary, middle, and secondary grades.

There are three important consequences of this process that should concern scientists and science educators:

- In some districts teachers, especially in the elementary grades, have been asked to reduce or eliminate the teaching and learning of science to allow more time for preparation in reading and mathematics. Districts often do not embrace the interdisciplinary concept that science can serve as an effective vehicle for learning of mathematics and development of reading skills, both essential for successful performance in science. Consequently, reduction in class time doing science may result in a cohort of students who are ill-prepared to appreciate and succeed in science when testing does begin.
- When science is finally tested in 2007–2008, or when districts recognize that they have to begin preparing students for the science examinations, they will rely heavily, if not exclusively, on their state science standards, which often reinforce the learning of facts rather than the more systemic and integrative approaches that are emphasized by the *NSES* and the *Benchmarks*. Unless state standards both require and reinforce the notion that quality science education also includes exploration, data analysis, and developing deep conceptual understanding of topics, teachers will be under pressure to focus primarily on factual information, lower-level thinking skills, and limited conceptual understanding. Moreover, these conditions suggest that teachers and school administrators will tend to focus on the specific content and examples that are planned for the assessment.
- NCLB permits individual states to use any assessment instruments they wish as long as they align with that state's content standards. However, assessments that authentically measure students' deep conceptual understanding, their skill and ability to explore, transfer knowledge from one topic to another, and to synthesize and draw conclusions from data are more expensive and difficult to develop, administer, and score than tests that focus on factual knowledge. Thus, there likely will be strong financial pressure to use the less expensive, less rigorous instruments that are currently available. These kinds of assessments would send strong messages about the kind of science education that is valued and could reverse some of the gains that are beginning to be reported around the country. The NRC has published several reports that focus on these issues (NRC, 2001c, 2003, 2005).

Science education is at a crossroad and will continue to be over the next several years. Whether our nation will finally realize the kind of quality science education that was envisioned in the national standards documents, and is required for the United States to continue to lead the world in science and technology innovations and in the practical application of those innovations, remains to be seen. It is incumbent upon today's scientists and science educators, especially those who are involved with higher education, to become more knowledgeable about the vision and emphases of the national standards and their reflection in the standards of the state in which they live and work, and the influential role scientists can play in shaping development and revisions in those standards and assessments.[9]

College-level scientists can become engaged with these efforts in many ways. For example, they can work with state boards of education to review science standards in their specific disciplines or more broadly when those standards are being revised. They can work locally on selection committees for textbooks and other science education resources to help district leaders, administrators, and teachers determine whether those resources conform to state standards and meet the need for high-quality materials. As parents, grandparents, and citizens, scientists can play important roles in their schools and communities as advocates for high-quality science teaching and learning for all students.

The focus, quality, and effectiveness of today's science education programs ultimately will result in college students who are or are not prepared to engage in science at the postsecondary level. Thus, postsecondary educators have a vital long-term stake and self-interest in today's K–12 science education programs and the policies that govern them. Higher education has had little influence to date on the development or implementation of standards because scientists have not been well represented at the table at either the district or state levels. For all the reasons outlined above, the time to do so is now.

[8] For more information from the U.S. Department of Education about this component of the law, see http://www.ed.gov/nclb/accountability/ayp/yearly.html.

[9] Access to individual state standards is available through a state's Department of Education or through http://www.education-world.com/standards/state/index.shtml.

REFERENCES

American Association for the Advancement of Science (1993). Benchmarks for Science Literacy, Washington, DC. http://www.project2061.org/publications/bsl/online/bolintro.htm (accessed 25 June 2006).

American Association for the Advancement of Science (1997). Resources for Science Literacy: Professional Development, New York: Oxford University Press. http://www.project2061.org/publications/rsl/online/index.htm (accessed 25 June 2006).

American Association for the Advancement of Science (2001). Atlas of Science Literacy, Washington, DC. http://www.project2061.org/publications/atlas/default.htm (accessed 25 June 2006).

Gross, P. R., Goodenough, U., Lerner, L. S., Haack, S., Schwartz, M., Schwartz, R., and Finn, C. E., Jr. (2005). The State of State Science Standards 2005, Washington, DC: Thomas B. Fordham Foundation. http://www.edexcellence.net/foundation/publication/publication.cfm?id=352 (accessed 25 June 2006).

International Technology Education Association (2000). Standards for Technological Literacy, Reston, VA. http://www.iteaconnect.

org/TAA/Publications/STL/STLMainPage.htm (accessed 25 June 2006).

Lerner, L. S. (2000). Good Science, Bad Science: Teaching Evolution in the States, Washington, DC: Thomas B. Fordham Foundation. http://www.edexcellence.net/foundation/publication/publication.cfm?id=42 (accessed 25 June 2006).

National Council of Teachers of Mathematics (1989). Curriculum and Evaluation Standards for School Mathematics, Reston, VA.

National Council of Teachers of Mathematics (2000). Principles and Standards for School Mathematics, Reston, VA. http://www.nctm.org/standards/ (accessed 25 June 2006).

National Research Council (1996). National Science Education Standards, Washington, DC: National Academies Press. http://www.nap.edu/catalog/4962.html (accessed 25 June 2006).

National Research Council (1997). Every Child a Scientist: Achieving Scientific Literacy for All, Washington, DC: National Academies Press. http://www.nap.edu/catalog/6005.html (accessed 25 June 2006).

National Research Council (1999). Designing Mathematics or Science Curriculum Programs: A Guide for Using Mathematics and Science Education Standards, Washington, DC: National Academies Press. http://www.nap.edu/catalog/9658.html (accessed 25 June 2006).

National Research Council (2000). Inquiry and the National Science Education Standards, Washington, DC: National Academies Press. http://nap.edu/catalog/9596.html (accessed 25 June 2006).

National Research Council (2001a). Classroom Assessment and the National Science Education Standards, Washington, DC: National Academies Press. http://nap.edu/catalog/9847.html (accessed 25 June 2006).

National Research Council (2001b). Investigating the Influence of the National Science Education Standards, Washington, DC: National Academies Press. http://nap.edu/catalog/10023.html (accessed 25 June 2006).

National Research Council (2001c). Knowing What Students Know: The Science and Design of Educational Assessment, Washington, DC: National Academies Press. http://nap.edu/catalog/10019.html (accessed 25 June 2006).

National Research Council (2003). Assessment in Support of Instruction and Learning: Bridging the Gap Between Large-Scale and Classroom Assessment - Workshop Report, Washington, DC: National Academies Press. http://books.nap.edu/catalog/10802.html (accessed 25 June 2006).

National Research Council (2005). Systems for State Science Assessment, Washington, DC: National Academies Press. http://www.nap.edu/catalog/11312.html (accessed 25 June 2006).

Rutherford, J. B., and Ahlgren, A. (1990). Science for All Americans, Washington, DC: American Association for the Advancement of Science. http://www.project2061.org/publications/sfaa/online/sfaatoc.htm (accessed 25 June 2006).

Sunal, D. W., and Wright, E. L. (eds.) (2006). Research in Science Education: Volume 2. The Impact of State and National Standards in K–12 Science Teaching, Greenwich, CT: Information Age Publishing.

Tanner, K., and Allen, D. (2002). Approaches to cell biology teaching: a primer on standards. Cell Biol. Educ. *1*, 95–100. http://cellbioed.org/pdf/02-09-0046.pdf.