DEVELOPMENT OF THE FRAMEWORK AND NEXT GENERATION SCIENCE STANDARDS: HISTORY AND REFLECTIONS

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In 2012, the Board on Science Education (BOSE) at the National Academies of Sciences, Engineering, and Medicine (the National Academies) released *A Framework for K-12 Science Education (Framework),* ushering in a coordinated, on-going national effort to improve K-12 science education in the United States. The *Framework*, which outlined a broad set of expectations for students in science and engineering in grades K-12, served to inform the development of new standards for K-12 science education, the Next Generation Science Standards (NGSS) and similar state standards. Since 2013 when the NGSS were released, 48 states, representing nearly 90% of students nationally, have adopted standards based on the *Framework* and are actively working to fully implement them.

Development of the *Framework* and NGSS took place over a period of 4-5 years starting in 2009 and culminating with the release of the NGSS in 2013. The writing process directly involved nearly 100 educators, scientists, and other stakeholders with additional input from over 10,000 individuals, 26 state level teams, and over 150 organizations in STEM education. This multi-step process was jointly undertaken by the National Academies, the National Science Teaching Association (NSTA), the American Association for the Advancement of Science (AAAS), and Achieve, Inc., with primary support from the Carnegie Corporation of New York. The National Academies, an independent, non-governmental organization that provides evidence-based guidance on a variety of topics and Achieve, Inc., a non-profit education policy organization, led the work of development.

In this paper we describe the development process and articulate the political and practical considerations that informed decisions along the way. We also provide reflections based on our perspectives a decade later. The description of the process is based on information from the documents themselves, explanations developed for the public (made available on websites and in other formats), internal reports to funders, and our own recollections. All four co-authors of this paper were involved in leadership roles during the development process. We acknowledge that our roles shape our perspectives on the process and we hope that our reflections offer food for thought as we begin to consider the next steps in our continued work as a community on improving K-12 science education in the United States.

In designing and carrying out the development process the leaders of the effort (including the authors of this paper), were constantly balancing the trade-offs inherent in standards as education policy documents designed to catalyze change. That is, that standards are documents that need to balance political and practical considerations while drawing on the best available evidence from research and from the experience of those working in schools. The development process itself, then, needs to be designed to respond to policy pressures, provide opportunities for input from a variety of stakeholders and be informed by evidence. This delicate balance informed the design of the process, but also led to compromises that form a basis for many of the subsequent critiques of the current standards. In our final reflections, we consider what we learned from the process and how it might inform future efforts.

THE MOMENTUM TOWARD NEW STANDARDS

Focused discussions about updating existing science standards began in 2008, motivated by several factors. First, there were persistent and growing concerns that the existing approaches to K–12 science education were not sufficient for preparing students to live in an increasingly technological world or compete for jobs requiring skills in science, technology, and engineering. The first sets of national standards in science were released in the mid-1990's and were 10 years old in 2006. National organizations were already recognizing the need to revisit standards with discussions held at the National Academies and a proposed project at NSTA called Science Anchors.

Second, in the decade since the previous sets of science standards were released, much had been learned about how people learn science and about how to improve instruction. Of particular concern was the lack of access to science in the early grades despite evidence that young children are capable of sophisticated science learning. There was also increasing evidence that commonly used methods of science instruction -- with an emphasis on lecture, reading about final form science, and memorization -- were not as motivating or effective for most students as problem or project-based instructional approaches. While the NSES called for the use of "inquiry" in science, this was taken up in states in a wide variety of ways and often did not lead to significant changes in pedagogical approaches. The inquiry standards were presented separately from the content standards and as a result, inquiry was often taught separately from the disciplinary science ideas in the content standards.

Third, the momentum toward common standards in mathematics and English/language arts, with adoption of Common Core State Standards (CCSS) in these disciplines across a large number of states, suggested that there was an opportunity for a similar set of common standards in science. There were two different guiding documents for science standards developed in the 1990's: the *National Science Education Standards* (NSES) developed by the National Academies and *Benchmarks for Science Literacy* developed by AAAS. Analysis of state science standards at the time indicated that there were distinct differences across states' standards depending on whether they aligned to the NSES or *Benchmarks* (NRC, 2008). In addition, both the NSES and *Benchmarks* were very broad documents and required significant interpretation on the part of states in order to produce a useable, technical document to guide state level decisions about assessment, curriculum and instruction. As a result, standards, curriculum and expectations for students in science varied greatly across all 50 states (NRC, 2006a, 2008).

The momentum for revising science standards was part of a larger national conversation about the need to elevate and improve mathematics and science education in the United States. The Carnegie Corporation in partnership for the Institute for Advanced Study had convened a commission in 2007 to study the state of mathematics and science education. The commission released a report in 2009 (Carnegie, 2009) that called for revised standards in mathematics and science among many other recommendations. In 2008, the National Governors Association and the Council of Chief State School Officers launched the effort that would result in the CCSS in Mathematics and English Language Arts. The work on the CCSS preceded the work on the *Framework* and NGSS and the lessons learned from the CCSS proved invaluable for planning the development and adoption process for the *Framework* and NGSS.

Beginning the Work

Recognizing the opportunity created by these convergent factors, the Carnegie Corporation of New York provided funding for a two-stage process of standards development. In the first stage the National Academies developed the *Framework*; in the second stage, a consortium of teams representing 26 states coordinated by Achieve, Inc. developed the NGSS which provide more detailed specification of what students should know and be able to do at each grade and serves as an adoptable model of state standards.

As noted, state support for common standards was an important initial impetus for the development of the *Framework* and NGSS. However, the relationship between the CCSS and the *Framework* and NGSS effort was never a direct one. Initially, leaders of the CCSS movement were concerned that if science was associated with the emerging mathematics and ELA standards, the controversial science content (evolution, climate change) might undermine and politicize the CCSS. However, over time the CCSS themselves become highly politicized for a variety of reasons unrelated to any connections to the NGSS work. The experience of the CCSS provided essential lessons for the leaders of the *Framework* and NGSS work and informed the design of the process. This included positioning NGSS as a national not federal effort, with no federal pressure or incentive for adoption, and working toward as transparent a development process as possible. This was in contrast to the CCSS initiative where the U.S. Department of Education's Race to the Top initiative encouraged states to adopt the CSSS. Though this was not a requirement for eligibility for the grant program, it was the easiest path to meeting the requirement of quality standards. This created the perception that the CCSS were a federal initiative rather than a multi-state, national one.

Considerations in the Initial Concept: Why 2 Stages of Development?

From the beginning of discussions about revisions to science standards, there was recognition that the development process needed to include educators, scientists, education researchers and a wide range of additional stakeholders. In addition, the process needed to provide multiple opportunities for public input on the developing standards providing as many people as possible with the opportunity to have a voice in the development. In order to move to a single set of national standards the work also needed to be spearheaded by a consortium of the lead organizations in science education, including at least the National Academies, AAAS and NSTA, so that the disparate prior efforts of these various organizations could be brought together into a single national (but not federal) project.

Separating the development of the *Framework* as a guiding document from the development of the standards themselves was essential to ensure that an independent body of scientists and science education experts, unencumbered by political pressures, could first define what all students should learn based on evidence from research and practice. This first stage of the work was orchestrated by the Board on Science Education of the National Academies.

It was equally important that the development of the standards themselves involve a broader group of educators including state level science education leaders. Extensive involvement of educators at all levels was essential for developing buy-in, ensuring that the needs of educators across the country were considered, and creating standards that could be implemented through adoption at the state level. The second stage of the process was orchestrated by Achieve, an organization with extensive experience working with states and education policy initiatives. The goal was to create a final set of standards that could be directly adopted by states or provide a model for states developing their own standards.

In addition to leveraging the strengths of the 2 lead organizations, the 2 stage process allowed more opportunity for public review and input. The National Academies' study committee process typically does not allow a committee or its members to share draft work broadly with the public in order to protect a given committee's deliberation of the evidence from political influence. In the case of the *Framework*, the National Academies took the unusual step of allowing and facilitating a limited period of public input on an early draft. This step was critical to the development and broad acceptance of the *Framework* itself. However, the four lead organizations recognized that broader public input, particularly from state level science education leadership, was needed in developing the standards themselves. This involvement was needed both to ensure that a wide range of perspectives was heard and also to help create a sense of collective ownership of the standards across the full range of stakeholders who would need to support them throughout state adoption and implementation processes. Achieve's positioning in the education policy and education landscape, with their close connections to states, allowed them to design and support the extensive development, public input and vetting process that was needed.

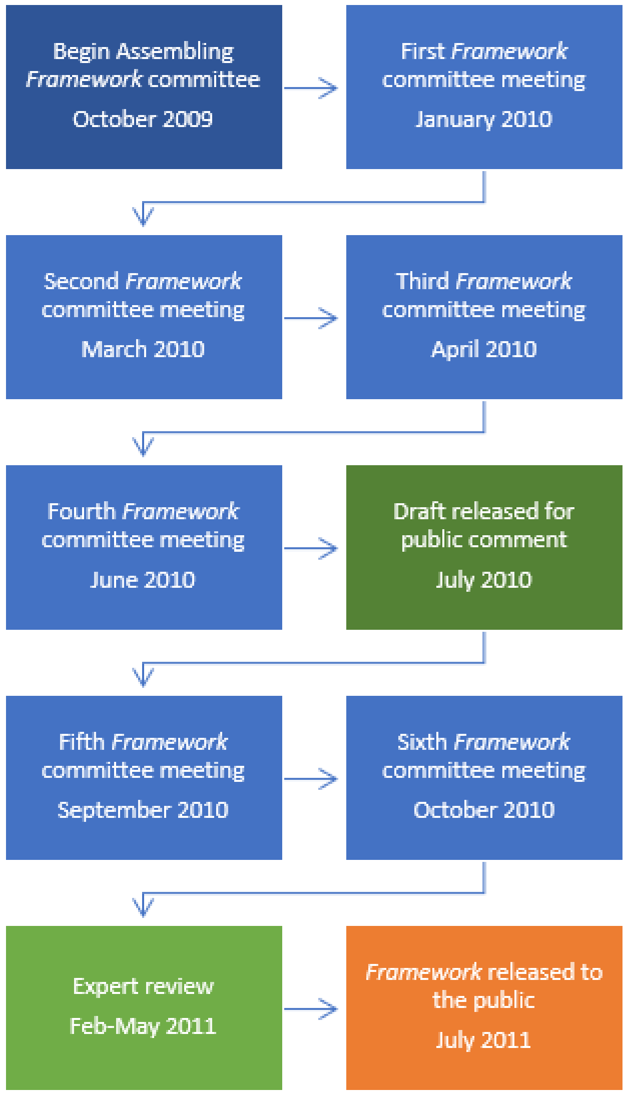
Throughout both stages of development, the National Academies and Achieve maintained close connections with the education leadership of both AAAS and NSTA, as well as the state level science education leadership represented by the Council of State Science Supervisors (CSSS). These organizations were kept informed about progress and asked for input on the work. Importantly, the lead executives of each of the National Academies, Achieve, NSTA and AAAS met quarterly to discuss progress and how they could continue to support the work. CSSS engagement was essential and helped orchestrate multi-state involvement in both the *Framework* review and in the development and adoption of the NGSS. Both CSSS and NSTA have continued to play key roles in supporting and catalyzing implementation efforts.

The two-stage process of development was a design feature intended to leverage the relative strengths of the National Academies and Achieve as well as to ensure sufficient public input. However, it turned out to be extremely valuable in the adoption and implementation process. States that faced internal pressure against adopting mutli-state standards had more flexibility to base their standards on the *Framework*. Currently 20 states have adopted NGSS with no or very minor modifications, while 28 have adopted state-developed *Framework*-based standards most of which strongly reflect the influence of the NGSS model.

DEVELOPMENT OF THE FRAMEWORK

To develop the *Framework*, the National Academies used the consensus study approach. This involves assembling a committee of experts who examine the available evidence and develop a set of recommendations based on this evidence. The *Framework* was developed over a period of 19 months by an 18 member committee of experts in the learning sciences, science education and scientists from many disciplines, appointed by the National Academies (see Figure 1 for an overview of the *Framework* development process).

Figure 1: Framework Development Process



The committee's work was guided by a statement of task that focused and bounded their deliberations (see Box 1). This statement of task was developed in collaboration with leadership of NSTA, Achieve and of the National Academies with staff and members of the Board on Science Education and approved by the Governing Board of the National Academies. Note that the statement of task asks the committee to identify core ideas in 4 main disciplines in science (life sciences, physical sciences, earth and space sciences, and applied sciences) as well as crosscutting concepts. This framing – to attend to disciplinary domains as well as to consider overarching concepts – echoes elements of both of the previous science standards documents (NSES and Benchmarks).

Box 1: Statement of Task for the *Framework* Committee

An ad hoc committee will develop and define a framework to guide the development of science education standards. In conducting the study and preparing its report, the committee will draw on current research on science learning as well as research and evaluation evidence related to standards-based education reform. This will include existing efforts to specify central ideas for science education, including the National Science Education Standards, AAAS Benchmarks, the 2009 NAEP Framework, and the redesign of the AP courses by the College Board.

The conceptual framework developed by the committee will identify and articulate the core ideas in science around which standards should be developed by considering core ideas in the disciplines of science (life sciences, physical sciences, earth and space sciences, and applied sciences) as well as crosscutting ideas such as mathematization, causal reasoning, evaluating and using evidence, argumentation, and model development. The committee will illustrate with concrete examples how crosscutting ideas may play out in the context of select core disciplinary ideas and articulate expectations for students' learning of these ideas for at least three key grade levels. In parallel, the committee will develop a research and development plan to inform future revisions of the standards. Specifically in its consensus report, the committee will

- identify a small set of core ideas in each of the major science disciplines, as well as those ideas that cut across disciplines, using a set of criteria developed by the committee
- develop guidance on implementation of the framework
- articulate how these disciplinary ideas and crosscutting ideas intersect for at least three grade levels
- create examples of performance expectations
- discuss implications of various goals for science education (e.g., general science literacy, college preparation, and workforce readiness) on the priority of core ideas and articulation of leaning expectations
- develop a research and development plan to inform future revisions of the standards

Note also that the statement of task calls for the *Framework* committee to create examples of performance expectations. This reflects an earlier report from the National Academies' Board on Testing and Assessment and BOSE, titled *Systems for State Science Assessment*, that highlighted the importance of "learning performances" which are detailed descriptions of what students need to be able to do to demonstrate their competency (NRC, 2008). That report recommended that standards move beyond abstract statements of knowledge that students should "know" or "understand" and articulate the ways that students should demonstrate their understanding by using their knowledge in practice.

As noted above, in an unusual step for National Academies' consensus committees, a draft of the *Framework* was released to the public online in the summer of 2010 so that the committee could gather comments from scientists, science educators, education researchers, and others. NSTA, AAAS, CSSS and other groups aided this effort by gathering feedback from their members. The committee then revised the *Framework*, drawing upon the comments. As a final step to ensure high quality, the *Framework* went through the National Academies' intensive confidential peer-review process. Over 20 additional experts reviewed the framework and provided comments and suggestions, which the committee considered in writing the final version. Details of each step of the development process are outlined below.

Who was at the table and why: Committee and Design Teams

The project began in earnest in Fall 2009 with identification of members of the National Academies' expert committee and assignment of staff to the project. Numerous individuals were considered for membership with attention to attaining a balance of expertise across members including science expertise, knowledge of learning and teaching, experience in classrooms and schools, and understanding of education policy and administration. Staff also sought balance in membership with respect to gender, race and ethnicity, and region of the country. The committee was made up of nine natural scientists all of whom were members of the National Academy of Sciences or of the National Academy of Engineering (including two Nobel laureates), and nine experts in science and engineering education including former classroom teachers, state science supervisors, learning scientists, and experts in education policy (see Appendix A for the list of committee members). This mix of expertise was essential for ensuring that the *Framework* represented robust science content as well as deep understanding of teaching and learning and of the K-12 education system.

The committee's deliberations were informed and supported by the work of four design teams, each focused on major disciplines in science and engineering as identified in the committee's statement of task: physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science (see Appendix A for a list of design team members). These teams consisted of individuals who brought additional expertise in science education in these respective areas. They were charged with developing evidence-based suggestions for what core ideas the committee should consider and how they might be sequenced over elementary and secondary grades. The work of the design teams was essential for allowing the committee to work quickly and stay on what was an aggressive timeline for synthesizing a large body of evidence.

The work of the committee and design teams was supported by professional staff of the Board on Science Education at the National Academies (see Appendix A for a list of project staff). The staff had experience with directing consensus studies as well as expertise in learning, teaching and education leadership at the state level.

Key Tensions in Developing the *Framework*

The *Framework* committee knew from the outset that the "blueprint" and recommendations they were developing would need to lead to standards that created consistency across states, but also allowed for adaptation depending on the needs and characteristics of specific state and district contexts. The standards also needed to be designed with recognition of the existing constraints in the education system while being visionary enough to produce positive changes in instruction and in the learning experiences of students. In balancing these demands, the committee confronted two key challenges.

Bridge just right instead of bridge too far

The *Framework* committee recognized that this work was an opportunity to impact how science is taught across the country, but also that in order for states to adopt and implement its recommendations they must be realistically achievable. The committee reflected frequently on the challenge to be ambitious for improved and more relevant science education without "building a bridge too far" for states to cross it.

For example, the alarm of so little instructional time devoted to science and engineering in elementary school years led to several discussions about how far the *Framework* and standards could push on expanding coverage of science in the elementary grades. A goal was to push for more coverage in view of clear evidence that young children can engage in science, they are interested in it, and it provides a rich context for connecting to other school subjects. Similarly, there was extensive discussion about the progressions laid out for each dimension and what reasonable 12^{th} grade end points should be given that the *Framework* was outlining the science that all students would be expected to master. Again, the committee strived to create a blueprint that would push improvement in the system while not overwhelming it.

There were other approaches, many raised during the public comment period, that the *Framework* committee discussed and concluded were too far beyond the current system and might lead to complete rejection of the new vision. One example was calls for a fully integrated curriculum that would not be organized by the traditional science disciplines (biology, chemistry and physics). Though this would better model the reality of how science researchers operate, the research that an integrated curriculum would be better for student learning was not conclusive and the committee was concerned about the "lift" of completely re-thinking curriculum, course sequencing, teacher certification, etc. Another example was full inclusion of computer science as a core discipline with substantial coverage in all grades from K through 12^{th} grade. The committee was especially concerned about the lack of curricula and teaching staff at all grades for supporting computer science. It is important to note that computational thinking is explicitly identified as one of the eight practices which provides an entry point for including elements of computing.

Creating a manageable set of ideas and concepts

From the beginning, one intent of the *Framework* project was to try to focus on a discrete set of core ideas that would allow a move away from "mile wide, inch deep" curricula. The vast amount of science information continues to grow rapidly, but the amount of time that teachers have is finite and certainly not growing. The *Framework* committee also recognized that it takes time to allow for students to learn by engaging in the practices of science and to struggle to make sense of what is going on in a phenomenon and how that relates to the science ideas they are learning. The challenge is that allowing this time requires limiting the number of discrete disciplinary ideas that students are expected to learn.

Determining what could be cut or combined into larger ideas was challenging. Scientists from each discipline wanted to see their science well represented. In addition, science educators, parents and others have expectations about what should be included in a high quality science education.

The knowledge needed by students in the 21st century was also expanding, rather than shrinking. The scientific community emphasized that students need a deep understanding of content that wasn't yet included in traditional high school physics, chemistry, and biology, such as the importance of Earth systems science (e.g., understanding climate change) and of engineering systems in the modern world. While the *Framework* committee worked hard to narrow their focus on a smaller set of disciplinary core ideas, it is still challenging to make time for students to engage with all of them over a given school year.

This difficulty of cutting core ideas has led to one of the persistent critiques of the *Framework* and NGSS -- that they didn't go far enough in narrowing down to a focused set of core ideas. In part, this is due to the challenge of developing documents that will be embraced and supported by numerous stakeholders. On the other hand, there were planet of people who were disappointed because their specific content did not get included.

Phase I of *Framework* Development

The committee and the design teams built upon the two previous standards documents for science—*Benchmarks for Scientific Literacy* (AAAS, 1993) and *National Science Education Standards* (NRC, 1996)—as well as *Standards for Technological Literacy: Content for the Study of Technology* (ITEEA, 2000). The committee also examined more recent efforts: the *Science Framework for the 2009 National Assessment of Educational Progress* (NAEP 2009), *Science College Board Standards for College Success* (College Board 2009), NSTA's Science Anchors project (NSTA 2009), and a variety of state and international science standards and curriculum specifications. The design teams were asked to begin their work by considering the ideas and practices described in these previous documents as well as the relevant research on learning and teaching in science.

The committee and design teams also carefully considered National Academies reports published since 2000. Research on how children learn science and the implications for science instruction in grades K–8 was central to *Taking Science to School: Learning and Teaching Science in Grades K–8* (NRC 2007). *America's Lab Report: Investigations in High School Science* (NRC 2006a) examined the role of laboratory experiences in high school science instruction, and *Learning Science in Informal Environments* (NRC 2009) focused on the role of science learning experiences outside school. Complementing these publications, *Systems for State Science Assessment* (NRC 2006b) studied large-scale assessments of science learning, and *Engineering in K–12 Education* (NAE and NRC 2009) explored the knowledge and skills needed to introduce K–12 students to engineering.

The committee met three times between January and April 2010. Each meeting included time to hear from outside experts and sessions for the committee to reflect on the expert input and to work on developing a draft for public comments (see Appendix B for a timeline and details about these meetings).

In February 2010, following the first meeting, the committee began to design a public feedback process. For this process, relevant groups were identified and key individuals within these groups were contacted for the purposes of informing them of the *Framework* process and to gain their support in organizing sessions providing feedback. These groups included CSSS, NSTA, discipline-focused science teaching professional associations and other stakeholder groups. National Academies staff shared the timing of the comment period, offered suggestions of how to solicit feedback from members of the organizations and offered a template for providing feedback.

Over the period from January through April, the design teams prepared drafts and presented them to the committee during the closed portions of the first three committee meetings. To develop and refine the final list of core ideas, the committee applied the following four criteria. A core idea should:

1) Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.
2) Provide a key tool for understanding or investigating more complex ideas and solving problems.
3) Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technical knowledge.
4) Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years.

Every core idea had to meet at least two of these criteria, and preferably three or all four. Note that together the four criteria include attention to the importance of an idea within science disciplines as well as consideration of demands of learning and teaching. These criteria were critical to maintaining focus on the most important science ideas for students to learn.

During May 2010, the leads of the design teams and several committee members with particular content expertise met over three days to forge their work into a format with similar features and grain size. This was sent out to the committee along with other drafted chapters for their feedback and suggestions for revision. Plans for the release of a draft *Framework* were finalized including design of a web-based questionnaire and a format for discussion groups. In May 2010, at a BOSE meeting, information about the committee and its work on the *Framework* was presented to and discussed with staff members from key Congressional committees, the Office of Science and Technology Policy, the National Science Foundation, and the U.S. Department of Education.

The fourth committee meeting was held June 17 and 18. The focus of this meeting was to agree upon the draft for public release. This meeting was held entirely in closed session.

Public Input

An initial draft of portions of the proposed *Framework* was released for public comment in July 2010. As noted earlier, it is very unusual for the National Academies to release a draft report for public comment. However the committee argued for the importance of providing an opportunity for input and, recognizing this, the leadership of the National Academies approved the input process.

Prior to public release, the draft of the *Framework* underwent expedited National Academies' peer review, and the public input strategy (on-line survey, focus groups and solicitation of expert opinions) was subjected to the National Academies Institutional Review Board (IRB). After scientific content and human subject review were completed, the draft was posted on-line as a PDF document on July 12 along with an on-line questionnaire. The draft and discussion group materials were sent to over 20 groups and organizations with directions to share across their networks and to disseminate to other organizations. The draft did not include all of the chapters intended for the final volume, although it did thoroughly address all three dimensions of the framework: crosscutting concepts, disciplinary core ideas, and scientific and engineering practices.

Major discussion groups reviewing the draft were held by the Council of State Science Supervisors and the National Science Teaching Association. Each organization prepared a summary report and submitted these in early August. A total of over 40 discussion groups were held ranging in size from 10 to 30 participants (total number of individuals across all focus groups was between 400-1200 individuals). In addition to the public feedback form, many other organizations and individuals also submitted comments in the form of letters to the committee.

In August 2010, National Academies staff undertook the job of analyzing the over 2000 individual on-line responses and the additional feedback provided by all of the discussion groups, letters from organizations, and individual experts. The staff and committee chair reviewed this input, developed summaries identifying the major issues raised, and outlined possible revisions. Committee members then evaluated these summaries and potential revisions, and they had the opportunity to examine the public feedback in detail.

Phase II of *Framework* Development

The feedback received through public comment led to substantial revisions of the draft document. (For more detail about the revisions made in response to the public comment, see Appendix A of the *Framework*). The revision process and development of additional portions of the *Framework* draft continued over a period of 6 months from September 2010 through February 2011.

In early September, 2010 the committee held its fifth meeting to review the feedback on the draft and consider what changes might be needed in response. This meeting was held largely closed session to allow the committee to dig deeply into feedback and possible revisions. There was an open session to bring in some fresh thinking on the research and development plan that the committee was developing for inclusion in the final report (which has not been released as part of the public draft). Revised drafts of the *Framework* were exchanged among committee members throughout the month.

Committee members continued to exchange drafts throughout the beginning of October in preparation for the sixth meeting in late October. This meeting was held entirely in closed session as the committee continued to work on organizational and content issues. From November 2010 through mid-February 2011 committee members and National Academies staff continued to work on revisions. The revision process included multiple rounds of committee communication to achieve committee consensus on the final draft report.

During this period while the committee was revising and finalizing the draft, National Academies staff worked to continue to raise awareness about the *Framework*. From September through December of 2010, National Academies' staff (often in partnership with staff from Achieve) presented to the American Institute on Biological Sciences, the National Association of Biology Teachers, the National Academy's Teacher Advisory Council, the Triangle Coalition, and at the National Science Foundation's Discovery Learning K-12 PI conference.

Institutional Peer Review of Final Draft and Public Release

In February 2011, the committee report entered the National Academies expert peer review. The review process is managed by a review coordinator (an expert knowledgeable in the subject area of the report who represents the interest of the domain, field or subject that is being reviewed) and a review monitor (a member of the National Academy of Sciences with some familiarity of the issues who represents the Academies). Given the range of expertise needed and the high profile nature of the report, the coordinator and monitor asked to expand the usual number of reviewers to 21 (up from the typical 14-15). While the committee was required to respond to all comments made by the 21 reviewers, the monitor and coordinator interpreted the review comments, weighed their significance and priority, and commented on potentially conflicting issues. Recruitment of reviewers took longer than expected because of the larger number of reviewers required and the need to ensure that reviewers covered all of the domains in science (and in biology, major sub-disciplines). It was also challenging to identify highly-qualified natural scientists from multiple disciplines (biology, physics, chemistry, earth and space science and engineering) who were interested in and qualified to review a report related to K-12 science education.

Reviews were returned to the National Academies staff and committee in early May, 2011. Staff worked with the committee chair and committee members to revise the report in response to the reviewers' comments. Due to the extensive revisions and the high profile nature of the report, the coordinator and monitor requested a re-review by a subset of reviewers to ensure that the response of the committee was adequate. The revised report was submitted for the re-review in June. The sub-set of reviewers provided additional comments. The committee chair and National Academies' staff made additional revisions and submitted them to the committee for approval and then to the coordinator and monitor. The coordinator and monitor approved the revision signaling that the report was finalized and staff could move forward with preparing it for public release. On July 19, 2011 a pre-publication version of the report (uncorrected proofs) was released to the public.

Content of the Framework

The overarching goal of the *Framework* is to provide guidance for standards, assessment, curricula, and instruction so that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science and engineering; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are informed consumers of scientific and technological information related to their everyday lives; can continue to learn about science and engineering outside school; and have the skills to enter careers of their choice, especially in science, engineering, and technology.

The *Framework* is based on a rich and growing body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K-12 science and engineering. From this work, the committee concluded that K-12 science and engineering education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design. Six guiding principles, drawn from what is known about the nature of learning science, underlie both the structure and the content of the *Framework* (see Chapter 2 of the report). These principles are:

- Children are born investigators
- Focusing on core ideas and practices
- Understanding develops over time
- Science and engineering require both knowledge and practice
- Connecting to students' interests and experiences
- Promoting equity

The *Framework* describes three dimensions of science learning that should be integrated into standards, curriculum, instruction and assessment: science and engineering practices, crosscutting concepts and disciplinary core ideas. It stresses that these dimensions should be woven together in science instruction, recognizing the fact that science and engineering consist of both knowing and doing; simply memorizing discrete facts or the steps in a cycle of experimentation or design does not lead to deep understanding and development of flexible skills. Instead, student engagement in the practices of science and engineering—what scientists and engineers actually do—must have a central place in science classrooms. The *Framework* outlines learning progressions, organized by grade bands, for the development of the disciplinary core ideas over grades K-12.

The *Framework* also provides guidance related to implementing standards including discussions around ensuring equity and describing what is needed in curriculum and instructional materials, assessment and professional learning for teachers to achieve effective implementation of its vision for science education. It also includes a research agenda for tracking and understanding the influences of standards.

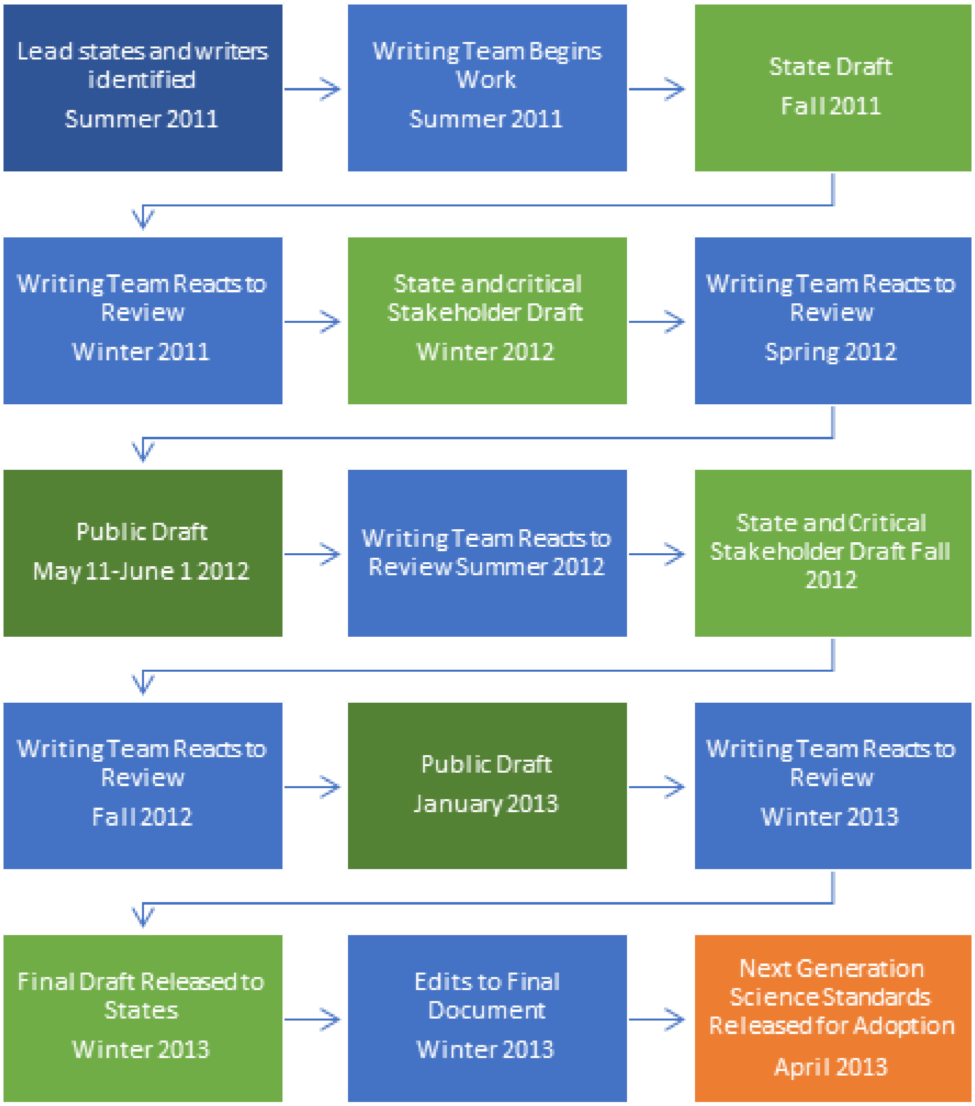
Finally, the *Framework* includes a set of 13 recommendations that provide specific guidance for standards developers (see Chapter 12 of the Framework). The committee explicitly recommended that science standards should be articulated as performance expectations that fully integrate the three dimensions. Prior standards often incorporated the idea of practices (or processes) of science; however, this was often expressed as additional content to be learned and assessed rather than an integral part of all science instruction. The descriptions of the three dimensions and the set of recommendations informed the development of the Next Generation Science Standards

DEVELOPMENT OF THE NEXT GENERATION SCIENCE STANDARDS

Following release of the *Framework*, a consortium of 26 Lead State Partners (Lead States), working with a team of 41 writers with expertise in science and science education an facilitated by Achieve, Inc., began the development of rigorous and internationally benchmarked science standards that were faithful to the *Framework.* Each of the Lead States created broad and representative stakeholder teams that provided detailed feedback on every draft of the standards. As part of the development process, the standards underwent multiple reviews, including two public drafts, allowing anyone interested in science education an opportunity to inform the content and organization of the standards (see Figure 2). Thus, the NGSS were developed through collaboration between states and other stakeholders in science, science education, higher education, business, and industry.

E

Figure 2: Steps in the NGSS Development Process (from the NextGenScience website)



Who Developed the Standards?

As noted above, from the outset the leaders of the *Framework* and NGSS development effort understood that numerous stakeholders needed to have the opportunity to contribute to standards development. Achieve recognized that public comment periods would not be sufficient for ensuring that a broad range of perspectives informed the standards. The perspectives of state leaders, of classroom educators and of other stakeholders in science education (e.g. community leaders, business and industry, higher education) needed to be considered as the work progressed. In addition, the development process itself needed to help build a broad coalition of stakeholders who understood and embraced the research of the *Framework* and the final standards document. (See Appendix B for the list of lead partner states, writing team members and Achieve staff).

Lead States

The tagline of the NGSS is “For states, by states”. This reflects the intentional and strategic involvement of state teams as leaders in the development process. A consistent question in the early days of the process was, “Who holds the pen?” This question was who is ultimately responsible and had the final say. The answer, simply put was the NGSS writers held the pen while the states directed their hand. There were 26 Lead States that provided input to the standards writing team. States volunteered to be Lead States for the development of the NGSS by way of a state partnership agreement signed by their chief state school officer and state board of education chair. The agreement included a commitment by states to convene instate, broad-based committee(s) (which ultimately ranged from 50 to 150 members) to provide feedback and guidance to the state throughout the process. Specifically, the Lead States made commitments to:

- Give serious consideration to adopting the resulting *Next Generation Science Standards* as presented (full adoption was NOT required).
- Identify a state science lead who will attend meetings with writers to provide direction and work toward agreement on issues around the standards, adoption, and implementation.
- Participate in Multi-State Action Committee meetings (a committee of the Council of Chief State School Officers) to discuss issues regarding adoption and implementation of the new standards.
- Publicly announce that the state is part of the effort to draft new science standards and make transparent the state’s process for outreach/receiving feedback during the process.
- Form a broad-based state level team that considers issues regarding adoption and provides input and reactions to drafts of the standards.
- Publicly identify a timeline for adopting science standards.
- Work together with other Lead States to develop implementation and transition plans while the standards are being developed that can be used as models for all states.

Following the publication of the *Framework*, Achieve invited all states to apply for the role of Lead State using the criteria above. The states submitted their commitments along with narratives expanding on their plan to engage their state and its stakeholders. Originally, Achieve intended to include only 20 Lead States, however, in response to the level of interest they expanded the group to 26 states. As noted above, each Lead State formed an in-state team that included members from a variety of sectors in the state. Over the 22 month development period the state-based teams reviewed drafts of the standards 6 times (2 reviews were state only, 2 reviews were states and critical stakeholders, 2 were as part of the public reviews). The work of the state teams was essential for creating a final standards document that was useable across states and for building a cross-sector coalition of stakeholders in each state who could be champions for standards adoption and implementation. It is important to note that while there were only 26 Lead States, all states were given the opportunity to provide feedback multiple times to ensure both buy in and awareness beyond the 26 Lead States.

Writing Team

The 41 member writing team included experts in elementary school science, middle school science, high school science, students with disabilities, English language acquisition, state level standards and assessment, and workforce development. K–12 educators played a central role in the development and made up most of the writing team (see Appendix B for a list of members). Individuals were selected based on recommendations from various groups, including NSTA and CSSS. The writing team was organized into committees, each focused on a different science discipline, grade band, or purpose, including a committee solely focused on ensuring the standards were accessible for students of all socio-economic backgrounds, races, genders, students with disabilities, and gifted students. While much of the work was done in these committees, the committees were often rearranged to allow for interdisciplinary and longitudinal learning progressions. To ensure fidelity to the *Framework*, the *Framework* design team leads acted as the chairs of the NGSS writing team committees. Achieve coordinated the writing team on behalf of the Lead States including bringing in the Lead State representatives together with the writers for face-to-face conversations to help make key decisions about the structure and development of the standards and to make sure the revisions that were made reflected state feedback.

Critical Stakeholders

In addition to the Lead States and the writing team, a group of Critical Stakeholders were selected to provide input. These were distinguished individuals and organizations that represent education, science, business and industry and who had an interest in K-12 science education and science standards. The Critical Stakeholders critiqued successive, confidential drafts of the standards and provided feedback to the writers and states, giving special attention to their areas of expertise. The members were drawn from all 50 states and had expertise in:

- Elementary, middle and high school science from both urban and rural communities
- Special education and English language acquisition
- Postsecondary education
- State standards and assessments
- Cognitive science, life science, physical science, earth/space science, and engineering/technology
- Mathematics and Literacy
- Business and industry
- Workforce development
- Education policy

Development Process

In designing the approach to standards development, the team at Achieve was guided by the recommendations from the *Framework* committee and by awareness of what kind of document would be most readily useable by states. The previous sets of standards from the 1990's provided high level guidance and required layers of interpretation by states in order to develop the kind of technical standards document that is needed to guide curriculum development and adoption, and development of assessment and accountability systems. A goal for development of the NGSS was that the resulting document would get closer to being a document that states could use directly with limited modifications, thereby providing more consistency across states. This consistency is particularly important for students who move from one state to another. If standards are significantly different, students can end up with significant holes in their understanding.

The development process involved multiple iterations between the writing team and the lead state teams (see Figure 1 for an overview of the steps in the process). The writing process began with a period of 4-6 months during which the writers became familiar with the *Framework*, the three-dimensional approach, the progress of ideas, concepts and practices across grades and the notion of performance expectations as the way standards would be framed. The notion of performance expectations was very deliberate. There were those in the early days that wanted to write separate sections, however the Framework made clear that three dimensional performances were to be the expectation for students. Additionally, the idea was to perturb the system enough to change science instruction and assessment. There was a strong feeling among the state representatives and writers that if the assessments continued to assess one dimension at a time, the instruction had virtually no chance to change. As a result, the decision was made to follow the recommendation in the *Framework* and write the standards as performance expectations.

Another of the early decisions the writers presented to the states was the architecture .of the standards. As an example of how the interactions worked, the original architecture listed the language from the Framework as the top level. The states directed the writers to have the performance expectations at the top to ensure clarity of what the assessable components of the standards were.

The writers also developed documents to support consistency across the various writing committees, including summarizing the learning progressions of the disciplinary core ideas from the Framework, and creating more detailed grade by grade progressions for .the science and engineering practices as well as the crosscutting concepts The summary and the more detailed articulations of the progressions are captured in Appendices E, F & G of the NGSS.

Over a period of 21 months, multiple drafts created by the writing team were shared with the state teams for feedback. The state feedback then informed rounds of revisions and the revised draft was shared with teams again. For each round of revisions, Achieve staff and the writing team made clear what changes were made in response to state input. Tracking this influence allowed the leaders of the state teams to show team members how their input was shaping the standards. They were also able to show state legislators, decision-makers and other stakeholders that the draft was being shaped by the state's feedback.

In addition to providing feedback on drafts, the lead state teams were a mechanism to develop awareness of the standards in each state, to highlight the state's role in the development process, and to cultivate cross-sector support and advocacy for the standards. In many states, the state science supervisor at the State Education Agency had a leadership role in these teams and provided continual updates to state legislators and policy-makers on the NGSS development work.

In addition to obtaining feedback from state teams, Achieve also coordinated two rounds of reviews and input from the critical stakeholders. They also held a discussion with science faculty in higher education to explore the inclusion and progressions of disciplinary core ideas at the high school level. This discussion focused on the expectations that faculty have for students entering science courses and the expectations of hiring managers in industry and how that might inform the expectations for students by the end of 12th grade. This exercise was also intended to be a deliberate conversation regarding what College and Career Readiness in Science really means. To this point, in mathematics and reading college and career ready was defined as students being able to immediately matriculate into credit-bearing coursework upon entry to college. As remedial courses are not part of science, this was a new conversation. The outcome of the meeting formulated the expectations at the end of 12^{th} grade, but it also exposed the general belief by many higher education faculty that they have to design introductory courses as if in-coming students have little to no science background.

Public Review and Comment

As was mentioned above, in addition to the four reviews by the Lead States and their teams and input from the critical stakeholders, Achieve sought out feedback from the general public during two public review periods. The first public draft of the NGSS was posted online from May 11 to June 1, 2012, and the second public draft was posted online from January 8 to January 29, 2013. These drafts received comments from more than 10,000 individuals including those working together in lead state review teams, school and school district discussion groups, and scientific society commenters.

Feedback on the public drafts was reviewed, coded into sortable spreadsheets, and summarized for state and writing team consideration. Where feedback was unclear or conflicting, lead state teams engaged in additional discussions. The writers then used this feedback to make substantial revisions to the draft standards. Both public reviews had a significant impact on the performance expectations (PEs). As a result of the first public review and subsequent state review, 95% of the PEs were rewritten. After the second public draft review period, 75% of the PEs were edited to add clarity and consistency across the document. (For more information about the public reviews and the changes made in response, see Appendix B of the NGSS).

National Academies Fidelity Review

As a part of the NGSS development process, the National Academies carried out a fidelity review of the final draft of the NGSS, comparing the standards to the vision outlined in *A Framework for K-12 Science Education*. The reviewers concluded that the NGSS are consistent with the content and structure of the *Framework.*

Structure of the NGSS

The NGSS documents include detailed three-dimensional performance expectations (PEs) intended as standards for each grade level or grade band in addition to a set of appendices further defining these expectations, for example the grade-band expectations for engaging in science practices or applying crosscutting concepts. The PEs describe what students must do to show proficiency in science. Each PE couples science and engineering practices (SEPs) with various components of the Disciplinary Core Ideas (DCIs) and Crosscutting Concepts (CCCs). There are 3 key features of the NGSS, outlined below, that represent innovations when compared to previous standards documents.

Performances

A core function of state standards is to provide guidance for assessments. In a post-NCLB world, they are seen as the contract between a state and the teacher regarding what and how students will be assessed. Prior standards documents listed what students should "know" or "understand." These ideas needed to be translated into performances that could be assessed to determine whether or not students met the standards. Different interpretations sometimes resulted in assessments that were not aligned with curriculum and instruction. The NGSS have avoided this difficulty by developing performance expectations that state what students should be able to do in order to demonstrate that they have met the standards, thus providing the same clear and specific targets for curriculum, instruction, and assessment. Another early decision was to not use the traditional "Bloom's Taxonomy" verbs and use the Science and Engineering Practices as the verbs. The thought was this would drive changes in assessment as they could no longer simply develop assessment items. with low levels of cognitive complexity. While use of the Science and Engineering Practices as the verbs created a certain amount of tension regarding the concern that teachers would only teach a performance expectation as written, the overall feeling was the messaging was critical if the expected change was to come to fruition.

The NGSS architecture was designed to provide information to teachers and curriculum and assessment developers beyond the traditional one-line standard. The performance expectations also include clarification statements that provided additional details about what was intended and assessment boundaries that provided limits or guardrails of where instruction should or should not, or did not need to go because they would be beyond the scope of the standards for that grade level. These are intended to guide educators as they develop curricula and assessments.

As the DCIs were selected in the *Framework* for their broad explanatory power, PEs were meant to be addressed in units of instruction that pulled across multiple PEs in "bundles" that have explanatory power for natural or human made phenomena. The intention was never that the three dimensions would need to be taught in the same way that they were written in the performance expectations. The ideas as that curriculum developers would pull together bundles of PEs for a unit that were relevant to students making sense of a phenomenon or designing a solution to a problem. As with all standards, they represent what all students should be able to do, but do not prohibit teachers from going beyond the standards to ensure that students' needs are met.

Foundation Boxes

To provide additional clarity and detail about how a given PE is grounded in the three dimensions, each PE includes a set of boxes placed below the statement of the PE that include text taken directly from the *Framework*. as well as the grade-specific expectations for each dimension These boxes offer more detailed guidance about the intent of the PE with respect to each of the three dimensions. They also provided support to curriculum developers, teachers and assessment developers who would need to be developing instruction and assessment that targeted these PEs without just "going" the PEs. This additional structure helped alleviate concerns that the standards would be used as curriculum and was done at the request of Lead States so that they do not need to begin implementation by "unpacking" the standards.

Coherence and Connections

Each PE also lists connections to other ideas across grade levels, within the grade level and between disciplines of science and engineering, and with CCSS in English Language Arts/Literacy and Mathematics. The idea of these lists is to support schools and teachers to help students see and build upon connections across courses, grades or subject areas.

A top priority was to ensure coherence of learning across grade levels while still keeping the scope of the standards manageable. This was accomplished in several ways. First, the writers focused on maintaining the learning progressions described in the Framework such that at each level, student expectations built on a foundation from prior levels. Second, where overlapping or redundant content arose during the drafting of the performance expectations, it was eliminated and placed in the area and grade level that made the most sense. The public feedback and feedback from key stakeholders were used to further prune content that was not critical to understanding the central focus of each larger DCI. Finally, small groups of educators were asked to review the NGSS for their grade-level/grade-band/disciplinary area with an eye toward ensuring teachability.

Appendices

To support implementation of these standards the developers also prepared a set of appendixes with additional information (see Box 2). The team that was charged to participate in standards development and review the drafts with ongoing attention to equity issues in any aspects of the document also developed a set of case studies illustrating how the standards might be used to support learning for a variety of non-dominant student populations. These studies are briefly described in Appendix D of the NGSS report. Appendixes E, F and G describe the progression of learning across grade levels for disciplinary core ideas, science and engineering practices, and crosscutting concepts respectively. The progression tables in Appendix F and G were developed by teachers and reflect progressions they felt were realistic for their students based on their experience at that time, because there was no research base available to inform these progressions. Additional Appendices were developed to help to guide implementation.

Box 2: NGSS Appendices

A Conceptual Shifts in the Next Generation Science Standards

B Responses to the Public Drafts

C College and Career Readiness

D “All Standards, All Students”: Making the Next Generation Science Standards Accessible to All Students

E Disciplinary Core Idea Progressions in the Next Generation Science Standards

F Science and Engineering Practices in the Next Generation Science Standards

G Crosscutting Concepts in the Next Generation Science Standards

H Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards

I Engineering Design in the Next Generation Science Standards

J Science, Technology, Society, and the Environment

K Model Course Mapping in Middle and High School for the Next Generation Science Standards

L Connections to the Common Core State Standards for Mathematics

M Connections to the Common Core State Standards for Literacy in Science and Technical Subjects

What the NGSS are NOT

The NGSS are standards, or goals, that reflect what a student should know and be able to do; they do not dictate the manner or methods by which the standards are taught. The NGSS were not intended to limit instruction to trying to teach one performance expectation at a time or as the sole targets of instruction. However, past practice of some schools and principals to ask teachers to always be able to say what standards are being addressed in each lesson plan have driven some to interpret the set of standards as a curriculum outline, rather than as a guide to student competencies that a curriculum should support students to develop.

The PEs are written in a way that expresses the concept and skills to be performed but still leaves curricular and instructional decisions to states, districts, schools, and teachers. While the NGSS have a fuller architecture than traditional standards the NGSS are not intended to dictate nor limit curriculum and instructional choices.

In writing the NGSS performance expectations care was taken to state the core idea and crosscutting concepts to be addressed as generally as possible, rather than also specifying the context in which that idea or concept should be applied. This was purposeful as it allows states, curriculum or assessment developers, and teachers to choose contexts with regional or local relevance rather than introducing a single phenomenon or problem in the PE that becomes a required topic nationally. Patterns, for example, can be seen in the northern hemisphere in the seasons, in the southern climes by changes in prevailing winds, in cities by traffic on roads, and everywhere by observing migrating species.

Balancing Practical, Political and Evidentiary Pressures

The role of standards in science education is complex and standards documents themselves are informed by a combination of evidence about teaching and learning, politics at multiple levels, values and priorities of communities, and the practical realities in schools and districts. The development process of the *Framework* and NGSS was designed to leverage the best available evidence while being sensitive to the political and practical realities of the moment. This delicate balance often required trade-offs and compromises.

The Importance of Transparency and Responsiveness

From the outset the leaders of the development processes for both the *Framework* and the NGSS recognized the need for as much transparency as possible in the development process with multiple opportunities for input. The approach was informed by experiences with previous standards at both the national level and the state level. The *Framework* and NGSS process intentionally built in multiple opportunities for feedback and anticipated that significant changes to the documents might be necessary to respond to the input. In addition, changes made in response to feedback were described explicitly so that it was clear to stakeholders that their input mattered. In this way, the development of the *Framework* and NGSS became a very large, national community effort. This resulted in documents that reflect the expertise and perspectives of numerous stakeholders, including classroom educators. In addition, the process of soliciting feedback itself became a mechanism for capacity building, engaging science educators and stakeholders across the country in discussions about priorities for science education and the latest evidence about teaching and learning in science.

Sensitivity to Political Context

Experience with previous science standards and education standards in general made leaders of the *Framework* and NGSS initiative aware of how important it was to be sensitive to how political issues can influence standards development and adoption. The periods of public comment on both documents and participation of state teams who represented a diverse set of stakeholders, helped to ensure that the standards presented current scientific understanding while avoiding language and framing that would appear to be partisan.

The integrity of the *Framework* and NGSS was helped by the independence and reputation of the National Academies. The expert committee which included top scientists in the world, made it more difficult to criticize the science content. Being able to point to a known set of committee members, with their credentials, who are broadly representative of science, engineering, education, and even geography is important.

The Common Core State Standards (CCSS) evolution provided important lessons that directly informed the *Framework* and NGSS model. While the CCSS began as an effort led and driven by states, the pressure placed by the Race to the Top program in the U.S. Department of Education caused some to infer that the standards were a federal initiative. For the NGSS, the leaders of the initiative allowed states flexibility as they worked toward state adoption and encouraged federal agencies to refrain from weighing in on the standards adoption. In fact, states were strongly encouraged to follow their usual processes and to not rush to adopt. Additionally, states were encouraged to concentrate on instruction first and assessment second.

The increasing politicization of the CCSS as they were implemented and as the national political landscape shifted provided powerful and somewhat alarming lessons about how things could go wrong. This informed how we proceeded with the NGSS. No federal funding was used to develop the *Framework* or NGSS, and there was no federal legislation that drove states toward adopting the NGSS. In fact, when leaders of the development effort spoke with staff in federal agencies they stressed that it would not be helpful to the science standards effort for agencies to provide funding or create mandates for adoption. This helped to clarify that the project was not driven by the federal government and did not represent an overreach of federal influence on state level matters.

Feasibility

As noted in the discussion of the *Framework*, the leaders of this effort understood that it would be challenging to create a vision and standards that would balance pushing for improvement in science education while being realistic about the existing constraints in the education system. The tension around "a bridge just right instead of a bridge too far" was alive during the entire development process of the *Framework* and the NGSS, as was the tension around how to create a final set of standards that were of reasonable "size" given the amount of time available. The public feedback process helped to calibrate on both issues, however, all involved in the development of both documents recognized the difficulty of striking the “perfect” balance.

While the *Framework* committee worked hard to narrow their focus on a smaller set of disciplinary core ideas, it is still challenging to make time for students to engage with all of them over a given school year. The problem of scope also had to be confronted in the development of the NGSS. The notion of bundling with respect to the PEs is meant to address the coverage issue. However, it is still a challenge.

The problem of amount of material and time is especially acute in the elementary grades. The intent was to raise the bar on what should be included in the elementary grades, but thus far in implementation it has been difficult to increase the amount of time devoted to science in the elementary grades. There are also challenges with the number of PEs in grades 6-12, particularly if students are to engage meaningfully in science investigation and engineering design as described in the *Framework*.

In addition, the *Framework* expands and deepens attention to disciplinary ideas that have typically not been included in a substantial way in K-12 curricula and courses – engineering and Earth and space science chief among them. This has raised questions about course sequencing and content in middle and high school that challenge traditional organization of material.

The Challenge of Making Technical Documents Accessible

The *Framework* and NGSS both contain a lot of information and are somewhat technical. This was necessary in the *Framework* to provide connections to the supporting evidence and sufficient detail to provide guidance to those developing standards. Similarly, the NGSS must contain enough technical detail so that states can readily use them to inform assessment and curriculum. However, the complexity and detail in both documents can make it difficult for educators who are new to the documents to quickly understand the changes represented in the *Framework* and how to use and interpret the NGSS. This is even more true for education leaders and decision-makers for whom science is one several subject areas for which they are responsible. While the appendices to the NGSS were intended to help inform implementation, they too provide a lot of information.

In response, various ‘readers’ guides’ emerged following the release of the *Framework* and NGSS, but all said similar things – read the introduction, explore the specifics of the intended learning goals, re-read the introduction, and delve into the supporting chapter and appendices. And then begin to imagine implementation in the classroom. There have also been efforts to create summaries for administrators and parents. However, these documents are not sufficient to fully convey the vision of the *Framework* and the complexities of the NGSS.

In fact, written standards documents alone are not designed to provide detailed guidance about classroom instruction and design of curricula. Educators need to be familiar with the documents, but to implement the vision, professional development for teachers and administrators that includes examples of what high quality, aligned instruction and curriculum look like is essential.

ADOPTION AND IMPLEMENTATION

All those involved in the development of the *Framework* and NGSS understood from the outset that the documents themselves were merely a starting point for improving science education. The real work comes with using the documents to catalyze change in districts, schools and classrooms.

Adoption

The next step toward making the vision described in the *Framework* a reality was state standards adoption. States, including the Lead States, were under no obligation to adopt the NGSS, but the Lead States had agreed to at least consider them in the adoption processes. As noted above, states were encouraged to follow the typical process for state adoption when considering the NGSS. This meant that if a state was not immediately due to consider new science standards, they should wait and follow the established timeline. As a result , adoption of the NGSS or standards based on the *Framework* has happened across a period of several years (see Table 1). Some states that were early adopters of the NGSS or *Framework* based standards have now had to go through another round of standards revisions due to their regular cycle of standards revisions.

Table 1: Timing of State Adoptions of Standards Based on the *Framework*

2013	Rhode Island, Kentucky, Kansas, Maryland, Vermont, California, Delaware, Washington, Washington D.C.
2014	Illinois, Nevada, Oregon, Oklahoma, New Jersey
2015	West Virginia, South Dakota, Arkansas (K-8), Iowa, Alabama, Connecticut, Michigan, Utah (6-8), Department of Defense Education Activity
2016	Hawaii, Indiana, Massachusetts, Missouri, Georgia, Montana, Wyoming, Tennessee, New Hampshire, New York, Idaho, Arkansas (9-12)
2017	Louisiana, Mississippi, Nebraska, Wisconsin
2018	Colorado, New Mexico, Arizona, Ohio, Virginia, Kansas*
2019	North Dakota, Maine, Alaska, Minnesota, Utah (K-5, 9-12)
2020	New Jersey*, Oklahoma*
2021	South Carolina, West Virginia*
2022	Pennsylvania, Texas, Kentucky*, Oregon*, Idaho*, Indiana*, Tennessee*

*Indicates second adoption or revision cycle

While many states did not adopt the NGSS whole cloth, the NGSS served as an exemplar for what standards based on the *Framework* might look like. In many cases, states used the three-dimensional performance expectation from the NGSS to design standards for state specific performance expectations. The shifting of state standards to three-dimensional performances was only possible because of the clear and consistent examples present in the NGSS.

The partnership with the Council of State Science Supervisors (CSSS) established during the *Framework* development stage, and the involvement of Lead State teams in the NGSS writing and reviewing stage of the work was critical to the adoption process. This partnership provided a broad contingent of state level science education leaders who were intimately familiar with the research regarding best practices in science education that informed both documents and could bring that to the standards development and adoption processes in their own states.

To provide some support for embracing the research based in ways the about impact science education their states, CSSS launched the Building Capacity in State Science Education (BCSSE) project. This project was designed to provide sustained professional learning for state science supervisors to gain fluency and utility with the *Framework*, create communication tools to disseminate key messages from the *Framework* to multiple state-based audiences, and develop a state-based strategic plan for work with the *Framework* and dissemination and adoption of NGSS. Through five meetings paced over two years, the BCSSE project brought together science education leadership teams from states to collaborate with the researchers who were part of the *Framework* committee and whose work was cited in the *Framework* report. This gave state teams an opportunity to learn first-hand about how this research could benefit students in their states and to reflect on what it would take to make the vision for science education a reality in their own states.

These meetings helped state teams, coordinated by the state science supervisors, to develop a common understanding of the research and common goals for what was for implementation. These groups often ended up playing key roles in advocating for standards that were based on the *Framework* and the research that informed it. The process also helped to build leadership among the state science supervisors who led the teams. For example, in some states suggested modifications to the science content in the standards made by influential people outside of the science education field included errors or omitted important science ideas entirely. Feedback from well-informed coalitions of state-level, grassroots stakeholders successfully pushed-back on these suggestions.

Implementation

Implementation of the new standards began following adoption with activity in state departments of education to create the supports and provide the resources that districts would need to shift their practice to reflect the vision in the *Framework*. The scale of achieving this task across the country is hard to overstate. There are 16,800 public school districts in the United States; around 98,000 schools; and over a million science teachers. As each state adopted the new standards, they needed to develop a strategy and timeline for the changes needed. This requires plans for changes in assessment, curriculum, instruction, and professional learning for teachers, as well as provision of resources. From the beginning, there was concern expressed about how teachers at all levels could be supported to make the necessary shifts in instruction, particularly because many policies in schools and districts and many widely available curricula were not aligned to the vision of the *Framework* and standards based on it. Professional learning for both teachers and administrators at scale was, and is, a key component to implementation.

Neither the *Framework* nor the NGSS specify a specific instructional approach, nor do they provide detailed guidance for design of curricula. However, as national, state and district leaders engaged in interpreting the *Framework* and NGSS for classroom educators, “phenomena based instruction” emerged as a powerful model of how to design curriculum and instruction that is consistent with the vision of the *Framework*.

Achieve, the National Academies, and NSTA developed a number of resources to support implementation. Achieve held meetings for state teams to help them develop strategies for moving forward and developed a number of tools for states to use to support implementation. They also developed tools for creating “smart demand”, that is tools for helping states, districts and schools to determine whether instructional materials and curricula were aligned to the Framework and NGSS. These tools -- the EQuIP rubric for science for reviewing units, the Next Generation Lesson Screener for revising lessons, and PEEC (which has been replaced by NextGenTime) for considering programs for adoption -- were made available for free online. The EQuiIP Rubric for Science was used to establish the Science Peer Review Panel, which reviewed free and publicly available units to determine how thoroughly they were designed for the NGSS. Free, private feedback was provided to designers whose materials did not reach the criteria for quality and alignment. Those materials that did meet the criteria were publicly identified to provide examples for teachers and for curriculum developers.

To support implementation and synthesize evidence on a variety of issues related to improving science education, BOSE produced a series of consensus reports including reports focused on assessment, teachers’ learning, and instruction across Prek-12th grade (see Box 3).

Box 3: Reports from the Board on Science Education on Implementing the *Framework* and Related Standards

Developing Assessments for the Next Generation Science Standards (2014)

Guide to Implementing the Next Generation Science Standards (2015)

Science Teachers Learning: Enhancing Opportunities, Creating Supportive Contexts (2015)

Seeing Students Learn Science: Integrating Assessment and Instruction in the Classroom (2017)

Design, Selection, and Implementation of Instructional Materials for the Next Generation Science Standards: Proceedings of a Workshop. (2018)

Science and Engineering in Grades 6-12: Investigation and Design at the Center (2019)

Science and Engineering in Preschool through Elementary Grades: The Brilliance of Children and the Strengths of Educators (2021)

Taking Stock of Science Standards Implementation: Proceedings of a Virtual Summit (2022)

Taking Stock of Science Standards Implementation: Planning for Progress: Proceedings of a Workshop—in Brief (2022)

As implementation has proceeded additional tools and support mechanisms have emerged developed by a wide variety of organizations. These includes open-source curriculum, a formal process for review of curricula, and numerous NGSS focused professional development programs. NSTA has provided numerous supports for implementation, with presentations at regional and national meetings, online professional development, publications and engagement through social media.

While there has been progress on implementation, there is still much progress to make. From Fall 2021 through Spring 2022, BOSE held series of meetings to explore the status of implementation and what kinds of support from national organizations would help states and districts continue to make progress. Discussions at these meetings underscored that translation of the *Framework* and NGSS into classroom practice is taking place, but the changes are uneven (NASEM, 2022a & 2022b). This observation was confirmed in a recent evaluation commissioned by the Carnegie Corporation of New York which found that while the *Framework* provided the science education community with a common vision, development of other elements that are required for implementation – aligned curriculum, instructional materials, professional development for preservice and inservice educators and assessments for example – are not fully developed (Horizon Research, 2022).

Furthermore, there is a need for systematic documentation of implementation efforts. The *Framework* included a research agenda designed to track implementation efforts and build the evidence base needed to inform future iterations of science standards. However, much of that agenda has not been taken up.

REFLECTIONS

A decade out from release of the *Framework* and the NGSS, it is an opportune time to reflect on the development process and on the trajectory of adoption and implementation. We, the authors of this paper, played key roles at the start of the initiative and have remained engaged in the work in a variety of capacities. In addition to the insights shared throughout the paper, we offer these final reflections in hopes that they will be productive food for thought in our collective work moving forward.

Centering Equity

Science education has historically been exclusionary, dedicated to preparing a limited number of selected students to be ready to become scientists. Systemic biases, sexism and racism have meant that many talented people are excluded from science and are not able to pursue science-related careers. Even as the kinds of jobs that require science knowledge has expanded and there have been calls to broaden participation in STEM fields, long held biases about who can succeed in science and deeply entrenched inequities in the education system have locked many students out of science.

Moreover, the *Framework* recognizes that the goals of k-12 science education should be broader than simply preparing students for future jobs, because science literacy is a necessary preparation for understanding the work around us and thriving in a highly technical world. This requires science educators to strive to provide all students with science knowledge that they can use to solve problems in their lives and communities, as well as in their employment. The *Framework* discuss this need and lays out a vision of science education for all, based on broadly accepted ideas of equity and inclusion at the time it was written. It stresses the idea that all students can and should learn science, and that it is important to provide equitable opportunities to learn starting in the earliest grades across schools serving students from all income levels and communities. The need for equity and the inclusion of students from varied backgrounds, and the failure to achieve it in science education has only become more obvious in the intervening years.

Furthermore, in the intervening years, research on what it takes to engage and interest of students in science and develop their identity as science learners for students from diverse cultural and social backgrounds shows more than just access to opportunity to learn is required.

A currently active NAS study committee is developing a report on how to support educational equity in science, technology, engineering, and mathematics (STEM) education at all levels of the PreK-12 system. This report and the research base that it builds upon will provide updated advice to the field and to education policy makers on this important topic.

The intention for the NGSS to support equity and inclusion of diverse students in science learning was clearly articulated throughout their development with the mantra "all standards, all students". As noted above, a team charged with upholding this vision helped raise awareness of what it required for the writing teams, and edited all performance expectations to avoid language that is discriminatory or adds unnecessary difficulty for language learners. They also provided supporting documentation for those implementing the standards to help maintain this vision (NGSS, Appendix D). However, standards themselves, no matter how carefully written, cannot be the primary vehicle driving equity and inclusion in science classrooms. All aspects of the system must take this intention seriously and carry out their work with full understanding of what it takes to achieve the goal of centering and advancing equity.

Critiques of the *Framework* and NGSS related to equity also point out that the original *Framework* committee and the teams involved in the development of the NGSS, while diverse in some ways, were not constituted to intentionally include people who work directly on equity issues in education and who represent the full range of communities across the country. As we continue to support implementation and as we look ahead to what future revisions to standards might look like, we must consider how to bring a broader group of people to the table to inform the development process and to design for equity from the outset.

Time Scales for Change and Revision of Standards

It has been a decade since release of the NGSS and over a decade since the release of the *Framework*. Recently there have been calls to consider revising or replacing the *Framework* and NGSS to leverage what has been learned during that time, to address perceived weaknesses or omissions of the 2 documents, and to better address societal issues that have come to the foreground in the past 10 years. In response, we have had extensive conversations with a number of state and national leaders in science education. These individuals have signaled strongly that it would be a mistake to undertake a substantial revision at this time. This is due to the timeline for achieving effective implementation at scale (especially given the staggered adoption times across states) and the current highly polarized national political context.

The life cycle for major changes to the *Framework* and the NGSS needs to consider how long it takes to develop instructional materials and assessments, and to enact wide-spread instructional change at the classroom level. This implementation process takes time – around 10 years including 3-5 years for development of aligned curricula and assessments and 3-5 years for teachers to fully implement the necessary instructional changes. Considering that the most recent state adoption occurred in 2022, in some locations implementation has just begun.

In addition, consider that a typical student in the United States is in school for 13 years. Ideally, a student will experience the approach called for in the *Framework* and NGSS for multiple years of schooling. If there is a major overhaul of standards frequently, this makes it difficult for students to have a coherent science experience across multiple grades.

For these reasons, we suggest that it makes sense to leave standards in place for 15-20 years. This means the process for developing new standards might begin in 2028 with consideration for adoption beginning in 2033-2038 (allowing 5 years for development). Ideally, there would also be time for development of a robust program of research and evaluation that would document implementation efforts and provide a real-time "feedback loop" for informing on-going efforts.

At the same time, it is critical that the science education community document and learn now from ongoing implementation efforts in ways that can inform future standards, and leverage new insights from research. For example, in the decade since the NGSS were released, there has been considerable research on learning and how it can develop across time for some aspects of the practices and crosscutting concepts. An updated version of the progression tables provided in the NGSS appendices that reflects such research, and also the experience of teachers as students experience learning based on these standards would be valuable.

We might also, as a community, explore how small improvements to the *Framework* and NGSS could be made now. There is substantial room for small scale innovations that will provide information about how future standards (or other guidance documents) might be improved especially to address shortcomings of the *Framework* and NGSS. These efforts can begin now and need to include collaboration among researchers, practitioners and policymakers.

The Power of a Common Vision

The *Framework* and NGSS are not "perfect" documents and many legitimate critiques of their structure and content have been raised over the decade since they were released. However, we also have seen how the common vision represented by these documents has advanced the collective work of the K-12 science education community in powerful ways. The documents allow for more robust and meaningful collaboration across states and districts with shared vocabulary and agreement about some fundamental goals for and approaches to K-12 science education. This has allowed teachers and education decision-makers and leaders to share strategies, materials, and lessons learned; and for national organizations to develop a variety of resources and other supports that can be used across the country. In addition, the shared vision is driving improvements in curricula, assessment, and professional development provided by commercial and non-profit vendors with the potential to counteract the outsized influence of large states – such as California, New York, Texas and Florida – to drive curricular content due to their sheer market size.

While we are still in the midst of implementation, we have made tremendous progress in the last decade. The *Framework* and NGSS provide a vision for science teaching and learning that is consistent with how students learn. Increasing numbers of students are experiencing science in more engaging and meaningful ways. Teachers are learning more effective ways to teach science as professional learning opportunities aligned to the *Framework* and NGSS slowly spread across the systems.

In many ways, the *Framework* and the NGSS were innovative and groundbreaking in terms of their expectations and structure. It is our belief that teachers want to teach what is best for their students. The challenge is in creating the supports across multiple levels of the K-12 system that are needed to help them get there. As we have noted throughout this paper, the *Framework* and the NGSS alone cannot and will not make the change in our science education that is needed. They are certainly a fulcrum for change, but they cannot be the lever of change. There are many components and hands that make up that lever.

The need for understanding and innovating in science, engineering and technology has never been greater. The issues of hunger, clean water, energy and climate change are impacting every living being and knowing the science, reviewing the evidence, building on the knowledge of others, and confirming results are ways to combat these issues. Today's students must have a robust, engaging, and progressive education in scientific and engineering practices, crosscutting concepts and disciplinary core ideas to help them thrive and be productive world citizens. Since most students will end their formal study of science in high school, we must have a K-12 curriculum built from the knowledge of research and practice embodied in the *Framework* and NGSS for the next ten years.

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APPENDICES

Appendix A

Framework Committee Membership, Design Team Membership, and Staff

NOTE: Affiliations and positions of all individuals are those at the time of participating in the development of the *Framework for K-12 Science Education*

Committee members

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Appendix B

Detailed Timeline of the Development of the Framework

Date	Activity
December, 2009	Finalize Framework committee of eighteen members – 9 members of the National Academy of Sciences and the National Academy of Engineering; 9 experts in education, education research and education policy.
January 28 & 29, 2010: First committee meeting	The committee met in both open (public) and closed (committee only) sessions. Open sessions provided opportunities for the committee to discuss the National Science Education Standards, the AAAS Benchmarks, the 2009 NAEP Science Framework, the redesign of the AP sciences program, and pertinent National Academies publications with their authors.
February, 2010	Based on committee direction, staff gathered additional input and worked with the design teams as they progressed on their assignments. During February, work to design a public feedback process began. For this process, relevant groups were identified and key individuals within these groups were contacted for the purposes of informing them of the *Framework* process and to gain their support in organizing sessions providing feedback. These groups included CSSS, NSTA, discipline-focused science teaching professional associations and other stakeholder groups. National Academies staff shared the timing of the comment period, offered suggestions of how to solicit feedback from members of the organizations and offered a template for providing feedback.
March 4-6, 2010: Second committee meeting	The open sessions that were held focused on research on learning progressions in science. Committee members, design teams and National Academies staff continued with drafting the report. During March, major communications efforts were accomplished through well attended sessions at the CSSS and NSTA annual conferences.
April 22 & 23, 2010: Third committee meeting	the open sessions focused on national and international perspectives on standards with a presentation on an international benchmarking study that Achieve had underway and a panel on models of state science standards. A panel discussion on equity, diversity and science education standards was also held in open session. Work continued on designing the public feedback process with the identification of additional organizations from which to solicit input.
May 2010	Leads of the design teams and several committee members with particular content expertise met over three days to forge their work into a format with similar features and grain size. This was sent out to the committee along with other drafted chapters for their

	feedback and suggestions for revision. Plans for the release of a draft *Framework* were finalized including design of a web-based questionnaire and a format for discussion groups. At the May BOSE meeting, information about the committee and its work on the *Framework* was presented to and discussed with staff members from key Congressional committees, the Office of Science and Technology Policy, the National Science Foundation, and the U.S. Department of Education.
June 17 & 18, 2010: Fourth committee meeting	The focus of this meeting was to finalize the draft for public release and was held entirely in closed session.
July 12, 2010 through August 12, 2010: Public review	Draft of a portion of the Framework released for public input. Feedback obtained through an on-line survey, focus groups and letters from professional societies and other organizations.
August, 2010	Staff analyzes the more than 2000 individual online responses and the additional feedback provided by all of the discussion groups, letters from organizations, and individual experts. The staff and committee chair reviewed this input, developed summaries identifying the major issues raised, and outlined possible revisions.
September 2010: Fifth committee meeting	This meeting was held largely closed session to allow the committee to dig deeply into feedback and possible revisions. There was an open session to bring in some fresh thinking on the research and development plan that the committee was developing for inclusion in the final report (which has not been released as part of the public draft).
October 27 & 28, 2010 Sixth committee meeting	This meeting was held entirely in closed session as the committee continued to work on organizational and content issues in the draft Framework.
November 2010 through January 2011	Continued refinement of the draft Framework in preparation for expert review. This included a professional edit for clarity of language.
February 2011 through May 2011	Framework undergoing expert review by 21 experts whose expertise reflected that of the original study committee
June 2011	Framework revised in response to expert review
July 19, 2011	Framework publicly released

Appendix C

Next Generation Science Standards Lead States, Writing Team and Staff

NOTE: Affiliations and positions of all individuals are those at the time of participating in the development of the *Next Generation Science Standards*

Lead States

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Arkansas

California

Delaware

Georgia

Illinois

Iowa

Kansas

Kentucky

Maine

Maryland

Massachusetts

Michigan

Minnesota

Montana

New Jersey

New York

North Carolina

Ohio

Oregon

Rhode Island

South Dakota

Tennessee

Vermont

Washington

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