

Important Developments in STEM Education in the United States: Next Generation Science Standards and Classroom Representations of Localized Scientific Activity

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Abstract

This paper examines important recent developments in STEM education, especially related to science education in the United States (U.S.). This examination begins with an abbreviated introduction of the newest science standards documents in the U.S., with a specific focus on the structure and main priorities of these documents. This is followed by an explanation of why priority in the standards is given to teachers engaging students in science and engineering practices to use disciplinary scientific ideas in explaining phenomena and solving problems. Finally, attention is briefly given to how these standards documents hold promise for acting as leverage points within the complex U.S. educational system for positively influencing the disconcerting issues consistently reported in national studies of U.S. classrooms.

Keywords: science education; standards

Large-scale studies of United States (U.S.) classrooms, arguably the most important part of the complex educational system, have consistently revealed problematic issues related to the experiences of students in science. Examples of these disconcerting issues include: lack of intellectual engagement, concerns for access to some students, curricular activities in place of adequate sense-making, and a failure to take students' prior knowledge into account or seek evidence-based explanations (Banilower, Smith, Weiss, & Pasley, 2006; Horizon Research International, 2003; Weiss, Banilower, McMahon, & Smith, 2001).

One factor, among many, which influences both U.S. schools and schools internationally are national standards documents. These documents are often enacted with the ambitious intentions of changing complex national educational systems. While complex systems are influenced by the cumulative milieu of pressures placed on them, there is recognition that certain systemic features, or leverage points, offer more potential for accomplishing desired changes compared to others, especially when consideration is given to the implementation of leverage points across multiple levels (e.g., policy makers, administrators, teachers) within complex systems. In the U.S., while not explicitly articulated, there is some consensus that the standards, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and the *Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013), have the potential to serve as leverage points to positively influence the disconcerting issues within science classrooms consistently reported in the U.S.

The optimism surrounding the U.S. standards documents lies in multiple features surrounding their implementation and content. Among features related to implementation is the recognition that these standards must permeate the educational system in order for their visions to be realized. This means that plans for implementing these standards must include consideration of how the standards will guide curriculum, instruction, teacher preparation and professional development, and student assessment (NRC, 2012). The reasoning behind these considerations is that "what ultimately happens in a classroom is

significantly affected by decision making distributed across the levels and multiple channels of influence” (p. 243) in complex educational systems. In the development of the standards documents, consideration and guidance are offered for how the multiple levels within the system can cohere such that the system components work together to support the new vision for science teaching and learning. As an example, when thinking about curriculum, there is a recognition that teachers, curriculum coordinators (school & district level), state agencies, curriculum development organizations, textbook publishers, and curriculum publishers must work in concert to produce instructional materials, textbooks, computer and media-based materials that are coherent with the new visions for science teaching and learning.

Beyond the considerations around implementation, optimism also lies in the rationale grounding the content of the standards documents. Relying on research in science studies that portray how scientists go about their day-to-day disciplinary work (e.g., Geire, 1999; Knorr Cetina, 1999) and research in science education related to how teachers can more authentically represent scientific activity for students (Lehrer & Schauble, 2006; Manz, 2015), the standards documents prioritize a more integrated notion of science teaching and learning. This prioritization aims to support learning through student engagement in approximations of scientific activity in science classrooms across K-12. This is evident as the standards’ emphasis “that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined” (NRC, 2012, p. 218).

Reiser (2013) explains that the vision of the standards documents “requires a dramatic departure from approaches to teaching and learning science occurring today in most [U.S.] science classrooms K-12” (p. 2). This article provides an introduction to these standards documents, but first some history related to their development is shared.

The Newest Standards Documents in the U.S.

In 2007 and 2008 the National Research Council (NRC) released two important documents, *Taking Science to School: Learning and Teaching Science in Grades K-8* (NRC, 2007) and *Ready, Set, Science!* (NRC, 2008). *Taking Science to School* represented a comprehensive synthesis of research about teaching and learning science from kindergarten through 8th grade (K-8). Relatedly, *Ready, Set, Science!* translated the latest educational research of *Taking Science to School: Learning and Teaching Science in Grades K-8* into a volume for K-8 practitioners. *Ready, Set, Science!* offered practical and accessible guidance to practitioners for translating research into practice in K-8 classrooms. Taken together, these NRC documents began the reconceptualization of science teaching and learning which formed the foundation of the *NGSS*. This reconceptualization can be seen in the ‘practices’ of science and engineering which were foregrounded in the place of what had, up to this point, overwhelmingly been referred to as inquiry:

Why not use the term “inquiry” instead? Science as practice involves doing something and learning something in such a way that the doing and the learning cannot really be separated. Thus, “practice,” . . . refers to doing something repeatedly in order to become proficient . . . learning something so thoroughly that it becomes second nature . . . using one’s knowledge to meet an objective (NRC, 2008, p. 34).

Collectively, these two documents began the task of reframing science teaching and learning, a task that was subsequently taken up in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [subsequently called the *Framework*] (NRC, 2012).

A Framework for K-12 Science Education

The *Framework* was seen as the initial step in developing the *Next Generation Science Standards (NGSS)* (NGSS Lead States, 2013). Among other key distinguishing features, the *Framework* was grounded in a) contemporary research on teaching and learning, b) epistemic and conceptual foundations from previous standards documents (AAAS, 1993; NRC, 1996), and c) identified science that all K-12 students should know. The writing committee for the *Framework* was made up of nationally recognized scientists, cognitive scientists, science education researchers, and standards policy experts. One round of public comment and revision was made to the *Framework* before it was finalized in 2012. The *Framework* includes the comprehensive rationale that guided the development process, including the guiding assumptions and disciplinary boundaries within which the authors worked. As an example, social and behavioral sciences are not fully addressed beyond ways in which they may manifest themselves in the natural sciences. The *Framework* introduces three dimensions seen as central to science learning: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs). Further and most importantly, the *Framework* emphasizes the importance of students engaging in the nexus of all three-dimensions in what is characterized as three-dimensional learning to support students' deeper understanding and an appreciation of the world around them. Put more succinctly, in three-dimensional learning, students engage in SEPs to use DCIs and CCCs to explain phenomena or solve problems.

In considering science and engineering practices, eight SEPs are identified which together represent the intellectual tools, or ways, in which scientists and students work at knowing or making stronger knowledge claims: (1) asking questions (for science) and defining problems (for engineering); (2) developing and using models; (3) planning and carrying out investigations; (4) analyzing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations (for science) and designing solutions (for engineering); (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information. As mentioned already, the focus on practices is not inconsequential. Beyond the distinction made in *Ready Set Science!* (NRC, 2008) between inquiry and practices, Ford (2015) argues, from the work of philosophers (e.g., Rouse, 2007), that the benefit of using practices in the *NGSS* to describe science foregrounds what is most important for students to understand related to the epistemic privilege afforded to science. Specifically, this is the idea that "scientific practice is based not on rules, but on processes of perpetual evaluation and critique that support progress in explaining nature" (Ford, 2015, p. 3). The science and engineering practices identified in the *NGSS* are artifacts of the regularities of these processes that represent candidate resources for developing and critiquing explanations to make progress at knowing.

The DCIs are the core ideas of the disciplines and are organized into four domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology and applications of science. The DCIs are organized learning progressions grounded in the notion that learning is a developmental progression and that learning in the natural sciences and engineering should become increasingly sophisticated as students move from earlier grades to later grades (i.e., K-12). The CCCs are concepts that are applicable across all domains of science. The seven CCCs are: (a) patterns, similarity, and diversity; (b) cause and effect; (c) scale, proportion and quantity; (d) systems and system models; (e) energy and matter; (f) structure and function; and (g) stability and change. The CCCs are conceptualized as "thinking tools or resources" useful across scientific disciplines. Since these are applicable across disciplines, the CCCs are seen as helpful in supporting the coherent development of students' science-informed views of the world.

Beyond identifying the SEPs, DCIs, and CCCs, the *Framework* provides in-depth discussion and description to elucidate the importance and specifics of what students should know and be able to do. As an example, comprehensive descriptions of the important features of the DCIs (e.g., biological evolution) or SEPs (e.g., students developing and using models) are explicated to support teachers in helping to discern what aspects of these ideas and tools are important to foreground for learners. In addition to the focus on three-dimensions of science learning, attention is also given to important considerations that need to be taken into account in realizing the vision of the *Framework*. These include considering, (a) how the three dimensions for science learning can be integrated; (b) how implementation will proceed related to curriculum, instruction, teacher development, and assessment; (c) issues related to equity and diversity in science and engineering education; (d) guidance for *NGSS* standards developers based on the *Framework*; and (e) research and development to inform future K-12 science education standards.

Next Generation Science Standards

Based on the guidance provided in the *Framework*, a writing team with members from collaborating states across the U.S., other stakeholders in science, science education, higher education, and industry completed the first draft of *NGSS* during the summer of 2011. The document went through two rounds of revisions based on feedback from two periods of public comment before it was finalized in 2013. **Given how instrumental the *Framework* was for guiding the development and providing the rationale for what is included in the *NGSS*, it is important that it serve as a compendium document used in concert with the *NGSS*.**

The *NGSS* does not identify curriculum; instead it outlines specific student performance expectations that “describe activities and outcomes that students are expected to achieve in order to demonstrate their ability to understand and apply the knowledge described in the disciplinary core ideas” (NRC, 2012, p. 218). These performance expectations are written such that each expectation partners a SEP, DCI, and CCC and includes clarification statements and assessment boundaries. The following is an example from high school physical science:

Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. [*Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.*] [*Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.*]

In this example, “Develop a model” is the SEP *developing and using models*, “release or absorption of energy” is the CCC *energy and matter*, and “chemical reaction system depends upon the change in total bond energy” is the DCI *structure and properties of matter and chemical reactions*. Grade-band (e.g., K-5; 6-8; 9-12) appropriate performance expectations are written for each DCI, SEP, and CCC such that students’ demonstrated facility in accomplishing performance expectations at each grade-band provide the foundational understandings and abilities necessary for more sophisticated performances at subsequent grade-bands.

Cumulatively, the *Framework* and the *NGSS* provide a rationale and guidance for learning across K-12, however they “do not predetermine how the three [SEPs, DCIs, CCCs] are linked in curriculum, units, or lessons”. Instead, the writers suggest “additional work will be needed to create coherent instructional programs that help students achieve these

standards" (NGSS Lead States, 2013, Appendix A, p. 2). Given this, science education researchers have begun to consider various theoretical perspectives that might be useful in supporting teachers and science educators in thinking about, and orienting toward, their work such that student experiences are more authentic to the discipline and equitably framed for access to all learners. In this, priority is given to engaging all students in classroom activity in ways that not only develops their understandings of the core conceptual ideas of each scientific discipline, but also offers all students access, insight, and facility into how these ideas are developed and refined and, as importantly, how the ideas are applied in explaining the world or addressing problems of societal concern.

Conclusion and Implications

The following, in *italics*, is the most important proposition of this article:

The U.S. standards documents (i.e., NRC, 2012 & NGSS Lead States, 2013) have the potential to serve as a leverage point to positively influence the disconcerting issues within science classrooms that are consistently reported in national studies of U.S. classrooms.

Lack of intellectual engagement, concerns for access to some students, curricular activities in place of adequate sense-making, failure to take students' prior knowledge into account or seek evidence-based explanations are, among others, the disconcerting issues that have consistently been documented in science classrooms (Banilower, Smith, Weiss, & Pasley, 2006; Horizon Research International, 2003; Weiss, Banilower, McMahon, & Smith, 2001). However, because of the consideration the standards documents give to implementation across the levels and multiple channels of influence within the complex U.S. educational system, and the rationale grounding their content, they are seen as a leverage point around which progress can be made to address these problems, particularly since the standards documents are grounded in both science studies research and contemporary research on teaching and learning. Additionally and importantly, because of the widespread adoption of these standards by several of the 50 U.S. states, either through state adoption of the NGSS (e.g., Connecticut) or state commitment to the *Framework* (e.g., Utah), optimism abounds about these documents in ways that have not been found previously when historically all 50 U.S. states developed their own state standards documents independently in ways that led to disparate priorities and consequently limited collaborative opportunities across states. Given this, it is expected that a commitment to collective collaborative efforts across U.S. states and regions around a common set of standards documents grounded in the most recent research will ultimately lead to effective synergistic efforts to develop teacher professional learning opportunities, curriculum resources, curriculum guides, assessments, and structures to support effective implementation of these new standards documents.



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