STEM Smart Brief

STEM Smart: Lessons Learned From Successful Schools

Teaching and Learning Under the Next Generation Science Standards

THE PROBLEM

The Next Generation Science Standards (NGSS) represent both a consolidation of and a departure from earlier efforts to delineate fundamental K–12 science knowledge. On the one hand, the *Framework for K–12 Science Education*—the NGSS's parent document—openly cites the past standards on which it builds, including the American Association for the Advancement of Science's *Benchmarks for Science Literacy* (1993) and the National Research Council's *National Science Education Standards* (1996).[1] On the other hand, the *Framework*, in its emphasis on intensive year-over-year development of a limited number of key science concepts and ideas, sets forth a distinctive vision: its three-dimensional model—composed of scientific and engineering practices, crosscutting concepts, and disciplinary core ideas—moves beyond the generalized terms *hands-on* and *inquiry* to lay the foundation for a clearer, more granular focus on what actually makes up good teaching and learning in the science classroom.

As of this writing, 16 states and the District of Columbia have formally adopted the NGSS since their release in April 2013, and individual districts have been aligning their science lessons with the standards even in many non-adopting states.[2] At the National Science Teachers Association annual meeting in March 2015, more than 100 groups of educators from 34 states attended a series of workshop sessions focused on the NGSS; only 9 of the states represented had adopted the standards.[3] Although the NRC's recent *Guide to Implementing the Next Generation Science Standards* cautions against rushing the process and expecting immediate improvements,[4] early results from the implementation work already underway will inevitably shape and define how the standards are applied in the near future. It is also vital that initial efforts to carry out the NGSS sustain and quickly build upon the momentum and enthusiasm they have generated. What follows is an overview—and by no means a comprehensive one—of several NGSS-aligned projects in the areas of curriculum, instruction, assessment, and professional development.

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THE RESEARCH AND PROMISING PRACTICES

Curriculum

As is noted in the *Framework*, the NGSS does not prescribe specific curriculum materials nor require a particular scope and sequence in lesson planning.[5] Furthermore, the *Guide* advises teachers and district leaders to avoid discarding old curricula wholesale and to be skeptical of inflated assertions from the promoters of new curricula: "It is likely, as has occurred with Common Core State Standards, that many of the most rapidly available textbooks and related resources claiming alignment to the NGSS will be superficially rather than deeply aligned and will not have been substantially redesigned."[6] The NGSS network states and partners have, however, provided a suite of tools on the national NGSS website with which to select, evaluate, and organize learning materials, one of which—the EQuIP rubric—will be familiar to many teachers because of earlier EQuIP rubrics created for use with the Common Core math and ELA standards.

Intended as a starting point for collaborative curriculum review and revision processes as well as a suggestion vehicle for curriculum developers, the EQuIP (Educators Evaluating the Quality of Instructional Products) document lists key NGSS-compliant criteria in the areas of standards alignment, instructional support, and student progress monitoring.[7] In early results from a set of case studies of middle school science curricula—IQWST (Investigating and Questioning Our World Through Science & Technology) and THSB (Toward High School Biology)—the NGSS EQuIP rubric was found to be particularly useful in focusing reviewer attention on three features: the role of phenomena, or the occurrences that students will observe and reason about; the extent to which the three dimensions work together; and coherence as considered from the point of view of the student as well as the discipline.[8] The lack of clarity around the latter element, in fact, has been described as a common weakness of standard K–12 science labs: "While there may be a clear logic from the developer's perspective as to how lessons fit together, it is often the case that the logic is not apparent to students…. Truly engaging in three-dimensional learning means students are engaging in the practices to figure out something or to solve a problem, and not simply because they were told to explain the patterns in a dataset or to model a process they are shown."[9]

Another middle school curriculum—Project-Based Inquiry Science (PBIS)—is the subject of a two-year efficacy study by SRI International, the first to attempt to assess student learning with NGSS-aligned outcome measures.[10] Assessments created by the researchers were administered to students both before and after the unit, and teachers in both the treatment and comparison groups received training in the *Framework*'s approach to practice-oriented learning. Teachers were also required to keep instructional logs of their implementation activities.[11] Results from the first year of the randomized controlled trial showed statistically significant gains on two post-unit tests for students in PBIS classrooms compared with students who had been taught from a textbook, and the gains were consistent across gender and racial groups. It's also worth noting that the teachers who implemented the experimental curriculum had never used it before, and they all showed greater willingness and ability to engage students in NGSS-aligned science practices as the study progressed.[12]

Interactions: Student Understanding of Intermolecular Forces

The Concord Consortium, the University of Michigan, and the Create for STEM Institute at Michigan State University are collaborating on the development of *Interactions*, a four-unit, semester-long high school curriculum focused on the forces that govern the interactions of atoms and molecules. Explicitly built around physical science performance expectations delineated in the NGSS, the curriculum employs computer simulations to help students visualize submicroscopic phenomena. Project investigators are also creating accompanying student learning assessments and educative materials for teachers.[13] Field tests have been conducted in California and Michigan, and the curriculum is currently undergoing revision. Several videos of *Interactions* being taught in the classroom can be found on the website of the National Science Teachers Association at http://ngss.nsta.org/ngss-videos.aspx, under "In the *NGSS* Classroom with Teacher Kristin Mayer."

Instruction

At the heart of what students will actually do in the NGSS-aligned classroom are the eight science and engineering practices. The question of how best to enact the practices represents a kind of frontier in K–12 education research: we already know a great deal about what works in the areas of curriculum, assessment, and professional development, but the study of how to effectively engage students in authentic science and engineering processes, and how to do so in ways that build complexity in student understanding year over year from kindergarten onward, is comparatively uncharted ground. In their analysis of the NGSS practice "planning and carrying out investigations" into five components, Duschl and Bybee argue for a refocus on science learning as a set of "struggle-type experiences"[14] without predetermined results, an iterative process in which students test and refine explanations of phenomena through observation and discussion: "If students only encounter preplanned confirmatory investigations following step-by-step procedures that ensure the desired outcome occurs, then important and relevant thinking and designing practices and struggles that are part of doing science and engineering get stripped away."[15] In a similar vein, Reiser, Berland, and Kenyon highlight four examples of classroom dialogue to illustrate how students can make sense of phenomena through a building of consensus in response to meaningful questions, with the teacher guiding and mediating, rather than controlling, the exchange of ideas.[16]

Even before the appearance of the NGSS, the K–12 education community had begun to take interest in model-based inquiry as a rich and flexible base strategy for the teaching of inquiry- or project-centered science. The inclusion of model development and use among the eight NGSS science and engineering practices has given impetus to efforts to both formalize approaches to and measure outcomes of lessons centered on student creation of scientific models. As Passmore et al. observe in a recent overview, "If it is relatively uncontested that models form the basis of most reasoning in science, then it seems obvious that they should form the basis of reasoning in science classrooms…. The presence of and attention to models as used by cognitive agents *for* specific purposes both focuses and organizes the cognitive activity that is primarily aimed at sense-making."[17] Teaching students across all grade levels how to develop and use models in authentic contexts is, of course, an intricate and challenging task: a recent study of third graders' performance on a model-building exercise found that the students gained skill in depicting *sequences* of phenomena but had trouble with representing complete *systems*.[18] The fifth graders in an earlier trial, on the other hand, learned over successive revisions to incorporate causal elements (including explanations of nonvisible events, which had been an obstacle for the younger learners), to employ model components to explain new phenomena, and to evaluate models for communicative strengths and weaknesses.[19] Careful calibration of learning progressions and appropriate scaffolding will be one of the keys to expanding use of model-based approaches.

Modeling Scientific Practice in High School Biology

Researchers from the University of California at Davis are designing a Web-based resource that will combine instructional materials and teacher networking and educative tools to support the teaching of high school biology. Based on results from an earlier four-year project focused on professional development, the current initiative aims to strengthen teacher understanding of model-based inquiry and to extend its use in the classroom. Both curriculum and professional development components are being piloted in classrooms and will eventually be disseminated through a website that includes videos of exemplary implementation and chat rooms in which teachers can discuss best practices.[20]

Assessment

The changes to curriculum and instruction brought about by the NGSS will necessitate dramatic changes in assessment. In explaining its call for a completely revamped science assessment system, the *Guide* cites the novel three-dimensional performance expectations that define student progress in the NGSS as well as the interwoven goals of an NGSS-aligned comprehensive assessment program: to support classroom instruction in both formative and summative ways, to monitor science learning at the school and district levels over time, and to oversee quality and equity issues from an administrative perspective.[21] The NRC report *Developing Assessments for the Next Generation Science Standards* urges a "bottom-up" approach to assessment creation, one that begins in the classroom and is first accountable to student learning needs rather than to district or state mandates,[22] The authors further recommend that data obtained for monitoring and oversight purposes by state and local policymakers be generated, at least in part, by classroom-embedded assessments and not on-demand or standardized tests.[23] The report also advocates that the new assessments, at all levels, include performance-based items—"those that require students to construct or supply an answer, produce a product, or perform an activity."[24] Such a system will demand significant time, personnel, and other resources to construct. In a discussion on assessments responsive to the Common Core standards, Darling-Hammond and Adamson describe ways in which time and cost efficiencies can be achieved during the development process, including participation in state consortia; online delivery and computer scoring; and the involvement of teachers in both development and scoring tasks, for stipends if at all possible.[25]

Initiatives aiming to develop NGSS-linked assessments have frequently drawn on the robust modeling and mapping strategies of evidence-based design (EBD). EBD-grounded work has yielded positive interim results from a multiyear effort to design classroom assessments for efficacy evaluations of NGSS-aligned curricula.[26] Although created several years before the NGSS, the online assessment design system PADI (Principled Assessment Designs for Inquiry), which combines tech-based tools with an evidence-centered approach, has been used to produce a variety of assessments for project- and inquiry-based curricula; it has shown particular versatility in contexts demanding application of differentiated instruction and universal design for learning (UDL) principles.[27] And the SimScientists project has generated a wealth of simulation-based assessment products that cover topics across the earth, life, and physical sciences; its most recent NSF-funded study will seek to develop simulation games that can be used as formative assessments in middle schools. Edys Quellmalz of SimScientists has summarized the advantages of the project's approach: "In science, digital technologies can represent dynamic causal, temporal, and spatial phenomena, giving students opportunities to deploy active inquiry practices. The technology-based, next-generation assessments are characterized by rich, complex, authentic contexts; interactive, dynamic responses; individualized feedback and coaching; diagnostic progress reporting; and links to supplemental instructional resources."[28]

Next Generation Science Assessment

Investigators at the Concord Consortium, SRI International, Michigan State University, and the University of Illinois at Chicago are devising NGSS-aligned formative assessments for the physical and life sciences at the middle school level. Delivered through an online portal, the assessment tasks variously engage students in drawing, model building, simulations, and other activities in order to gauge their progress toward meeting key performance expectations. Scoring rubrics and accompanying instructional materials for teachers are also under development. A set of physical science tasks has already been completed, and the first draft of the life science tasks is scheduled for completion in spring 2016. Further information on Next Generation Science Assessment and access to the task portal can be found at http://nextgenscience.wpengine.com.

Professional Development

The *Guide* enumerates six features of quality teacher professional development: (1) focused on subject-matter content over general pedagogical guidance; (2) responsive to the specific nature of teachers' classroom practice, accounting for both grade level and instructional materials; (3) centered on real-life examples of classroom interaction, thus supporting teachers' active engagement and problem-solving skills; (4) conducive of collaborative analysis and discussion, thus enabling teachers to enact the skills NGSS will demand of students; (5) sufficient time and duration, with multiple PD sessions spread over the course of the school year; and (6) school policy and practice apart from teacher learning must align with and promote desired changes.[29] Expanding on the last point, the *Guide* also recommends that administrators and district officers receive formal training on what the NGSS are and what three-dimensional science learning looks like in the classroom.[30] In describing their own efforts to clarify the standards for principals within a curriculum study, one group of researchers observed that early and sustained cooperation is crucial: "Implementing the NGSS will be easier if we think of teachers and leaders as co-learners, instead of demanding compliance to specific indicators of standards that few people understand well."[31]

Two recent professional development initiatives combine technology-enabled case analysis within a study-group format. Science Teachers Learning through Lesson Analysis (STeLLA) asks teachers to examine video segments of classroom interactions through the thematic lenses of Student Thinking (to elicit and support student enunciation of knowledge) and Science Content Storyline (to create a focused and coherent set of instructional goals and activities).[32] Footage from nonparticipant teachers is used at first, and then the group proceeds to analyzing video and student work from their own and one another's classrooms.

STeLLA teachers also receive intensive training in science content and NGSS-relevant practices. Originally developed for upper elementary teachers, the STeLLA program is currently being adapted for use with preservice and first-year elementary as well as high school science teachers. Another study is testing wholesale implementation for all K–6 teachers within a high-needs urban district.[33] While STeLLA predates the NGSS by several years, Next Generation Science Exemplar (NGSX) was explicitly developed in response to the new standards. In facilitator-led groups of about 15 participants, K–12 teachers utilize the NGSX online-learning environment to view clips of teacher–student interactions, respond to discussion prompts, and access background resources and scaffolding tools. Teachers also engage in three-dimensional, practice-centered learning themselves. The NGSX development group has so far produced two pathways, or learning modules: Argumentation, Explanation, and Modeling the Behavior of Matter as well as a Facilitator Pathway that can be used in train-the-trainer contexts to scale up the program. Other pathways are in the pipeline, including a life sciences strand on modeling population interactions and natural selection.[34]

Building Capacity for the NGSS through Networked Improvement Communities

Researchers at the University of Washington are developing a professional development program that uses networked improvement communities (NICs) to intensively train teachers in enacting the NGSS science practices with their students. Teachers meet in teams along with teacher educators, researchers, and administrators to learn about the standards, plan instruction, review student responses, and exchange ideas and resources. Equity is a primary focus of the project: the schools in which the NICs have been tested are primarily low income and highly diverse, with an ELL population of about 20%. First piloted in middle and high schools, the program has expanded to serve five Seattle-area elementary schools as well.[35] Background, tools, and a video gallery on the project's approach to science teaching can be found at http://ambitiousscienceteaching.org.

FINAL WORD

The challenge of implementing the Next Generation Science Standards calls for a coherent, holistic approach led by district and school leaders: no single element of the system—curriculum, instruction, assessment, or professional development—can be considered in isolation from the others. As more NGSS-aligned projects yield results, best practices across all domains will, ideally, find their way into the classroom, even in non-adopting states and districts.

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