J Sci Teacher Educ (2014) 25:211–221
DOI 10.1007/s10972-014-9381-4

NGSS and the Next Generation of Science Teachers

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Published online: 11 March 2014

Abstract This article centers on the *Next Generation Science Standards* (NGSS) and their implications for teacher development, particularly at the undergraduate level. After an introduction to NGSS and the influence of standards in the educational system, the article addresses specific educational shifts—interconnecting science and engineering practices, disciplinary core ideas, crosscutting concepts; recognizing learning progressions; including engineering; addressing the nature of science, coordinating with Common Core State Standards. The article continues with a general discussion of reforming teacher education programs and a concluding discussion of basic competencies and personal qualities of effective science teachers.

Keywords Next Generation Science Standards (NGSS) · Educational shifts · Learning progressions · Three dimensions · Nature of science · Common Core State Standards

Release of the *Next Generation Science Standards* (NGSS) in April 2013 set the stage for educational reforms at the national, state, and local levels. These reforms center on teachers' professional development, school programs, and assessments and accountability. Based on the National Research Council report, *A Framework for K-12 Science Education* (NRC, 2012), the NGSS describes a contemporary vision that has implications for classroom teaching and student learning and thus the professional education of future teachers.

This article begins with a general discussion of standards for science education, their history, influence on the education system, and development of NGSS. The

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latter sections elaborate specific educational shifts based on the NGSS and recommendations for processes to accommodate those educational shifts. The article concludes with a discussion of some personal characteristics of effective teaching. I am referring to characteristics such as the perceptions science teachers have of students and enthusiasm for teaching. Such characteristics are not accommodated by the contemporary vision of NGSS. The personal characteristics are beyond competencies of science content and practices but perceived as important by students and many science teacher educators.

Science Education Standards

Although the history of science education reveals numerous committee reports, yearbooks, and other publications that served as "standards," one can reasonably argue that it was the late 1980s and early 1990s that brought the term standards into the science education community. *Science for All Americans* (Rutherford & Algren, 1989) provided the basis for *Benchmarks for Science Literacy* (AAAS, 1993) and prepared the United States for *National Science Education Standards* (NRC, 1996). The NGSS present contemporary policies for science education.

The fundamental idea behind science education standards is to describe clear, consistent, and comprehensive science content and abilities. Then, based on the standards, reform essential components of the science education system—programs for school science, teaching practices, and assessments at local, state, and national levels, and, in the case of this article, programs for undergraduate students who plan on being science teachers.

Development of the *Next Generation Science Standards*

Development of NGSS began in 2010 and consisted of a two-step process. The first phase of development was led by the National Academy of Sciences. The National Research Council (NRC), the operational arm of the National Academy of Sciences, developed *A Framework for K-12 Science Education* (NRC, 2012). The *Framework* provided a solid foundation in current science and learning research on the science concepts all K-12 students should know and the science and engineering practices they should be able to do. To develop the *Framework*, the NRC convened a committee of 18 nationally and internationally recognized experts: practicing scientists, including two Nobel laureates; cognitive scientists; science education researchers; and science education standards and policy experts.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) has three parts. The first part presents a vision for science education which includes the guiding assumptions and organization. Part two provides the content for science and engineering education. Finally, part three addresses the means to realize the vision by addressing the integration of content, implementation, equity, and guidance for the NGSS. The *Framework* describes three dimensions for standards: science and engineering practices, crosscutting concepts, and core ideas in science disciplines. The NRC *Framework* provided guidance for developing standards through recommendations designed to ensure fidelity to the *Framework* and serve as direction for the development of standards. For this discussion, the following summarizes the key NRC recommendations for standards development.

The standards should:

- Set rigorous goals for all students.
- Be scientifically accurate.
- Be limited in number.
- Emphasize all three dimensions.
- Include performance expectations that integrate the three dimensions.
- Be informed by research on learning and teaching.
- Meet the diverse needs of students and states.
- Have potential for a coherent progression across grades and within grades.
- Be explicit about resources, time, and teacher expertise.
- Align with other K-12 subjects, especially the Common Core State Standards.
- Take into account diversity and equity (NRC, 2012, pp. 297–307).

The second phase of the development was a state-led effort managed by Achieve. Twenty-six states pledged their commitment to give serious consideration to adopting NGSS. Each state also committed to create a broad-based team comprising K-12 representatives (including science teachers), scientists and engineers from the business community, employers, and education leaders. These state committees provided feedback on drafts of the standards and were critical partners. The teams also provided updates for key constituents within their states.

The final NGSS document was developed through the collaborative effort of 26 lead states in cooperation with stakeholders in science, science education, higher education, and business and industry. Draft standards underwent multiple reviews, including two publicly released drafts, which provided all interested and involved individuals and groups with an opportunity to inform the proposed content and practices as well as organization of the NGSS. This process resulted in a set of rigorous, high quality K-12 science education standards that passed a final review for fidelity by the NRC. NRC reviewers, using the vision and content of the framework as a baseline, evaluated the consistency of the draft NGSS compared to the framework. The review panel included members of the original NRC committee and other experts who were familiar with the framework and the NGSS. The National Academies Press (NAP) published the final document (NGSS Lead States, 2013).

Understanding the Influence of NGSS on the Educational System

The NGSS represent a significant departure from past approaches to science education. With policies representing a new vision of science education, one should reasonably ask—What changes are implied for states and districts adopting NGSS? How will NGSS affect curriculum, instruction, and assessments? What are the

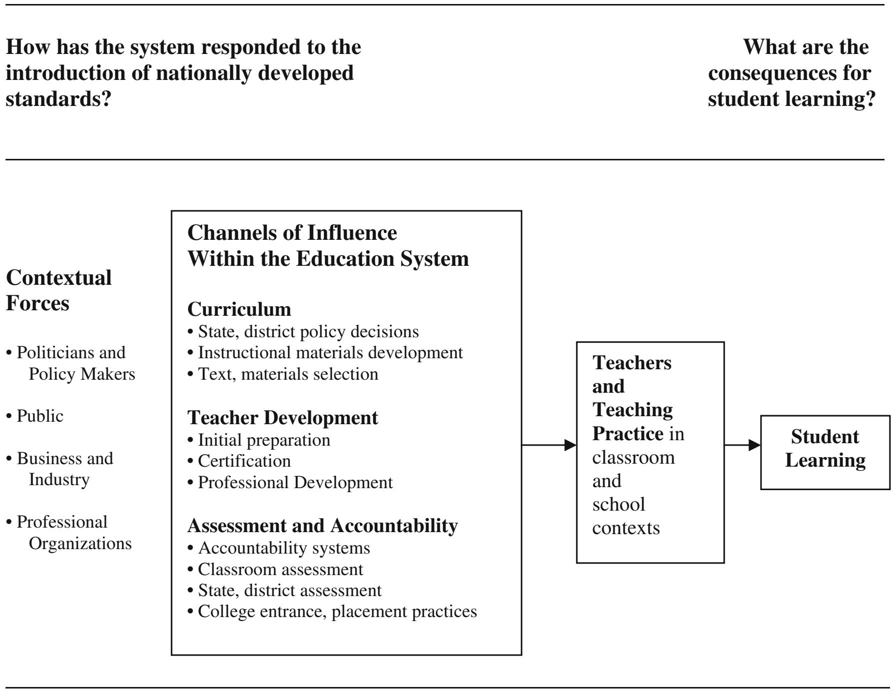

Fig. 1 The influence of standards on the educational system

implications for science teacher education? And, in time, how has NGSS affected students' learning and achievement? It is worth noting that the U.S. education system is a large, complex, and layered system. In that system, one recognizes the form, function, and decisions at national, state, local, and classroom levels of organization. More specifically for this discussion, faculty at colleges and universities make decisions about the experiences, courses, and competencies required to meet graduation and certification requirements of future teachers.

The National Research Council report, *Investigating the Influence of Standards: A Framework for Research in Mathematics, Science, and Technology Education* (NRC, 2002), provides guidance in understanding the channels of influence within the education system and, in this discussion, on the education of science teachers. Figure 1 describes three main routes or "channels" through which reform ideas based on national standards influence various levels of the educational system and eventually classroom teaching, student learning, and achievement. The primary channels through which the NGSS will influence the educational system are: curriculum, teacher development, and assessment and accountability (see Fig. 1).

The perspective summarized in Fig. 1 will help those responsible for the initial preparation and continuing professional development locate their place in the system and recognize that others will have responsibility for curriculum and assessments, for example.

Understanding the Educational Shifts in NGSS

The NGSS presents an opportunity to improve curriculum, teacher development, assessment and accountability, and ultimately student achievement. In order to bring this opportunity to reality, science teacher educators must address educational shifts in NGSS. Although the educational shifts refer to NGSS, in reality, they have direct implications for teacher development. The following description of educational shifts is based on *A Framework for K-12 Science Education* (NRC, 2012) and descriptions in NGSS (NGSS Lead States, 2013) and the Appendices for NGSS. To be accurate, this discussion addresses the shifts closely related to teacher development.

Interconnect Three Dimensions

NGSS standards have three dimensions: (1) disciplinary core ideas, (2) scientific and engineering practices, and (3) crosscutting concepts. Most state and district standards and subsequently science teacher education programs express these dimensions as separate entities, if the three are addressed. The integration of rigorous content and application reflects how science is practiced and implies a science education program that provides deeper experiences with, and understanding of, science concepts and practices. How and where the three dimensions are included in science teacher education presents a challenge. Perhaps the most significant challenge is experiences with the integration of three dimensions as this suggests the need for investigations and simulations.

Recognize Learning Progressions

Science concepts in NGSS build coherently from K-12. The NGSS presents a progression, from grade-band to grade-band, that builds understanding and abilities throughout a students' K-12 science education. This innovation could be addressed in curriculum and instruction courses or in methods of teaching science. In general, it is an issue for state, district, or school programs.

Include Engineering Design

The NGSS includes both science and engineering. Science and engineering practices and crosscutting concepts are designed as an integral component of the standards. Consistently, science teachers express a concern about their lack of understanding engineering, in particular the differences between scientific inquiry and engineering design. While it may be desirable, I do not think there is a need for a course on "introduction to engineering." There is a clear need to complement experiences with the science practices with those of engineering practices, i.e., design. The need to understand engineering may be accommodated with chapters in methods textbooks and experiences in courses on teaching science. Addressing the need to understand engineering in the manner just described places student experiences in the context of science, as intended by the inclusion of engineering in NGSS.

Address Nature of Science

The nature of science was not directly addressed in *A Framework for K-12 Science Education*; however, feedback from the states and public clearly and strongly indicated a need to include an understanding of the scientific enterprise. So, the nature of science is included in NGSS, an addition I strongly support. The basic understandings about the nature of science are expressed in the categories and statements in Tables 1 and 2.

The NGSS appendices elaborate these categories in the form of learning progressions for grade bands K-2, 3–5, 6–8, and high school. The content for the nature of science is stated as part of the practices and crosscutting concepts and presents an educational shift for instructional materials, science teaching, and assessing learning outcomes. In my personal opinion, one shared by many others, teacher education programs should give much more emphasis to the nature of science. A potential downside to the integration of the nature of science is that it adds to an already complex set of standards. I believe the importance of the nature of science offsets this concern. Further, the fact that the NGSS connects the nature of science to the science and engineering practices and crosscutting concepts presents an efficient way to introduce this essential domain in contexts that are fundamental to implementation of the standards.

Coordinate Science with Common Core State Standards for English Language Arts and Mathematics (CCSS)

Implementing the CCSS presents an opportunity to be a part of students' comprehensive education. The NGSS makes connections between the individual standards and components of CCSS. While this may be perceived as an addition, and thus a problem, the coordination of experiences in school science and assessment programs may be appropriately perceived as an opportunity to address three sets of standards. Addressing the CCSS in methods courses seems a reasonable recommendation, one that connects, for example, non-fiction reading and writing

Table 1 Nature of science categories most closely associated with practices

Scientific investigations use a variety of methods
Scientific knowledge is based on empirical evidence
Scientific knowledge is open to revision in light of new evidence
Scientific models, laws, mechanisms, and theories explain natural phenomena

Table 2 Nature of science categories most closely associated with crosscutting concepts

Science is a way of knowing
Scientific knowledge assumes an order and consistency in natural systems
Science is a human endeavor
Science addresses questions about the natural and material world

Table 3 Educational shifts based on NGSS and their implications for science teacher education

From	To	Implications
Learning facts (e.g. parts of the cell)	Explaining natural phenomena (e.g. how cell structures relate to cell functions)	Students develop models and make sense of the natural world by using evidence to develop explanations
Single dimensions of science (e.g. disciplinary core ideas for physical science)	Interconnections of three dimensions of science (e.g. science and engineering practices, crosscutting concepts, disciplinary core ideas)	Students use the practices to gather data and form explanations using crosscutting concepts and disciplinary core ideas
Grade level content (e.g. middle school life science)	Progression of core ideas and practices across K-12 (e.g. coherent horizontal and vertical development of concepts and practices)	Students learn concepts below and above a grade-level
Science as a single discipline (e.g. biology)	Science and Engineering (e.g. practices of engineering design incorporated with science)	Students learn and apply the practices of engineering design
Science as a body of knowledge (e.g. conceptual structure of a discipline)	Science as a way of knowing (e.g. nature of science as an extension of practices and crosscutting concepts)	Students understand the nature of scientific knowledge
Science as a stand-alone discipline (e.g. separate time or course in curriculum)	Science connected with common core (e.g. English language arts and mathematics incorporated with science)	Students' science education program includes experiences that incorporate reading, writing, and mathematics

and mathematics to science and engineering practices in particular and school science programs in general.

One clear implication is the need for science teacher education programs that include assessments. Further, the incredible complexity of the NGSS and educational shifts presents significant challenges for those with responsibilities for educating future science teachers. Table 3 summarizes the educational shifts and briefly describes implications for teacher development.

Reform of Programs for Science Teacher Education

The changes implied by the *Framework for K-12 Science Education* (NRC, 2012) and NGSS (NGSS Lead States, 2013) imply dramatic changes in teacher education programs. This section describes three ways that science teacher educators could approach the reform. These strategies represent a continuum of possibilities aligning the teacher education program with the shifts implied by NGSS. I certainly recognize that teacher educators and departments will approach these changes differently. My intention is to help initiate thinking about the process of adapting science teacher education to accommodate the innovations of NGSS.

Revise Elements of the Current Program

This model involves examining the current program to identify components that can be adapted to accommodate the educational shifts implied by NGSS. This is a "tune up the engine" approach. How can science content courses be adapted? What changes are implied for the teaching methods course? Are there changes that could be incorporated in the educational psychology course? Is there an educational technology course that could be adapted? Where and how can the connections to Common Core be introduced?

This approach is grounded in the realities of the education system, especially at the college and university level. The system is complex, to say the least. Further, the responsible individuals have their ideas about teaching and learning and those ideas do not necessarily align with NGSS. So, small revisions, incremental changes may be the way to begin evolving the program to better meet the needs of students and state requirements.

Replace Components of the Current Program

In this approach, short units based on NGSS would be developed and replace key components of the current program. These short units would provide teacher candidates with intense experiences where the aforementioned essential features of NGSS are applied to their learning. This is an "overhaul and replacement" of some parts of the car. It seems an easy replacement unit could be developed for some or all of the methods course. After all, science teacher educators are often the ones with most knowledge and understanding of NGSS. Could a project-based unit be incorporated in the methods course? Students might design and teach a NGSS-based unit in a field course. It may be possible to incorporate a scientific investigation in a required content course.

The replacement unit approach requires initial work on development of the units and identification of elements of the program that could be replaced and still meet the requirements for graduation, certification, and licensure. If I had to make one recommendation for a replacement unit, it would be to involve undergraduate students in a full investigation that involves a team with the science and engineering practices, crosscutting concepts, and disciplinary core ideas and progresses from an initial question about natural phenomena to the formulation of a model, collection and analysis of data, discourse about the evidence and proposed explanation, and communication of the explanation. Such an experience should provide opportunities to learn about science with most, if not all, of the educational shifts of NGSS. I also am certain that the experience would be very meaningful for future teachers.

Reform Science Teacher Program

This approach assumes a complete reform of the current program. One would begin with NGSS and design a program that would provide undergraduates opportunities to learn the science content and practices in contexts that would be aligned with their future work as teachers. This would be a new and innovative program. The analogy here is to buying a new car. One considers the needs, cost, and benefits of the model and proceeds with an appropriate purchase.

Reforming science teacher education should begin with the innovations of NGSS; for example, the integration of science and engineering practices and crosscutting concepts. The integration centers on the need for activities and investigations as the context for integration. The *National Science Education Standards* (NRC, 1996) included similar components, but they were not stated as performance expectations. So, content, inquiry, and unifying concepts could be taught separately. The NGSS use of performance expectations requires an integrated approach to curriculum, instruction, and assessment. This is quite different from an approach to teacher education structured on the idea of "how to teach A" and "how to teach B."

I acknowledge that this approach would be relatively rare. It also would be very exciting. For states that adopt the NGSS (or variations) as the state standards, reforming science teacher education programs would be a direct implication of the adoption. It would be an opportunity to think about the NGSS and the unique needs of elementary, middle, and high school science teachers. Then, design a program for them. Some components of the program might include scientific investigations, an introduction to engineering design, an in-depth study of a scientific breakthrough, study of NGSS, applications in classrooms, and design of a NGSS-based unit for student teaching.

Concluding Discussion

The initial preparation of classroom teachers shapes their knowledge, abilities, and dispositions. This may seem obvious. But, the NGSS (NGSS Lead States, 2013) presents new challenges for those preparing science teachers.

Basic Competencies

Knowledge of the life, Earth, and physical sciences continues to be a requirement of effective science teaching. The disciplinary core ideas described in the *Framework* and *NGSS* is similar to past standards, for example, NSES. To these fundamental ideas, the NGSS adds crosscutting concepts and the nature of science.

Relative to basic abilities, the NGSS places a new emphasis on science and engineering practices (SEP). These practices are both knowledge outcomes and cognitive abilities for students. They should, for example, know that scientists ask questions about nature, use models, and require evidence as the basis for explanations. In addition, students should develop the cognitive abilities to formulate models, apply mathematics, construct arguments based on evidence, and communicate the results of investigations. In order to achieve these aims, science teachers should develop basic competencies for the knowledge and practices.

The NGSS performance expectations for students require that the three dimensions be integrated. This requirement is very significant and requires basic competencies of science content, practices, and their pedagogical implications. Relative to the latter, these are new and unique methods, e.g., use of models using evidence as the basis for arguments, and incorporating engineering design, that should be considered basic competencies for science teachers beginning their career.

For reasons that are obvious, competence in subject matter knowledge and pedagogical methods and strategies are prominent in reference to preparation of teachers in general (see, e.g., Wilson, Floden, & Ferrini-Mundy, 2001; Allen, 2003) and science teachers in particular (see, e.g., National Research Council, 2001). Yet, there is more that contributes to effective teaching. Most agree that teaching matters and that basic competencies are essential. So, what other factors make a difference in a teacher's effectiveness? I propose there are personal qualities that make a difference.

Personal Qualities

Why is it that some teachers are knowledgeable and use different teaching strategies; yet, they are not as effective as they should be? Let me state this in a positive way. What is the constellation of qualities that contributes to effective science teaching? Personal qualities should be a part of the constellation. This said, the aforementioned reports (Wilson et al., 2001; Allen, 2003; NRC, 2001) do not include personal qualities. In fact, many discussions of teacher development do not include personal qualities. One outstanding exception is the National Board for Professional Teaching Standards (NBPTS) which includes "Teachers are committed to students and their learning."

Historically, research by Combs (1969) provided some insights about personal qualities of effective teachers. Confirming the prior discussion, good teachers are well informed and use appropriate methods. They also have accurate perceptions about people (i.e., students) and their behavior. They have a clear and consistent frame of reference about students and those perceptions guide their interactions with students. In addition, they recognize that one's purposes, whether as teacher or student, is a major contributing factor in learning. In contemporary discussion, this is referred to as "sense making" by the student.

I can be a little more specific about personal qualities and their relationship to effective science teaching. In the late 1970s, I became interested in the characteristics of good science teaching. To be specific, using a Q-sort, I investigated students', teachers', academics', and scientists' perceptions of the ideal science teacher (Bybee, 1973, 1975, 1978). At the time, I was teaching a course on science methods and was author of a methods textbook. Like many teacher educators, I held the view that good science teaching was based on two things. First, good science teaching required a solid understanding of science in general and one's discipline in particular. Second, it required knowledge of and ability to use a variety of different teaching strategies. Results of my investigations confirmed the importance of these competencies. However, I was surprised by other results. Most samples rated personal qualities higher than knowledge of science and pedagogy. Indeed, adequacy of personal relations with students and enthusiasm for science teaching consistently rated higher.

Because this is an article about NGSS, I present the point about personal qualities as a reminder that effective science teaching is more than the level of knowledge about science and engineering practices, crosscutting concepts, and disciplinary core ideas. The next generation of science teacher educators should attend to the entire constellation of competencies and qualities that contribute to effective teaching and learning.

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