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GUEST EDITORIAL

Understanding the Big Picture for Science Teacher Education: The 2018 NSSME+

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In 2012, the National Research Council (2012) published *A Framework for Science Education: Practices, Crosscutting Concepts, and Core Ideas* (the Framework). The Framework was the basis for the *Next Generation Science Standards: For States, By States* (NGSS Lead States, 2013), which, to date, have been adopted or adapted by 39 states and the District of Columbia. These documents lay out an ambitious vision for science instruction, central to which is students learning science by engaging in the practices of science (i.e., doing science). Making this vision a reality is no small task and requires reexamining several aspects of the science education system, including how teachers are prepared, inducted into the profession, and supported throughout their career. Although teachers play a crucial role in ensuring that all students have high-quality science learning opportunities, other elements of the education system also factor into students' school experiences.

Although there is a tremendous amount of research about science education in general, and more recently studies focused on implementation of the NGSS, few provide insights at a national scale. Since 1977, the National Survey of Science and Mathematics Education (NSSME) has periodically collected data about the status of science and mathematics education in the United States, providing opportunities to examine the influences of new initiatives and policy shifts such as the NGSS. In 2018, Horizon Research, Inc., conducted the sixth iteration of the study, titled the 2018 NSSME+ (the plus symbol reflects the inclusion of computer science education in the study for the first time).[1] Results of the study provide an opportunity to examine where the nation is in terms of providing all students with the type of science education envisioned by the Framework, as well as reflect on steps that might be taken to move us closer to that vision.

The 2018 NSSME+ (Banilower et al., 2018) collected an enormous amount of data from schools about policies and practices related to science teaching and from teachers, including demographic information, their preparation for teaching and feelings of preparedness to teach science and engineering, professional learning opportunities, instructional practices, and the influences of a variety of factors on instruction. Selecting an appropriate subset for this space was quite challenging, and rather than try to paint

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uste.

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a complete picture of all the study data, I chose to select data most relevant to understanding the state of K–12 science education in the United States.[2] First, I share insights from the study about the extent to which science instruction currently reflects what is envisioned by the Framework. Then, I delve into factors that might help explain why instruction looks the way it does, including data on how teachers are prepared and supported to teach science. Finally, I share some thoughts about the implications of these data, particularly in terms of preservice preparation and in-service professional growth, for achieving the vision laid out in the Framework.

To what extent does science instruction reflect the vision in the Framework?

The 2018 NSSME+ included questions about teachers' objectives for science instruction and their instructional practices. It also asked elementary teachers of self-contained classes (i.e., they are responsible for teaching all core subjects) how much time they devote to science, mathematics, reading and language arts, and social studies. As can be seen in Figure 1, across all elementary classes, students receive, on average, only 20 min of science instruction per day. Students in the primary grades (i.e., K–2) receive, on average, 17 min per day of science instruction, and those in the intermediate grades (i.e., 3–5, and sixth-grade self-contained classes) 23 min per day.

For classes at all grade levels, the 2018 NSSME+ included questions about teachers' objectives for science instruction and their instructional practices. On the positive side, three quarters of middle and high school classes and just under half of elementary classes have a heavy emphasis on students understanding science concepts (see Table 1). However, fewer than half of secondary classes, and only a quarter of elementary classes, have a primary goal of students learning how to do science (i.e., learn the practices of science). In addition,

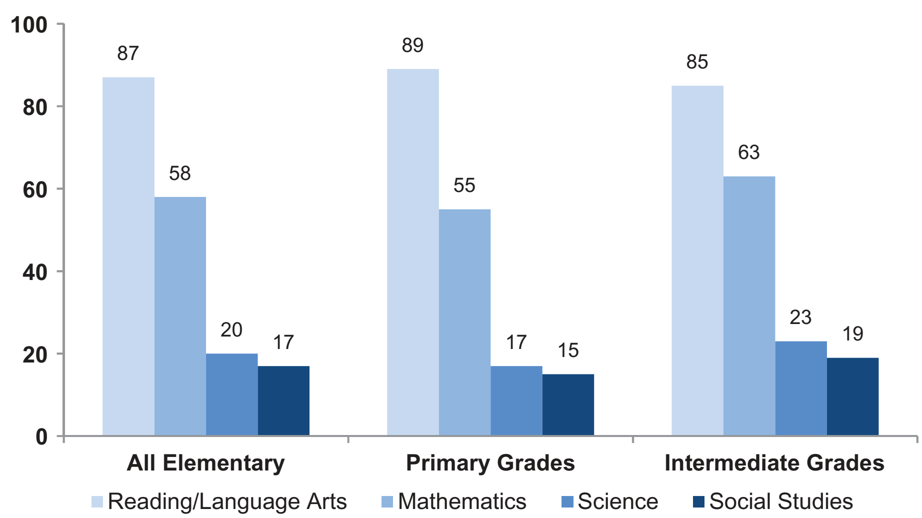

Figure 1. Average minutes per day.

[2]The Report of the 2018 NSSME+ provides more complete results and is available at www.horizon-research.com/NSSME. Subsequent reports will focus specifically on trends over time and issues of equity. All reports and other products from the study are, or will be, available free of charge on the project Web site.

Table 1. Science classes with heavy emphasis on various instructional objectives, by grade range.

	Percent of classes					
	Elementary		Middle		High	
	%	*SE*	%	*SE*	%	*SE*
Understanding science concepts	47	1.7	77	1.8	76	1.8
Learning how to do science (develop scientific questions; design and conduct investigations; analyze data; develop models, explanations, and scientific arguments)	26	2.0	46	2.1	41	1.3
Developing students' confidence that they can successfully pursue careers in science and engineering	23	2.0	30	1.9	35	1.5
Learning science vocabulary and/or facts	27	1.9	37	2.2	32	1.6
Increasing students' interest in science and engineering	27	2.2	35	2.1	31	1.5
Learning about real-life applications of science and engineering	20	2.1	28	2.0	29	1.2
Learning test-taking skills and strategies	20	1.5	23	1.8	23	1.4
Learning about different fields of science and engineering	8	1.9	7	1.2	7	0.8
Learning how to do engineering (e.g., identify criteria and constraints, design solutions, optimize solutions)	8	1.8	10	1.2	5	0.7

increasing student interest in science and engineering and developing their confidence that they can successfully pursue careers in these fields are heavily emphasized in only about a quarter to a third of classes. The study also shows that classes composed of mostly low-prior-achieving students are less likely to emphasize these types of objectives than classes of mostly high-prior-achieving students (these and other data referenced in this editorial are not included due to space limitations, but can be found in the full report).

In terms of instructional practices, the study found that lecture and whole-class discussion are very commonly used, occurring in 78% to 92% of classes, depending on grade range, at least once a week (see Table 2). About half to two thirds of classes engage students in hands-on or laboratory activities on a weekly basis; fewer have students write reflections about what they are learning.

The survey also asked how often students in science classes are engaged in doing science as described in the Framework. Results (not shown) indicate that students often engage in aspects of science related to conducting investigations and analyzing data. For example, about half of middle and high school classes have students organize and represent data, make and support claims with evidence, conduct scientific investigations,

Table 2. Science classes in which teachers report using various activities at least once a week, by grade range.

	Percent of classes					
	Elementary		Middle		High	
	%	*SE*	%	*SE*	%	*SE*
Explain science ideas to the whole class	85	1.9	92	1.0	92	0.9
Have students work in small groups	75	1.6	87	1.5	84	1.5
Engage the whole class in discussions	90	1.0	89	1.2	78	1.3
Have students do hands-on/laboratory activities	53	1.9	63	2.0	68	1.6
Focus on literacy skills (e.g., informational reading or writing strategies)	60	1.6	46	2.3	33	1.6
Have students write their reflections (e.g., in their journals, on exit tickets) in class or for homework	43	2.0	47	2.1	28	1.4
Engage the class in project-based learning activities	29	2.2	31	2.3	28	1.7
Have students read from a textbook, module, or other material in class, either aloud or to themselves	37	1.7	39	2.6	26	1.7
Have students practice for standardized tests	17	1.3	19	1.7	20	1.5

and analyze data at least once a week. At the elementary level, about a third of classes engage students in these activities weekly.

In contrast, students tend to not be engaged very often in aspects of science related to evaluating the strengths and limitations of evidence and the practice of argumentation. For example, fewer than a quarter of secondary science classes have students, at least once a week, pose questions about scientific arguments, evaluate the credibility of scientific information, identify strengths and limitations of a scientific model, evaluate the strengths and weaknesses of competing scientific explanations, determine what details about an investigation might persuade a targeted audience about a scientific claim, or construct a persuasive case. Even fewer elementary classes engage students in these activities weekly, and about a third never do so.

In short, there are some aspects of instruction that appear to be well aligned with the vision of the Framework, but other aspects are not. As has been the case for the past several iterations of the NSSME, instructional time for science at the elementary level is limited. At all grade levels, teachers report emphasizing developing conceptual understanding, but focus less on having students learn how to do science and encouraging student interest in science. Further, lecture and discussion are still the primary instructional approaches used, and although teachers report engaging students in hands-on and laboratory activities fairly often, it appears that students are not asked to critically think about and question evidence on a regular basis. These results are not that surprising given the deliberately slow rollout of the NGSS. A potential downside, though, is that, because there is a lack of sufficient examples of NGSS-aligned instruction, practitioners will focus on features of the NGSS rather than develop the depth of understanding necessary to implement them as intended or just see them as another passing fad. (Anecdotally, I have heard leaders of professional development [PD] programs for science teachers state, "The NGSS are the same thing we've always done, just with a new name.") In addition, a number of elementary schools have reduced the already limited instructional time devoted to science in favor of "integrated STEM experiences" (e.g., robotics activities) or "maker spaces" (which might be wonderful experiences for students, and have the potential to spur interest in science, but in and of themselves are not sufficient for students to learn science in the way envisioned by the Framework). Given the number of states that have adopted standards based on the NGSS, and current data on instructional practices, one cannot help but wonder what states, schools, and teachers mean when they say they are implementing the NGSS.

Why might instruction look the way it does?

There are a number of reasons instruction might look the way it does, and by no means are all of those reasons directly related to teachers. These reasons might include state, district, and school policies and practices; availability of resources for science instruction; teachers' beliefs about what constitutes effective instruction; teachers' content and pedagogical preparation; and the backgrounds of students. In this section, I share data about some of these factors.

One reason might be that teachers do not have the resources needed to implement an investigative style of instruction. Elementary schools spend less than $2 per student on science equipment, consumable supplies, and software; middle schools spend about $3 per student; and high schools almost $7 per student. Although these amounts are increases over the amount spent per pupil in 2012, the bulk of the increase appears to be in schools that serve the most well-off students (i.e., the fewest students eligible for free or reduced-price lunch). Further, when asked about the adequacy of facilities, equipment, consumable supplies, and technology, elementary teachers were the least likely and high school teachers the most likely to indicate having adequate resources for science instruction.

Another factor affecting instruction is the instructional materials (textbooks, etc.) used. Currently, there are only a handful of vetted materials aligned with the Framework and NGSS. Thus, it might not be surprising that the most commonly used type of instructional material is teacher-developed lessons and units, particularly in middle and high school classes (see Table 3). Textbooks and modules are still used fairly frequently, as are lessons and units teachers obtain from Web sites, at conferences, and from colleagues. It is apparent from these data that teachers are cobbling together materials from a variety of sources, raising questions about both quality and coherence.

Another reason might be teachers' beliefs about teaching and how students learn science. On the one hand, most teachers have a number of beliefs consistent with the vision in the Framework. For example, 90% or more of teachers in each grade range agree that (a) teachers should ask students to support their conclusions about a science concept with evidence, (b) students learn best when instruction is connected to their everyday lives, (c) students should learn science by doing science, and (d) most class periods should provide opportunities for students to apply scientific ideas to real-world contexts. On the other hand, they also hold beliefs inconsistent with research on learning (Donovan & Bransford, 2005). Roughly one third of science teachers at each grade level agree that teachers should explain an idea to students before having them consider evidence for that idea, and more than half agree that hands-on and laboratory activities should be used primarily to reinforce ideas that the students have already learned. Despite recommendations that students develop an understanding of concepts first and learn the scientific language later, 66% to 77% of science teachers at the various grade ranges think that students should be given definitions for new vocabulary at the beginning of instruction on a science idea. These data are particularly interesting as, despite the fact that nearly all teachers believe students learn science best by doing science, fewer teachers have students learning to do science as an instructional goal or are engaging students in the science practices during instruction. Understanding this

Table 3. Science classes basing instruction on various instructional resources at least once a week, by grade range.

	Percent of classes					
	Elementary		Middle		High	
	%	*SE*	%	*SE*	%	*SE*
Units or lessons you created (either by yourself or with others)	47	2.4	76	2.0	86	1.0
Commercially published textbooks (printed or electronic), including the supplementary materials (e.g., worksheets, laboratory handouts) that accompany the textbooks	38	1.9	45	2.6	50	1.7
Units or lessons you collected from any other source (e.g., conferences, journals, colleagues, university or museum partners)	28	2.0	43	2.4	49	1.7
Lessons or resources from Web sites that are free (e.g., Khan Academy, PhET)	23	2.1	31	1.8	31	1.8
Commercially published kits or modules (printed or electronic)	29	2.1	21	2.4	21	1.5
Lessons or resources from Web sites that have a subscription fee or per-lesson cost (e.g., BrainPOP, Discovery Ed, Teachers Pay Teachers)	49	2.2	34	1.9	16	1.1
State, county, district, or diocese-developed units or lessons	32	2.4	21	1.9	14	1.2
Online units or courses that students work through at their own pace (e.g., i-Ready, Edgenuity)	7	1.0	9	1.0	9	1.0

discrepancy between beliefs and actions, and how to bridge that gap, seems crucial for successful implementation of the NGSS.

How teachers are prepared for their roles likely affects what they do in their classrooms as well. It is generally accepted that, although not sufficient, understanding the content they are supposed to teach is necessary for effectively teaching it. The 2018 NSSME+ included several items about teachers' college course work and pathway to the classroom. It likely will not be a surprise that 91% of high school science teachers have a science-related college degree, but only 54% of middle school science teachers and just 3% of elementary science teachers have a science-related degree. Further, only a third of elementary teachers have taken at least one course in each of Earth, life, and physical science (nearly a third have taken a course in one or none of these areas).

In terms of pedagogical preparedness, only 23% of elementary teachers feel very well prepared to develop students' conceptual understanding of science ideas, compared to 42% of middle grades teachers and 58% of high school teachers; fewer feel very well prepared to develop students' abilities to do science (see Table 4). In addition, very few science teachers at any grade level feel very well prepared to provide science instruction that is based on students' ideas or incorporate students' cultural backgrounds into science instruction. The data also indicate that the teachers with the strongest preparation tend to teach in the wealthier schools.

Further, better than 4 in 10 elementary teachers have had no science-related PD in the last 3 years; only 5% have had 36 hr more of science PD. (For comparison, roughly 20% of secondary science teachers have had no PD in this time frame, and about 30% have had 36 hr or more.) Thus, the vast majority of the elementary science teaching force has limited preservice preparation to teach science, and minimal in-service support to do so.

How best to prepare elementary teachers of science is an unsolved problem and potential solutions need to go beyond their preservice programs and consider changes to the way elementary schools staff and support science instruction. For example, the design of a preservice program would likely be substantively different if it were preparing science specialists rather than generalists. Similarly, the resources needed to support

Table 4. Science teachers considering themselves very well prepared for each of a number of tasks, by grade range.

	Percent of classes					
	Elementary		Middle		High	
	%	*SE*	%	*SE*	%	*SE*
Develop students' conceptual understanding	23	1.5	42	2.2	58	1.5
Use formative assessment to monitor student learning	28	1.7	48	2.2	52	1.6
Develop students' abilities to do science (e.g., develop scientific questions; design and conduct investigations; analyze data; develop models, explanations, and scientific arguments)	17	1.5	38	1.9	46	1.6
Encourage students' interest in science and/or engineering	26	1.3	42	2.2	44	1.6
Encourage participation of all students in science and/or engineering	31	1.6	44	2.3	43	1.6
Differentiate science instruction to meet the needs of diverse learners	19	1.3	33	2.0	35	1.5
Provide science instruction that is based on students' ideas	12	1.1	21	1.8	25	1.4
Develop students' awareness of STEM careers	9	0.9	21	1.8	21	1.2
Incorporate students' cultural backgrounds into science instruction	11	1.1	15	1.3	18	1.4

Note: STEM = science, technology, engineering, and mathematics.

effective instruction at the elementary level might also need to be designed differently for specialists and generalists.

What does all of this mean for moving forward?

Although there is evidence that the science education system has some alignment with the vision laid out in the Framework, there clearly is still a long road ahead before we, as a nation, are providing a high-quality science education to all students. I cannot emphasize enough that I believe that the vast majority of teachers are doing the best job they can, given the contexts in which they work. W. Edwards Deming is credited with saying "Every system is perfectly designed to get the results it gets." Thus, if we want different results, aligning all parts of the system to support the vision of the Framework will be necessary. With this thought in mind, the data from the 2018 NSSME+ should not be interpreted as being critical of teachers, but rather should be used to consider ways the science education system might need changing.

An important discussion the science education community should have is around what teachers need to know and be able to do, as well as what resources are needed in classrooms, for all students to receive high-quality science learning opportunities. In having this discussion, it will be important to recognize the different issues at different grade bands. For example, although a large majority of high school teachers have a substantive background in science (even if some are teaching some science classes outside their primary area of expertise), they might not have an understanding of how to teach in a way aligned with the Framework. At the elementary level, the vast majority of teachers work in self-contained classrooms and have little preparation in science or how to teach it. It is also important to keep the scale of the education system in mind. There are more than 100,000 schools in the nation serving one or more grades K–12, and roughly 1.2 million teachers of science in these schools, nearly 80% of whom are elementary grades teachers.

Although there might be debate over certain aspects of what we think teachers should know and be able to do, there likely would be broad agreement over several others. One aspect is that teachers need to have a vision of what effective science teaching looks like; they also need to understand what the critical components of that vision are and why they are critical if they are to avoid grabbing at features of instruction. Having prospective and new teachers exposed to several instances of high-quality instruction and having opportunities to analyze and discuss those instances relative to one or more instructional models is one way many teacher education programs are trying to address this need.

Teachers also need to have knowledge of the content they are expected to teach at a level beyond what their students are expected to master. Otherwise, it would be extremely difficult for teachers to facilitate productive learning experiences. (Although learning can take place through lines of inquiry that do not allow students to reach a firm conclusion, given the limited amount of time devoted to science and the amount of material in the NGSS students are expected to learn, how much do we want to devote to these types of investigations?) Teachers also need to understand the students they are teaching—what motivates them, what their interests are, what experiences and prior knowledge they have to draw on, and so on—and how to use this knowledge appropriately.

Teachers should also have the resources and other supports necessary to make use of their knowledge and skills. As a nation, we should be ashamed that any students go to schools that are overcrowded, in disrepair, and unable to provide teachers and students with the materials needed for a high-quality education.

There are a number of innovative and exciting things happening in science education, including new approaches to preparing teachers in preservice and the development of mentoring programs designed to support novice teachers during their formative initial years of teaching. There are still big challenges remaining, though, especially in terms of going to scale with reforms. One approach that I, and others, advocate for is investing in the development of high-quality instructional materials and helping teachers understand the critical design features of those materials. There is evidence that learning opportunities are more effective when teachers base instruction on well-designed instructional materials and when they are supported to make principled adaptions to instructional materials for tailoring instruction to their students' needs (cf. Banilower, Boyd, Pasley, & Weiss, 2006; Penuel & Gallagher, 2009). Yet, the vast majority of science teachers appear to be cobbling together instructional materials from a wide variety of sources or developing their own lessons and units. The paucity of instructional materials aligned with the Framework and NGSS at this time might, in part, explain this phenomenon (although a similar pattern was found in the 2012 NSSME). If a sufficient collection of aligned materials can be developed, teacher preparation programs could increase their emphasis on helping prospective teachers understand the design principles and when and how to make adaptations based on students' needs. PD programs for in-service teachers could continue deepening their understanding and skill at being responsive to the different funds of knowledge their students bring to the classroom.

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