Opportunities to Improve the NGSS

A Blog by Andy Zucker & Penny Noyce

http://ImproveTheNGSS.org

Note: This document includes all the NGSS blog posts in chronological order beginning with the earliest post.

Welcome to our blog

Posted November 23, 2019

Thank you for reading this blog. We will add posts several times each month, or even weekly. You can subscribe by clicking the link at the top of the right column.

Your participation in the conversation about science education standards can be important. Education standards are intended to meet the needs of a large number of individuals and groups. By the same token, changing standards requires widespread discussion before revisions are made.

We worked on the white paper "Opportunities to Improve the *Next Generation Science Standards* (the NGSS)" for more than six months before posting it on this website in late 2019, making the paper widely available. Earlier, several experts agreed to review a draft and provide comments, for which we are grateful. In future blog posts we will highlight some of the comments and suggestions we received from them and from others, and we invite you to offer your own comments on this blog.

We will also have space here to expand on ideas in the paper. For example, we will identify some of the instructional materials teachers can use now to better support the goal of developing students' scientific literacy, a goal we identify as the most important reason to strengthen the NGSS.

Leave a comment or send us an email if you would like to write a post for this blog.

Andy and Penny

The NGSS is one piece of a bigger system

Posted December 6, 2019

Several reviewers noted that education standards like the NGSS are only one influence on classroom instruction, whether in science or other subjects. We heartily agree! Their comments are an important reminder.

The quality of science teachers, the support they receive, the amount of time allocated to teaching science, the nature of high-stakes tests, support of STEM education by parents and the community—these are just a sample of other important influences on teaching and learning science. One reviewer wrote, "I agree with the ultimate goals for raising scientifically literate students … but I question what new and improved standards will do without addressing the current lack of infrastructure to implement them."

The white paper does not claim that improving the NGSS is the one and only way to improve science education. At the same time, the NGSS promotes an excessively narrow vision of science and scientific literacy, so we should not be surprised when many teachers adopt that narrow vision.

As an example, too many parents believe that vaccines cause autism. Students graduating high school ought to know that the Centers for Disease Control and Prevention (the CDC) is an excellent source of information about vaccine safety and about many other public health issues. Similarly, students should learn that the Intergovernmental Panel on Climate Change (the IPCC) is a primary source of information about the causes and the impacts of climate change. Organizations like the CDC and the IPCC are central to NGSS practice #8, "obtaining, evaluating, and communicating" science-related information, bringing together experts from many institutions to synthesize and vet scientific findings. Such institutions are one key mechanism for determining scientific consensus, if and when it exists. Yet the NGSS makes no mention of any scientific institution. Nor does it explain how science helps to inform public policy—about vaccines, climate, food safety, or other issues. This is short-sighted.

Improving the NGSS is no guarantee that science instruction will improve, yet guidance from national standards cannot be ignored merely because other factors are important, too.

Andy and Penny

One expert's comments on the white paper

Posted December 9, 2019

We asked Professor John L. Rudolph to review a draft of the white paper. Professor Rudolph is chair of the Department of Curriculum and Instruction in the School of Education at the University of Wisconsin-Madison, where he educates future science teachers. His recent book *How We Teach Science: What's Changed and Why It Matters* is a comprehensive history of American science education from the late nineteenth century to the present, making him exceptionally knowledgeable about how goals of science education have evolved over time.

After reviewing the paper, Professor Rudolph wrote:

> *"Thanks so much for sharing your white paper on revising the NGSS. I thought it was excellent. I have to say that it aligns almost exactly with my own critique of where science education is currently and where it's heading under NGSS…. All the things you suggest I would heartily endorse. In fact, your outline of things neglected by NGSS closely parallels the syllabus of the science teaching methods course I teach every fall….*
>
> *I think that we're on the cusp of a change that will begin to prop up the legitimacy and authority of science given the way science and truth have been so thoroughly denigrated in the public sphere of late. Your work will, I think, be part of helping push things in that direction…. It helps that the paper is so very clear and readable too."*

We were optimistic when we asked reviewers for their comments, but frankly we were not sure what experts would think of the white paper. These comments from Professor Rudolph, and others, were encouraging to us. Without widespread support it is unlikely that science education standards will be improved.

Comments from another expert reviewer

Posted December 16, 2019

One of the experts who reviewed a draft of our white paper is Dr. Cary Sneider, an architect of the NGSS, and a member of the NGSS writing leadership team. His comments were extensive and generous, and began, "*This is a nicely crafted article that should definitely be published.*" Here are other highlights:

"*I like a lot of what you said about how the NGSS could be improved …. I especially resonate with your comments about distinguishing truth from fiction (and outright lies).*"

"*A decision that I lament*," he wrote about development of the NGSS, was to leave out a core idea identified in the *Framework for K-12 Science Education* (the template for the NGSS), namely, **ETS2 - Links among engineering, technology, science, and society**. "*Some of what you say has been left out [of the NGSS] is included in this core idea*," he said, and we agree. In particular our concern that the NGSS has nothing to say about the relation between science or technology and public policy would be addressed had the NGSS incorporated this core idea from the *Framework*. As leader of the engineering team of NGSS writers, Sneider takes full responsibility for this missing piece, and hopes it will be reinstated when it's time to update the NGSS.

At the same time, Sneider, a retired researcher, museum educator, and visiting scholar at Portland State University, expressed a number of reservations about the recommendations offered in the white paper. "*It takes more than a decade to implement a new set of standards, especially if they are quite different from what was there before. Also, some states have just recently adopted new standards*," he wrote. So, in his view it is too early to make significant changes to the NGSS. Others have made similar comments, noting how long it takes to fully implement new standards.

Some of the missing pieces we identified in the NGSS, Sneider wrote, are intentionally absent, notably discussion of key principles of science teaching. Although he agrees that appropriate classroom pedagogy is essential for effective science education, the purpose of the standards is just to state what students should know and can do at the end of instruction, and not specify any specific curriculum materials or teaching methods, leaving that up to state officials to provide guidance.

Another of Dr. Sneider's reservations is that "*everyone wants to add topics they think are missing*," but authors of the NGSS were trying to focus on fewer important topics rather than on too many topics taught quickly and ineffectively. "*Prior standards have had more than any teacher can do in a year,*" he noted. Anyone who wants to add new topics to the NGSS during future updates should at the same time identify other topics that should be taken out to make space for the new material. Otherwise, the process that leads to bloated textbooks will just continue. He recommended that we add a section to our white paper about what could profitably be taken out of the NGSS to make room for the recommended additions.

The last area to highlight in his comments is that Dr. Sneider pointed to Appendix H and some of the "foundation boxes" in the main text of the NGSS as places where the nature of science is already highlighted. "*I'm not sure why you feel it is not there*," he wrote.

These are thoughtful comments, which we appreciate. There are obviously large areas of overlap in our views of how to improve the NGSS, as well as significant differences. Rather than try to respond in this post to each of the reservations Dr. Sneider expressed, we will simply refer readers to the white paper. We hope that we provide a sound rationale for each of our suggestions, and as we wrote, we believe that our suggestions could be implemented “without significant disruption to the science curriculum.”

Barriers to reading about science for school

Posted January 5, 2020

A distinguishing feature of the 2010 Common Core State Standards initiative was the increased emphasis on having students read nonfiction books and magazines for school, including reading about science. The name of the standards tells the story: *The Common Core State Standards for English Language Arts (ELA) & Literacy in History/Social Studies, Science, and Technical Subjects*.

An increased emphasis on reading nonfiction reflects the reality that as students enter higher grades they need greater skills and stamina for reading informational text. Reading nonfiction calls for different strategies, vocabularies, and habits than reading fiction. Students need to learn to question the text, and to summarize it for themselves to help them retain information. These skills don’t come automatically, so teachers need to help students become better readers of nonfiction. For understandable reasons the authors of the Common Core believed that the responsibility for teaching students to understand literary nonfiction should be shared by teachers in non-ELA classes, notably in history, social studies, and science classrooms.

However, the glaring absence of any similar language in the Next Generation Science Standards stands as a significant barrier to achieving the Common Core’s goals for reading nonfiction. Science teachers who are guided by the NGSS are simply not encouraged to assign students to read about science, besides reading a textbook or class handout. This is a missed opportunity. After all, in adult life, reading newspapers, magazines and books becomes a vital way for people to maintain and extend their understanding of current science.

What’s more, we recently became aware of a related barrier: the poor availability of science books and magazines in schools. A questionnaire for the 2015 National Assessment of Educational Progress (NAEP) asked eighth grade science teachers, “To what extent does your school system (including your school and school district) provide you with science magazines and books (including digital forms, such as online magazines and books)?” Remarkably, 30% of teachers responded “none,” i.e. no science books or magazines, and another 35% of teachers responded “a small extent.” Is it surprising then, that 40% of these eighth grade teachers indicated they ***never*** have students read a book or magazine about science?

What about the school library, which also includes encyclopedias and newspapers, in addition to books and magazines? In 2015 45% of grade 8 students reported they ***never*** used library resources for science class. Similarly, 54% of grade 12 students reported in 2015 ***never*** using library resources for science class.

Is this the reality that developers of the NGSS wanted to encourage? Probably not. Although the standards writers undoubtedly wanted to see students carrying out investigations and discussions, they probably meant to include reading and writing among the ways that students should acquire, evaluate and communicate information. The NGSS ought to be explicit in asking science teachers to promote more reading about science among students.

There are many wonderful nonfiction science books available, as well as fictional narratives with a strong scientific base. Who will assign them if the standards suggest they are unimportant, that reading and writing don't merit specific Performance Expectations? Indeed, who will even *encourage* young people to stretch their minds through science reading? Reading about science or even science fiction can elicit a love of science, provide a way to pursue personal interests, and sometimes foster young people's identification with scientists and engineers. National standards should make these kinds of encounters between students and ideas more, not less, likely to occur.

Penny and Andy

Why should anyone trust science?

Posted January 16, 2020

A remarkable feature of our current time in history is an increasing distrust of authority, whether the church, the government, or the world of science. It is easy to hypothesize reasons for this distrust, from news of malfeasance to the growth of conspiracy theories on the Internet; but distrust leaves us with very little basis for making public policy. Thus the new book *Why Trust Science* by geologist and historian of science Professor Naomi Oreskes is both timely and welcome. Our recommendations to improve the NGSS by focusing greater attention on the nature of science are well aligned with Oreskes' findings.

Perhaps best known for co-authoring the scathing critique of climate denial *Merchants of Doubt*, Oreskes nevertheless takes her title question seriously. She begins with a historical overview of the philosophy of science. While this essay can be a heavy slog for the non-specialist, it is enlightening to read how thinkers of the past have wrestled with the question of where science's special authority—and effectiveness—come from. Is it the elevated and disinterested nature of scientists themselves? Does it lie in an internally consistent and universal scientific method? Simple examination of history can demonstrate weaknesses in either formulation.

Partly by examining cases where science has gone right or wrong—the Limited Energy Theory, which held that higher education or a profession would harm a woman's reproductive faculties; the eugenics movement; the theory of continental drift; resistance to the idea that birth control pills can cause depression; and arguments over the value of flossing our teeth—Oreskes comes up with her own list of five elements. Oreskes calls these elements "pillars" that, when present, make scientific conclusions something we can rely on. The first is consensus: a fringe idea is less trustworthy than one that has been confirmed and widely endorsed by qualified scientists. The next two, method and evidence, line up with what we expect of science and its vetting. But Oreskes adds two more: diversity and values. A diversity of perspectives from qualified members of the scientific community, she suggests, can help prevent or correct the skewed thinking that has led to faulty and biased "science" in the past. Moreover, Oreskes argues that instead of aspiring to a lofty stance of having no values beyond the pursuit of truth, scientists should be up front about their values, for example that we have a moral responsibility to leave a habitable earth to our descendants on the one hand, or that the free market admits of no compromise on the other.

The most entertaining part of the book lies in its five case examples, listed above, which continue into an argument over the value of sunscreen. In each case, Oreskes shows how mistakes that arise can be attributed to neglect of one of her five pillars. She then practices what she preaches by opening her argument to response and critique from five different scientists' voices. These commentaries approach the problem of trust in science from viewpoints ranging from technology as popular evidence that science "works" to the "replication crisis," which has led to retractions of published papers and established ideas.

For now, let's keep an eye on the reasons to trust science that Oreskes has offered. People should trust science when scientific experts on the matter in question, building on evidence and using accepted methods, reach consensus after broad discussion and debate among a diverse group of qualified critics. Conclusions emerging from such science are subject to change—in the same way that Einstein added to and improved Newtonian physics—but it is scientific consensus that provides a firm foundation leading to useful and effective increases in understanding the natural world.

Penny and Andy

Resisting scientific misinformation

Posted February 2, 2020

A year ago we posted a free, one-week curriculum unit for grades 6-12 called Resisting Scientific Misinformation. To date there have been over 3,000 downloads. Last week *The Science Teacher* published an open-access article about our materials, which we hope will result in additional attention to and use of the materials.

Helping students resist scientific misinformation is one of the important missing pieces in the NGSS. As we developed the curriculum materials, this missing piece became an impetus to look for other missing pieces and to write the white paper posted on this site.

It was interesting to learn recently that accepting misinformation is a bigger problem in the United States than in many other nations. As a *Boston Globe* article reported:

> *"Nearly 10 percent of the online stories followed most closely by readers in the United States in December came from [untrustworthy news] sites…. Enthusiasm for these sites in the United States far outstrips that of [France, Italy, Germany, and the United Kingdom]. The British are especially resistant; news from unreliable sites made up just 1.2 percent of the most-followed stories among British Web surfers."*

As you might expect, there are a variety of ways to help students with the problem of misinformation; unfortunately, none of them are addressed directly by the NGSS. One approach is to use technology-rich services that help users separate information from misinformation. For example, one can install software from NewsGuard, a startup that evaluates the trustworthiness of Internet news sites, including whether the news site identifies its owners, backers, and authors of articles. A green check mark appears for users who install the software in their web browsers.

Snopes is an easy-to-use website that has evaluated thousands of claims for accuracy, which includes a list of the "hot 50" rumors circulating online. Checkology describes itself as "a browser-based platform where middle school and high school students learn how to navigate today's challenging information landscape by developing news literacy skills," and it includes lessons educators can use with classes. A basic version is free, while a premium version requires a subscription.

This list of technology-rich resources to help users sort information from misinformation could be greatly expanded. We use some of them and we're glad they exist.

At the same time, students need to learn how to judge for themselves the thousands of dubious science-related claims that appear on social media, on TV or radio, or elsewhere. New claims appear all the time. Using our unit (free online), teachers guide students through evaluating for themselves a number of "scientific" claims, some of which turn out to be valid, and others not. The materials focus on four approaches to evaluating claims: a better understanding of advertising, including ways some advertisers try to fool you; asking the right questions about a dubious claim; understanding more clearly how scientists reach their conclusions (including the vital role of such institutions as the Centers for Disease Control and Prevention); and distinguishing between more and less reliable sources of scientific information.

The unit concludes by asking students to investigate a dubious claim by using appropriate websites, and then writing a short synthesis of their findings. Again, we find the NGSS is lacking in asking students to investigate claims for themselves, even such timely issues as the risks and benefits of teenage vaping.

Research on helping people resist misinformation

Posted February 9, 2020

Research about "what works" in education is surprisingly thin. So it is good news for teachers and policymakers that multiple studies demonstrate that various approaches to help people resist misinformation do just that; they work.

One example comes from the Stanford History Education Group (SHEG). You may remember that SHEG documented how poorly most high school students are able to distinguish between fake or misleading online news sites compared to accurate sites. In one summary (2016), Stanford researchers summed up students' ability to reason about information on the internet in one word: "bleak."

To address this problem, SHEG developed a set of Civic Reasoning Online curriculum materials. A recent evaluation involving more than 3,000 students showed that those who used the SHEG materials grew considerably more in their ability to evaluate online sources than a control group of students who did not use the materials. *Education Week* published an article about this study last month.

As we developed our free one-week unit for grades 6-12, Resisting Scientific Misinformation, we based the materials on a number of high-quality studies about helping people resist misinformation. For example, a 2017 study demonstrated that educating people about misleading argumentation techniques, such as are often used by advertisers and climate change skeptics, helps reduce the influence of those techniques. Another study found that if people know what a high percentage of climate scientists agree that human beings are the major cause of climate change they become better able to resist climate change misinformation. And we relied on other studies, too.

In short, there is good reason to believe that teachers can help students resist scientific and other types of misinformation. This goal is critically important at a time when social media spreads misinformation at an alarming rate.

We wish that authors of the *Next Generation Science Standards* had focused far greater attention on teaching students to be "careful consumers of scientific and technological information related to their everyday lives," as urged in *A Framework for K-12 Science Education*, the template for the NGSS. Misinformation of all kinds, notably including scientific misinformation, has become a far more serious problem since that Framework was published in 2012.

There are somewhere between 100,000 and 200,000 teachers of science in grades 6-12 in the United States. By anyone's reckoning, only a tiny fraction of them now focus on teaching students *how* to distinguish between science fact and science fiction. That is a shame. If national or state science education standards emphasized the importance of teaching students how to judge the quality of information they encounter, a far larger number of teachers would focus on this important topic.

Teaching about the Coronavirus, COVID-19

Posted February 15, 2020

The current coronavirus epidemic, now known as COVID-19, presents an ideal opportunity for teachers to present real-life, cutting-edge, relevant science. Some of the scientific ideas, such as simple messages about hygiene, can be taught at any level, but others are particularly appropriate to middle and high school students.

Some of what there is to be learned falls squarely under existing NGSS core ideas in the life sciences, such as:

- What is a virus? Are viruses alive? How do viruses differ from bacteria?
- Some scientists think the infection might have originally come from snakes, others from armadillos or some other mammal. What arguments do they make? How are scientists communicating these ideas? How does "science" come to a conclusion?
- How might a virus pass from one species to another?
- How might modern transportation technologies allow a human virus to spread?
- What does exponential growth look like? (For older students, what is R_0?)

Then there are other topics that we have suggested should be included in the standards, but are not now, such as learning about vaccines, the importance of scientific institutions and organizations, and the impact of science on policy. For example:

- What are vaccines, and how are they developed? Should we develop a vaccine against COVID-19, and how long will it take?
- How does the current danger to Americans of COVID-19 compare to dangers from measles, Ebola, or the flu? Where and how can people find the answer?
- Which organizations, like WHO and the CDC, are directing the American response to the epidemic? What do these organizations do? Are they trustworthy?
- How are different governments, local and national, such as in China and the U.S., making policy decisions about how to handle the new virus? (Examples include: controlling social media, building hospitals, directing army medics to report to Wuhan, shutting down travel between cities, establishing quarantine sites, screening travelers.) Which of

these actions do students believe are necessary? Which are effective? Who should be making such decisions?

Lastly, misinformation about science is a growing problem that teachers should teach about:

- Are there examples of misinformation about the coronavirus that are being spread online? What are some examples (e.g., articles here and here)?

Some enterprising teachers are already beginning to develop lessons about COVID-19. For example, here is an excellent lesson from high school teacher William Reed, posted on the NSTA blog. (http://blog.nsta.org/2020/02/05/novel-wuhan-coronavirus-whats-the-real-story/)

But note that the lesson's links to the NGSS fall only under Science and Engineering Practices, and, with a stretch, to Crosscutting Concepts. We agree with the National Science Teachers Association (NSTA) that science should be taught in the context of societal and personal issues (Position Statement here), and that students need to learn more about the nature of science than is included in the NGSS (Position Statement here). It's a shame that this lesson on COVID-19, which provides a great opportunity to teach relevant science, has to struggle so hard to "fit" with the standards.

Wouldn't teachers and students be better off if the NGSS were revised to address some of these ideas more directly? Wouldn't we all be better off if teaching science in the context of societal and personal issues and with greater attention to the nature of science became core parts of the NGSS, instead of separate priorities promoted by NSTA?

Some state standards are better than the NGSS

Posted February 22, 2020

Education is primarily a responsibility of states and localities. Each state is free to establish its own education standards, and they differ from one state to another. Below we compare science education standards in two states, Washington and Massachusetts.

Washington State is one of 20 states that have adopted the Next Generation Science Standards. A search on the internet leads to a web page titled, Washington State Science and Learning Standards. There one reads,

> *The Washington State Science and Learning Standards (WSSLS), previously known as the Next Generation Science Standards-NGSS, are a new set of standards that provide consistent science education through all grades, with an emphasis on engineering and technology.*

In other words, in Washington State the NGSS is called WSSLS, but the two documents are otherwise identical. That means the WSSLS has the same strengths as the NGSS, such as establishing the goal that students learn about climate change, but also the same weaknesses. For example, WSSLS does not emphasize teaching science in the context of societal and personal interests. There is no suggestion that students learn about the impact of science on public policy, such as policies to reduce carbon emissions, or how to find accurate information about an unfamiliar science topic, such as vaping.

Although Position Statements from the National Science Teachers Association (NSTA) focus on the importance of taking a broader view of science education than the NGSS, Washington

State's Science and Learning standards make no reference to NSTA's recommendations. It is presumably a source of frustration for the NSTA to realize that their Position Statements are not incorporated into the WSSLS or into many other states' science education standards.

On the other hand, Massachusetts is an example of a state that has taken a different approach. In the state's Science and Technology/Engineering (STE) Learning Standards, one reads that,

> *While the Massachusetts STE standards have much in common with NGSS, public input from across the Commonwealth during the development of the standards identified several needed adaptations for Massachusetts:*
>
> - *Include technology/engineering as a discipline equivalent to traditional sciences.*
> - *Include only two dimensions (disciplinary core ideas and science and engineering practices) in the standards, while encouraging the inclusion of crosscutting concepts and the nature of science in the curriculum.*
> - *Balance broad concepts with specificity to inform consistent interpretation …*

The idea that every science lesson must include the three dimensions identified in the NGSS was rejected by Massachusetts. A result of that modification is to provide teachers with greater flexibility, such as making it easier to plan lessons.

There are other important differences between the NGSS and the Massachusetts STE learning standards. One difference is to more clearly emphasize the importance of reasoning with evidence, including reasoning about claims found in media of any kind. (The word "media" appears dozens of times in the STE standards.) Specifically, in Massachusetts students should learn to:

> *"Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, and determining what additional information is required to solve contradictions,* and
>
> *Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media, verifying the data when possible.*" (pp. 66-67)

Another difference is that Massachusetts adopts as a guiding principle the idea that:

> *"An effective science and technology/engineering program addresses students' prior knowledge and preconceptions."* (p. 9)

The NGSS, on the other hand, makes no mention of students' prior knowledge and preconceptions.

Yet another important difference is that preparing students to apply STE knowledge "to real-world applications needed for civic participation" is an explicit goal of the standards (p. 5). This is similar to NSTA Position Statements. However, in the NGSS there is no mention of civic participation.

For a variety of reasons, Massachusetts students perform unusually well on national and international tests, compared to students in other states. There is simply no evidence that adopting science education standards different than—better than—the NGSS harms the state's students in any way. To the contrary: we believe that establishing better goals for science education helps students.

The NGSS as assessment standards

Posted March 7, 2020

Several people have pointed out that at its heart the NGSS is a set of Performance Expectations (PEs) for students. In other words, the NGSS is intended to identify what students should know and be able to do in science by the time they reach particular grade levels. The theory behind this approach is that states adopting the NGSS will assess students using these performance expectations (which include all three dimensions: disciplinary core ideas, scientific practices, and cross-cutting concepts).

Teachers are free to add to what is in the NGSS. In fact, because these standards are intended for *all* students, some students' learning surely will go beyond the standards. For example, students in Advanced Placement classes, who are likely to attend college, are expected to learn more science than what is included in the NGSS.

Architects of the NGSS adopted this approach in part to satisfy teachers who were saying or thinking, "Just tell us what the test will cover and I will teach my students accordingly." At the same time, designers of the standards wanted to keep the total set of expectations to a realistic size. In other words, they developed the NGSS as a floor or a minimum, not a ceiling.

This is all understandable, yet it begs the question whether the set of minimum expectations that comprise the NGSS is an appropriate set. If we assume that many school systems are hard pressed to teach their students everything in the NGSS—something we have also heard from well informed people—then it seems likely that for many students the totality of what they learn in science will be dictated by what is in the NGSS.

Is it really sensible that students studying in science classes aligned with the NGSS could graduate high school without discussing the relation between science and public policy (e.g., food and water safety, pharmaceutical testing, or regulating nuclear energy)? Or without even knowing the names and functions of key government science agencies like the FDA, the CDC, or the IPCC? Does it make sense that the NGSS does not encourage teachers to prioritize societal and personal concerns related to science—including science-based issues like smoking, vaping, immunizing children, and the quality of supposedly "scientific" information in advertising and social media? These are examples of goals or expectations missing in the NGSS.

In contrast, the NGSS expects *all* students to be able to "evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other." Also, according to the NGSS *all* students should be able to "use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem."

Think about these priorities the next time you are on a bus or subway or in some other place with dozens of people representing a broad slice of the American population. Are the NGSS expectations what *you* think is the most important science for every adult to know? Are these the right expectations for *all* students?

Preparing students for college and careers

Posted March 14, 2020

The NGSS introduction states that its "content is focused on preparing students for college and careers" (p. xiii). Perhaps it is not surprising that even someone familiar with the NGSS may never have focused on that part of the standards; after all, the standards are 324 pages long, with another 170 pages of appendices.

Nonetheless, it is clear that authors of the NGSS were aware of the focus of their work. As we wrote in our last post, one of the NGSS Performance Expectations is that all students should be able to "use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem." A typical American will never use that knowledge, nor is it necessary to use mathematics to understand the most important aspects of ecosystems. We can only assume that the NGSS includes this performance expectation, and various others, because the authors, who were mainly disciplinary specialists, were aiming at preparing students for college and careers.

As we wrote in our last post, authors of the NGSS were not thinking primarily of students as future citizens concerned about science in the context of societal and personal concerns. Earlier science education standards included those focal points; however, the people who created the NGSS made a conscious decision not to. Indeed, as an earlier post indicates, one of the key writers for the NGSS now regrets that the connections between science, technology, and society were left on the cutting room floor, as the expression goes.

Only about a third of Americans over the age of 25 hold a four-year college degree, and even today graduating from college is not the norm. In 2015 fewer than half of adults ages 25-34 had earned an associate's degree or more. Indeed, only 85 percent of students even graduate high school. And of course the majority of students will not need a specialists' knowledge of science or technology, such as acquired in college, for their future jobs.

Yet *all* students will benefit from applying their understanding of science to decisions in their later lives (e.g., about health care for themselves and others). Similarly, students will apply science to decisions they make as citizens (e.g., deciding whether to support candidates who don't accept mainstream scientific findings, or voting whether to approve state or regional carbon fees).

Preparing students for college and careers is a reasonable goal, up to a point. However, we don't believe it should be the exclusive goal of national science education standards at the expense of other priorities, such as teaching science in the context of societal and personal concerns.

Will required state tests, or national exams like the SAT, focus on students' science knowledge and skills as related to societal and personal concerns? Will students be expected to demonstrate that they can distinguish between more or less reliable sources of scientific information? These are examples of performance expectations that are not priorities under the NGSS as it is now written. That concerns us, and we hope it concerns you.

Andy

NGSS priorities matter

Posted March 27, 2020

It matters which topics the Next Generation Science Standards say are important, for many reasons. The NGSS affects what is written in textbooks, how textbooks are judged and purchased, what questions are asked on national, state and district science tests, and much more.

In response to the COVID-19 emergency, surely many students are now learning about the CDC, immunizations, how the science of epidemiology influences public policy, ways to find sources of reliable information online, the 1918 Spanish flu epidemic, and other related topics. However, it's a safe bet that until the current pandemic hit the U.S. only a small minority of science teachers focused on those topics—because none of them is included in the NGSS.

The NGSS also has a real, less direct influence on research about science education. Most science education researchers focus on topics widely considered important. One result is that we have little data about teaching and learning topics the NGSS does not include. A nationally representative sample survey of science teachers tells us, for example, that 70 percent of high school biology teachers feel "very well prepared" to teach genetics, and the same survey provides similar data for nearly two dozen other disciplinary content areas. *

In contrast, there are no reliable national data about how often science teachers connect lessons to societal or personal issues, or about how well prepared science teachers believe they are to teach using those perspectives. One expert on the use of SSI in schools, Professor Troy Sadler at the U. of North Carolina, emailed recently that conducting a sample survey of teachers asking about teaching SSI "would be useful, but to my knowledge no one has done it."

That is not because no one cares about focusing on societal or personal issues. In fact, as we reported in an earlier post, Cary Sneider, one of the architects of the NGSS, regrets that the links among engineering, technology, science and society—which were part of the *Framework for K-12 Science Education* on which the NGSS was based—were not included in the standards. He hopes that this significant omission will someday be remedied, as do we.

In fact, there are many excellent instructional materials available to science teachers that focus on the intersection of science with public policy or personal choices, topics that are sometimes known as Socio-Scientific Issues, or SSI. As an example, in 2014 the National Science Teaching Association (NSTA) published *It's Debatable: Using Socioscientific Issues to Develop Scientific Literacy*. One set of lessons, especially appropriate for biology classes, is called *A Fair Shot? Should Gardasil vaccines be mandatory for all 11-17-year-olds?* Another set of lessons asks students whether schools should charge a "tax" to discourage young people from eating unhealthy foods. Besides these, there are countless other SSI topics that could be taught in elementary and secondary schools, and many lesson plans exist.

But are science teachers prepared to teach SSI? Getting science teachers ready to teach those topics means preparing them to handle questions related to ethics and civics, not just science. They must be willing to discuss controversial issues, manage class discussions in which divergent opinions are expressed, and help students use evidence to reason *with* science and not only *about* science. Teacher preparation programs are less likely to focus attention on such matters if, in effect, the NGSS says those teacher skills and dispositions are not very important. We simply don't know how many science teachers are well prepared to teach science in the context of personal and societal issues. Nor do we know what constraints they face with SSI, such as feeling time pressure to “cover” topics in the standards, or the need to prepare students for high-stakes tests.

Connecting science to personal and societal issues (SSI) is only one of the important priorities we identified as missing in the NGSS. However, thinking about the “missing data” related to teaching SSI in schools provides an example of science education research that would be useful to improve teaching and learning, and even more useful if the NGSS prioritized SSI.

** Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). Report of the 2018 NSSME+. Chapel Hill, NC: Horizon Research, Inc.*

Andy

A more positive perspective

Posted April 5, 2020

We recently spoke with Dan Damelin, a Senior Scientist at the Concord Consortium who has experience as a science teacher, curriculum developer, and provider of professional learning for teachers. Below is an edited version of Dan’s comments.

Dan: For many years I’ve held a firm belief that students learn best though discovering things for themselves. In the science classroom this means providing students with opportunities to engage in exploring the world like scientists. Until the NGSS, “inquiry” was always separate from other content standards, and usually thought of as an aside or add-on, not integrated into everyday experiences in the science classroom. It didn’t help that state testing almost solely emphasized content over process.

The critical breakthrough of the NGSS was to write the standards in such a way that engagement in science and engineering practices is part of the standard itself. With the influence of the NGSS, I’ve experienced a huge increase in teachers seeking help on how to teach from a more student-centered, phenomena-oriented, and inquiry-based approach. So I think NGSS has done a great service in promoting instruction that helps students learn about science by doing science.

I don’t think that the NGSS is perfect, but I see these standards as an opportunity to promote many goals that I support, and believe the integrated nature of the standards, each of which incorporates disciplinary core ideas, science and engineering practices, and crosscutting concepts, is integral to achieving those goals. For these reasons I would be reluctant to support a large-scale overhaul of the Framework on which the NGSS is built.

However, I do agree with many of the concerns you have written about. For example, there is no disciplinary core idea in the NGSS that covers epidemics—and now pandemics—so strict adherence to the NGSS would preclude teaching about that. However, the NGSS is intended to be a foundation, not a ceiling on what all students learn. Many curriculum developers are producing new instructional materials that are largely consistent with the NGSS and that focus on epidemiology and other additional topics—even if those phenomena are not 100% aligned with NGSS. I think the NGSS can also serve as a template for the integration of disciplinary ideas, practices, and crosscutting concepts, which can guide teachers and curriculum developers in designing materials that integrate practices regardless of the phenomenon being explored.

I do understand that many will interpret the NGSS as some limit on what they should be teaching and empathize with your desire to make sure anything you think is critically missing is directly included. If you feel that critical disciplinary core ideas or practices are missing I would encourage the two of you to suggest specific changes you would like to see in the text of the NGSS. The heart of the document is a set of Performance Expectations (PEs) describing what students should know and be able to do. I recommend you propose adding new PEs that you think are needed. For example, you might add a PE related to epidemiology, or extend the practice on "Obtaining, evaluating, and communicating information" to include student understanding of the role of scientific institutions, like the CDC. However, if you do that you will probably also want to suggest removing some PEs, so the list of expectations does not simply become longer, because, as you know, one of the strengths of the NGSS is that it reduced the number of disciplinary core ideas to make room for more time to learn through engagement in science practices.

Your white paper suggests adding information to the NGSS about how students learn science. I wonder whether you can do that in a meaningful way without adding a large amount of new text and changing the basic structure of the document. The NGSS is intended to provide assessment boundaries. Imagine if we started adding pedagogical directives to the standards. Which should we add? There are many approaches, and it would change the entire nature of the NGSS, so I think it's best to avoid that potential minefield.

Another of your concerns is that you would like teachers to be encouraged by the standards to teach science in the context of societal and personal concerns. That's a great approach, one that has been adopted by many in the education research field who are developing curricular materials aligned with the NGSS. There are two approaches to influencing science teaching related to NGSS—change the NGSS itself, or try to influence the way NGSS is interpreted. The NSTA Position Statement "Teaching science in the context of societal and personal issues" is an example of the latter approach. Those researchers I know developing NGSS-aligned curriculum have all taken a particular stance on what it means to align with the NGSS. They are leading by example. I tend to take that same approach. I don't want to suppress any debate around the NGSS. It's not perfect and will itself be revised someday, so I encourage you to push for the kinds of changes you want to see.

Andy: Dan, the primary goal Penny and I hope to achieve with the white paper is to start a conversation about the strengths and the weaknesses of the NGSS. There is undoubtedly more than one way to improve the existing standards. Your approach is not the same as ours but we share many of the same goals for what science education should accomplish. That is an excellent starting point for a conversation. Thank you for your thoughts about the NGSS.

Modest changes to the NGSS would not be enough

Posted April 20, 2020

A number of science educators believe that the NGSS has sufficient strengths that any improvements should be made simply by adding to or subtracting from the existing document. For example, as we wrote earlier, a science educator who provides professional learning experiences for science teachers reported that he has seen a large increase in teachers seeking help on how to teach from a more student-centered, phenomena-oriented, inquiry-based approach. In his opinion (and he is not alone), the NGSS has done a service in promoting instruction that helps students learn about science by doing science, so he is reluctant to make major changes.

Even though some science educators agree that certain important ideas are missing from the NGSS, their preferred approach would be to add performance expectations (PEs) as needed (e.g., students should be able to describe the functions of some key scientific institutions, such as the CDC). At the same time, in order to keep the list of expectations to a realistic number, as some PEs are added they believe that others would need to be removed.

On the surface this seems reasonable. Certainly some improvements could be made in this way, and that would be a good thing. However, tinkering with the NGSS would not change its overall purpose ("preparing students for college and careers"), which is too restrictive. That approach also would not incorporate NSTA Position Statements advocating teaching more about the nature of science, and linking science to personal and societal issues.

In addition, the requirement that every lesson incorporate the three dimensions identified in the NGSS unduly limits the curriculum. It is not necessary to "do science" every day, focusing only on the list of topics in the NGSS. Some days students might read a news article and summarize it, or research an unfamiliar topic, like vaping, and write a few paragraphs about what they learned. In fact, reviewing articles and lessons published in professional journals such as *The Science Teacher* makes it clear that good teaching does not always look like what the NGSS says it should. The NGSS moved the proverbial pendulum in the right direction—doing more science—but moved it to an extreme.

Lessons from the pandemic about science education

Posted May 27, 2020

Phi Delta Kappan magazine recently published an article we wrote about improving the Next Generation Science Standards, with the title above. The text begins:

> "If students in the United States master everything in the *Next Generation Science Standard*s but learn nothing else about science, then they will graduate high school without knowing anything about immunization, viruses, antibodies, or vaccines, or about organizations such as the Centers for Disease Control and Prevention and the World Health Organization. They will never have been asked to investigate such topics as the efficacy of measles vaccine or the risks of vaping. They will never have been asked to read science-related books or articles in the popular press. Nor, for that matter, will they have been taught how to find reliable sources of information about science or how to evaluate and reject scientific misinformation, such as, for example, fringe theories about the origin of the 2019 novel coronavirus. And yet, these same students will have been required to master a host of more technical standards, such as learning to "use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem," even though few of them will ever use such knowledge."

In the middle of a devastating pandemic, is this the best set of national science education standards that the United States can muster? We don't believe so, and we are not the only ones.

Since the standards were released, the National Science Teaching Association (NSTA) has issued position statements in 2016 and 2020 reiterating how important it is for students to learn about science "in the context of societal and personal concerns," whether to inform their own health care decisions or to allow them to participate in public debates about vaccination requirements, the regulation of pesticides, online privacy protections, the importance of "social distancing," or any number of other policy issues.

Unfortunately, the NGSS does not include "societal and personal concerns" as priorities. We believe more students would be interested in science if their teachers taught the subject in the context of personal and societal concerns. Moreover, by adopting that approach the United States would educate a more scientifically literate population.

NSTA has largely done its part. Improving science education standards will require leadership at the state level and among other national organizations, including the National Research Council of the National Academies of Science. It was the NRC that developed *A Framework for K-12 Science Education*, which acted as a blueprint for the NGSS. Although the *Framework* prioritized teaching science in the context of societal and personal concerns, the NGSS largely abandoned that perspective. It is time for the NRC to weigh in.

We hope that the *Kappan* article attracts a large number of readers, from a wide variety of backgrounds, and not only science educators. As we wrote, "It is often said that war is too important to be left to the generals. One might add that science education is too important to be left to the scientists."

It is vital to teach students about scientific institutions

Posted October 7, 2020

In our recent *Phi Delta Kappan* magazine article Penny Noyce and I quoted a former president of MIT, Susan Hockfield, who wrote in *Science* that if the public hopes to "get the most from this scientific golden age," then it will have to understand the critical roles played by scientific institutions. We pointed especially at governmental institutions whose mission is to use science for the public good.

Teaching about these institutions is easy to do. In fact, I can recall being taught about scientific institutions when I was in elementary school. *My Weekly Reader* included articles about the World Health Organization (WHO), and other scientific institutions, in language appropriate for young people. It still shocks me to realize that the Next Generation Science Standards does not say teachers should mention even a single scientific institution. Authors of the NGSS evidently did not believe that knowing about these institutions is part of the minimum knowledge needed by students to become scientifically literate adults.

American society is now paying a heavy price, because federal science-based institutions—about which most people have been taught nothing—are being attacked by President Trump and members of his administration. Seven former heads of the Food and Drug Administration (FDA) recently issued a public statement expressing deep concern about the politicization of the agency. "At risk," they wrote, "is the FDA's ability to make the independent, science-based decisions that are key to combating the pandemic and so much more." Similarly, four former heads of the Centers for Disease Control and Prevention (CDC) publicly expressed concern that political leaders are "attempting to undermine the Centers for Disease Control and Prevention" and subvert public health guidelines.

Social scientists use the term "inoculation" for the concept that exposure to some important ideas (e.g., fossil fuel companies may use advertising to mislead you) later reduces "infection" by misinformation. It seems very likely that teaching young people about the role and function of key science-based agencies, as well as the nature of scientific integrity, will later help them resist political efforts to undermine those agencies.

The Trump administration has undermined scientific institutions over and over again, for years. Isn't it time for leaders in science education to suggest that learning about the key role of scientific institutions is basic to developing young people's scientific literacy? Unfortunately, the science education establishment is very resistant to re-examining the NGSS. It will be up to states, districts, and hundreds of thousands of science teachers to make the choice to help "inoculate" Americans against anti-science propaganda.

Andy

Developing students' scientific literacy

Posted November 19, 2020

The primary goal of K-12 science education should be to develop students' scientific literacy. For example, the New York State P-12 Science Learning Standards identifies that very goal, stating that, "our education system [should] keep pace with what it means to be scientifically literate."

But what exactly does "scientific literacy" mean? One way to define it would be to stack up the *Next Generation Science Standards* (NGSS), the appendices to the NGSS, and the *Framework for K-12 Science Education* (the template for the NGSS). Scientific literacy could be defined as everything in those documents. But that is close to 1,000 pages of text.

English teachers and science teachers can agree that 1,000 pages makes for an unwieldy definition. Can we do better?

The Program for International Student Assessment (PISA)—which periodically tests thousands of students in dozens of countries across disciplines, including science—developed a more concise definition. For PISA:

> *Scientific literacy is defined as the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen….*

That's not bad. Actually, it's quite good. PISA's definition can easily encompass the three dimensions of the NGSS: disciplinary core ideas (DCIs), scientific practices, and cross-cutting concepts. Scientifically literate people know some science content and understand, generally, how scientists practice science and develop new knowledge.

But beyond that, and equally important, PISA's definition emphasizes, as the NGSS does not, that scientific literacy is for everyone, not just for college graduates or those who often use science as part of their jobs. In other words, the goal of developing students' scientific literacy is simply not the same as "preparing students for college and careers," the stated goal of the NGSS. The latter is a cramped, narrow view of scientific literacy. It conveys a message that the NGSS is a "prerequisite" to the real work that comes later: college and careers. "Don't worry about applying science outside of college or careers," is an unintended message, especially to the millions of students who are not college-bound.

For more than three decades, from the time that *Science for All Americans* was published by the American Association for the Advancement of Science in 1989, key leaders in science education have focused on educating *all* students. As the AAAS book states, "When demographic realities, national needs, and democratic values are taken into account, it becomes clear that the nation can no longer ignore the science education of any students," including the non-college-bound student and the many others who won't use much science in their careers. The book's introduction expands on the idea:

> *Education has no higher purpose than preparing people to lead personally fulfilling and responsible lives. For its part, science education—meaning education in science, mathematics, and technology—should help students to develop the understandings and habits of mind they need to become compassionate human beings able to think for themselves and to face life head on. It should equip them also to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. America's future—its ability to create a truly just society, to sustain its economic vitality, and to remain secure in a world torn by hostilities—depends more than ever on the character and quality of the education that the nation provides for all of its children.*

As Penny Noyce and I have written recently in *Education Week*, the narrow view of the NGSS almost certainly makes science class less appealing to many students. People are interested in themselves and other people, and the national science education standards say little that humanizes science, little that could literally put a human face on the subject. For example, the NGSS does not mention a single scientist by name and the words "women" and "minorities" don't appear in the text of the NGSS.

If Americans want to develop *all* students' scientific literacy, Penny and I believe science teachers need to put a greater emphasis on the following five topics, "keys to scientific literacy." These are:

1. Teach science in the context of societal and personal issues
2. Tie scientific literacy to traditional forms of literacy
3. Teach how to find reliable scientific information and how to reject junk science
4. Include some important events in the history of science
5. Help females and minority students realize their potential in science

The NGSS devotes hundreds of pages to identifying what students should learn, focusing almost entirely on science content and scientific practices. By having students learn mainly about investigating scientific "phenomena," the NGSS leaves behind many other important aspects of scientific literacy.

Andy

Why teach history of science?

Posted December 2, 2020

The Science Teachers Association of New York State (STANYS) asked me to be keynote speaker at their 125th annual conference, which was an honor. The presentation primarily focused on five keys to teaching scientific literacy. This post is about one of them: teaching students some history of science. (The previous post identifies all five keys.)

The title of my 30-minute presentation was "Teaching for scientific literacy, in a pandemic." (A recording is available online beginning at 17 minutes 20 seconds, and for those who want a quick overview, you can download a copy of the slides and an edited text version of the talk.)

When the Next Generation Science Standards was being developed, the National Science Teachers Association wrote that it was important "to make it clear that all students need to understand the nature of science and the history of science." However, in the end history was barely mentioned in the NGSS, or in most state standards. Why does that matter? The answer is that knowing a little about the history of science helps students understand the *nature of science* and how science fits into society. Fortunately, teaching a little bit of history is easy because it takes hardly any time.

A timely example is that opposition to science based on religion, ideology, or simply asserting that something is true, without evidence (as many people in the White House have done during the pandemic), is a familiar and distressing phenomenon. In the early 1600s, when Galileo found evidence that heavenly bodies move around one another, the Church, which was incredibly powerful, ignored the evidence, called Galileo a heretic, and placed him under house arrest. He was courageous, and in the long term his ideas were accepted. In the short term, the Church was powerful and it set back humanity's search for truth.

More recently, a twentieth-century agronomist named Trofim Lysenko rejected the theory of natural selection and other widely accepted ideas about genetics. Lysenko was utterly wrong but he was strongly supported by Joseph Stalin and other Soviet leaders. He set back Soviet agriculture by decades, and was responsible for thousands of unnecessary deaths. Some scientists were even executed simply for rejecting what Lysenko claimed to be true.

Thousands of unnecessary deaths were caused by relying on false "science." That should sound familiar to anyone who has lived through the pandemic. Students should learn that scientists have been held back by ideologues before. Teaching students about Galileo and Lysenko, for example, can help inoculate young people against new false scientific claims made by powerful people. In the face of global climate change and a worldwide pandemic, the stakes of accepting settled science are higher than ever, and more students need to learn some history of science to become scientifically literate.

Several weeks after the keynote talk, *Ed.* magazine, from the Harvard Graduate School of Education (HGSE), published an issue called "Pivot: The Future of Education in a World Turned Sideways." That issue contains an essay I wrote about the need to improve science education, including the following paragraph:

> *Professor Fletcher Watson, who taught at HGSE for more than 30 years, wrote that he made some science education colleagues uncomfortable by prioritizing the word "education" over "science." His point was that experts need to think broadly, beyond their areas of specialization. Although science educators have some first-rate ideas, one does not need to be an expert to identify many key elements of scientific literacy; that is a task for everyone.*

I am grateful to Watson and my other science education mentors for exposing me to their clear and broad-minded thinking about science education. Watson was one of the developers of Harvard Project Physics (HPP), a more humanistic approach than other high school physics curricula of its day. HPP included some key events in the history of science in order to illustrate how scientists do their work.

James Rutherford was also a co-developer of HPP, and later directed the American Association for the Advancement of Science's Project 2061, which in 1989 published *Science for All Americans* (quoted in the preceding blog post). *Science for All Americans* includes an entire chapter called Historical Perspectives, which explains why learning about history of science is important.

Another mentor was Irma Jarcho, with whom I taught at the New Lincoln School. She was interested in and taught K-12 students about all aspects of science, including the impacts of science and technology on society and ethical issues raised by science. In 1982 Jarcho and several of her colleagues founded the *Teachers Clearinghouse for Science and Society Education Newsletter*, which is published to this day.

It is troubling to see what a narrow view of scientific literacy is reflected in current standards documents after all the work done by an earlier generation of science educators. Eliminating a focus on the history of science provides a good illustration of the problem.

Andy