The Challenge of Getting Earth and Space Science Into U.S. High Schools

M. E. Wysession¹

¹Department of Earth, Environmental, and Planetary Sciences, Washington University in St. Louis, St. Louis, MO, USA

Abstract The Next Generation Science Standards (NGSS), which have now been adopted or adapted by 45 states and Washington, D.C., as their public K-12 science education standards, are not only revolutionizing the way science is taught but are providing significant opportunities for an increased presence of Earth and space science (ESS) in public high schools in many states across the U.S. The NGSS, which grew out of the National Research Council’s Framework for K-12 Science Education, are the latest in a > 150-year history of attempts to shape the science education standards within U.S. states. NGSS-designed curricula, which focus on the practices of science and allow students to explore science through following storylines developed around student-relevant phenomena, are engaging and effective, and are reshaping K-12 science courses at a surprisingly rapid pace. In the process, large numbers of U.S. high schools that have never included substantial ESS are now doing so for the first time, providing a significant opportunity to make substantial improvements in general U.S. geoscience literacy. There is still far to go and a successful integration of ESS into the K-12 education across all states will require substantial service work on the part of geoscientists.

1. Introduction

We are in the midst of an amazing if somewhat quiet revolution in the United States: high schools across the states are adding substantial, quantitative, practice-based Earth and space science (ESS) into their curricula at a level never seen in their histories. The path to this has been a difficult one, spanning centuries, with many starts and stalls. I am uneasy declaring any kind of victory at this point, as there is much that has yet to be done and severely limited financial resources for teachers, educational materials, and classrooms make this far from a done deal. However, getting high-quality geoscience into high school curricula is a necessary first step, and with nearly all of U.S. states adopting or adapting the Next Generation Science Standards (NGSS) (National Research Council [NRC], 2013), that has now mostly happened. In this article, I will try to provide my perspective on how this revolution is occurring.

I have another reason for telling this story, which is that I wanted to write an example of a Perspectives journal article, from the perspective of being the current editor-in-chief of the publication. Perspectives is relatively new and of a sufficiently different format than any other AGU journal, so it has garnered a substantial amount of puzzlement and confusion. Although it is important to understand that there is no one single format for Perspectives articles, enough geoscientists have asked me what I think an article should look like that I have decided to provide my own example, weaving together the story of a geoscience accomplishment, in this case related to K-12 geoscience education, with the author’s own personal and professional actions and decisions.

Ironically, starting off this story with an engaging topic (of getting ESS into U.S. high schools) is in keeping with the philosophy of both Perspectives and the subject of the story, the NGSS. The art of storytelling is an effective and tried-and-true means of conveying information, and can be a useful format for a Perspectives article. Similarly, the NGSS are heavily influenced by the ideas behind phenomenon-based learning (PhBL), where students develop a deep understanding of a topic by carrying out scientific practices that follow an engaging storyline wrapped around the hook of a compelling phenomenon. In this case, the hook, the phenomenon, is about getting geoscience into high school classrooms.

In writing a Perspectives article, you may find that the story will write itself, in a sense. My initial idea for this article was of a broad overview of the long struggle to get substantial ESS into K-12 classrooms, spanning more than 150 years, weaving through various aspects of formal and informal education, science education policies, state educational standards, and the textbook publishing industry. As I started writing, however, I found that the compelling story I had to write was of a key period of time from 2009 to 2013 and of the perspective I had
from my own involvement with it. I think that this was a better way both to
depth a reader’s understanding of the K-12 science education landscape and
and motivate readers, in turn, to write their own Perspectives article addressing
their own storyline (and maybe even write a K-12 textbook as well!).

2. Science Education Standards

There are two key things to know about U.S. K-12 science education
standards: we have been struggling with these for a very long time and the
struggling primarily occurs at state and not federal levels. Perhaps the first
documented case of secondary education science standards goes back to
Horace Mann, who adapted the standards of Frederick the Great, the King
of Prussia, for Massachusetts in 1853 (see Figure 1 for an educational time-
line related to this discussion). Since then there have been many different
models for science education standards motivated by a variety of factors that
have included individual personal and career development, national security,
maintaining a stable society, and the continued development of scientific
discovery (see Bybee & DeBoer, 1994 for a good discussion of pre-twentieth
century standards).

It is also illegal in the U.S. to have a national science curriculum, or curric-

The Common Core was a states-led national project sponsored by the National Governors Association (NGA) and the Council of Chief State School Officers (CCSSO) (NGACBP/CCSSO, 2010) that had originally been adopted by 45 states. However, many states later rescinded participation because of the way the Common Core were implemented.

The writing of the Common Core was led by the organization Achieve, which is a non-profit bipartisan organization created at a 1996 National Education Summit by a group of state governors and business leaders. Achieve worked under the guidance of the NGA and CCSSO. Both hold the copyright to the Common Core, so although this was a national project, it was not a federal one. However, this distinction got a bit fuzzy when the U.S. federal government made funds available to states on a competitive basis through the “Race to the Top” program.

“Race to the Top” (R2T) provided $4.35 billion in funds through the 2009 American Recovery and Reinvestment Act (ARRA) that were to be provided to the 12 states that scored highest in a competition based on a rubric that involved a wide set of criteria related to improving math and English education. A requirement of eligibility for the R2T funds was that a state commit to the adoption of the Common Core (Wysession & Rowan, 2013). This began to resemble a federally mandated curriculum, and irrespective of the quality of the standards, the Common Core began to receive considerable push-back, particularly from traditionally conservative state legislatures.

When we started the work at the National Academy of Science (NAS) committee that would produce the report A Framework for K-12 Science Education (NRC, 2012), it was our intention that the science standards that would result from our report would be something like “CCII” – a Phase Two of the Common Core. By the time we were

3. The Common Core

Another challenge that the NGSS faced was that it followed the 2010 roll-out
of the “Common Core” standards for mathematics and English language arts.

The Common Core was a states-led national project sponsored by the National Governors Association (NGA) and the Council of Chief State School Officers (CCSSO) (NGACBP/CCSSO, 2010) that had originally been adopted by 45 states. However, many states later rescinded participation because of the way the Common Core were implemented.

The writing of the Common Core was led by the organization Achieve, which is a non-profit bipartisan organization created at a 1996 National Education Summit by a group of state governors and business leaders. Achieve worked under the guidance of the NGA and CCSSO. Both hold the copyright to the Common Core, so although this was a national project, it was not a federal one. However, this distinction got a bit fuzzy when the U.S. federal government made funds available to states on a competitive basis through the “Race to the Top” program.

“Race to the Top” (R2T) provided $4.35 billion in funds through the 2009 American Recovery and Reinvestment Act (ARRA) that were to be provided to the 12 states that scored highest in a competition based on a rubric that involved a wide set of criteria related to improving math and English education. A requirement of eligibility for the R2T funds was that a state commit to the adoption of the Common Core (Wysession & Rowan, 2013). This began to resemble a federally mandated curriculum, and irrespective of the quality of the standards, the Common Core began to receive considerable push-back, particularly from traditionally conservative state legislatures.

When we started the work at the National Academy of Science (NAS) committee that would produce the report A Framework for K-12 Science Education (NRC, 2012), it was our intention that the science standards that would result from our report would be something like “CCII” – a Phase Two of the Common Core. By the time we were
done, however, there was no longer any such talk, and when the NGSS work began, it not only had a different title but a different set of procedures from the Common Core.

4. Earth Science Literacy Initiative

My involvement with the NRC Framework was as chair of the ESS Design Team. That invitation, however, followed many years of professional decisions on my part, some easy, some difficult. By the time the NRC Framework was beginning (2009), my career focus for two decades had been on deep-mantle seismological research at Washington University in St. Louis (WashU), but I had kept one foot in the world of K-12 science education.

Post-undergraduate (Brown University, 1984) I was a middle and high school math and physics teacher in Staten Island, New York. Although very rewarding in many ways (certainly not financially – my subsequent annual graduate stipend at Northwestern University was larger), it was the most difficult job of my career and I only lasted 2 years. However, it gave me an important perspective on K-12 education that I could have gotten in no other way.

I left the K-12 world in all ways in 1991 when I started as a junior WashU professor, but in 1998 the opportunity arose to contribute to the writing of a new ninth-grade-level physical science textbook with the publisher Prentice Hall (Wysession et al., 2004). “Physical science” is a strange course, combining physics and chemistry into a single year of science that some states then required as the first of two years of required science (the second year usually being biology) and other states required as a prerequisite for later chemistry and physics courses. Physical science is less common now that most states have moved to requiring three or four years of high school science. Some states even crammed some ESS chapters in with the chemistry and physics, and that was where I got invited: to write the five ESS chapters. However, with my physics background and teaching experience, I soon had written most of the physics chapters as well.

There is a snowball effect that usually happens with careers – the more you do of something, the more that opportunities of that something arise. That happened for me with educational work. From 2005 to 2010 I served as chair of the Education and Outreach (E&O) standing committee for IRIS (Incorporated Research Institutions for Seismology). The IRIS E&O program, which has been brilliantly led by John Taber for more decades than he would like to admit, was the largest and most impactful E&O program funded by NSF-GEO. At that point IRIS E&O had already created materials at many levels of formal and informal education, with a substantial contribution in the area of K-12 materials, largely due to the pedagogical expertise of Michael Hubenthal (Taber et al., 2009).

My work with IRIS E&O then snowballed into co-chairing the Earth Science Literacy Initiative (ESLI). ESLI was the brainchild of Jill Karsten, the longtime Program Director for Education and Diversity within the Directorate for Geosciences (GEO). Jill foresaw the national need for an Earth science literacy framework and set aside funds for its construction. The ocean sciences community had begun something similar earlier in 2002, culminating in the 2005 Ocean Literacy Principles and Fundamental Concepts (NGS, 2006; Schoedinger et al., 2010). In 2006 the climate science community started on a similar framework, funded by NOAA and AAAS (U.S. Global Change Research Program [UGCRPCSP], 2009), and in 2007 the atmospheric science community followed suit with funding from NSF and NOAA (University Corporation for Atmospheric Research [UCAR], 2008).

Because of the prominence of the IRIS E&O program within the geoscience education community, Jill asked John Taber and me to co-chair a parallel Earth Science Literacy effort, and ESLI began in 2008. By the following year, 150,000 copies of the complete Earth Science Literacy Principles (ESLPs) were printed in time (October, 2009) for 16,000 to be mailed by the American Geological Institute (AGI) to all U.S. K-12 earth science teachers as part of the annual Earth Week distribution. Synergy is always a good thing when making career choices and part of my decision to undertake this role with ESLI was that I was concurrently filming a 48-part video lecture course for the Teaching Company’s “Great Courses” video lecture series called “How the Earth Works,” based on 15 years of teaching intro undergraduate Physical Geology (Wysession, 2008). I had just gone through an extensive examination of the scope of Earth science, prioritizing the essential geoscience that would make it into the 24 total hours of video content, so I was as ready as I would ever be for leading the construction of an Earth science literacy framework.
The creation of the ESLPs was an extraordinary example of community cooperation. At its core was a remarkable organizing team of scientists with diverse backgrounds across the geosciences who also had a dedication to education (including David Budd, Karen Campbell, Martha Conklin, Gary Lewis, Robert Raynolds, Robert Ridky, Robert Ross, and Barbara Tewksbury). Jill Karsten assigned a dynamic and expert young NSF Einstein Fellow, Nicole LaDue, a former high school Earth science teacher (and now prominent science education professor), to facilitate the project, which was later overseen by NSF program manager Lina Patino. The project began with a 2-week online workshop for 350 geoscience researchers and educators, a remarkable achievement at that time, facilitated by Peter Tuddenham of the College of Exploration. It was followed by a 36-person in-person writing workshop and many rounds of reviews and approvals. The final 9 “Big Ideas” and 75 “supporting concepts” were released as an attractive brochure and an AGI-produced set of accompanying videos (Earth Science Literacy Initiative [ESLI], 2009; Wysession et al., 2012).

5. NRC Framework for K-12 Science Education

The ESLPs were widely used in a variety of arenas such the development of educational products and meetings with Congressional staffers; in an age of rampant misinformation and even disinformation, there is tremendous power in being able to hold up something and say “The science community stands behind this!” In the face of the current flood of information, there is also a need for experts to identify the essential information of scientific fields. With a rapidly growing Internet, there is no shortage of information in the world: “google” the word “volcano” and a half-second search now returns more than 2 billion results. However, this is overwhelming for people and the “wiki” algorithms that prioritize the most frequently visited sites cannot be trusted to show the most important ones. Most importantly and relevant to this discussion, the ESLPs also provided the foundation for the ESS content of the NRC Framework and, in the process, the NGSS.

When we began the work at the National Academy of assembling the science content for the NRC Framework, we (the ESS team: me, Don Duggan-Haas, Scott Linnemann, Eric Pyle, and Dennis Schatz) had a huge advantage over the other three Design Teams of Life Sciences, Physical Sciences, and Engineering. Those teams had to roughly start from the beginning on assembling what would be called the Disciplinary Core Ideas (DCIs) of their fields, whereas we held the community-created Earth science, ocean science, atmospheric science, and climate science literacy frameworks in our hands, hot off the presses.

Sadly, this was not the case for space and planetary science. I had tried hard to get NASA to pull together a community-driven literacy framework, but it never materialized. During this time period I was occasionally teaching a 3-day workshop to NASA engineers on the geology of Earth, Moon, and Mars. I did this about a dozen times at various different NASA research centers as part of NASA’s internal education program (the affable director, Roger Forsgren, had seen my “How the Earth Works” video course and asked if I could do something focused on planetary geology for NASA’s internal education program, APPEL), and this gave me the opportunity to interact and collaborate with many brilliant NASA scientists (including Harrison “Jack” Schmidt, which was a remarkable honor for me). However, the fragmented and competitive nature of the various NASA centers proved to be an insurmountable obstacle to getting them to coordinate on a space and planetary science literacy framework.

The goal of the 2011 NRC Framework (the final draft was released in 2011, although the official publication date is 2012) was to provide guidance for the construction of the states' science education standards, following in the footsteps of the highly influential previous NRC report, the 1996 National Science Education Standards (NSES) (NRC, 1996). Our Framework team was a fascinating mixture of people, deftly organized and coordinated by Berkeley physicist Helen Quinn. There were three distinct groups participating: (a) esteemed scientists, mostly National Academy members, including some Nobel prize winners; (b) experts in the scholarship of teaching and learning, the psychology of student learning progressions, and educational curricula and assessment; (c) and the disciplinary Design Teams, populated by a mix of people with interests in both research and education within specific fields. The other three design teams (besides ESS) included Life Sciences (chaired by Roger Bybee), Physical Sciences (chaired by Joe Krajcek), and Engineering (chaired by Cary Sneider).

I initially feared that things would not go well for ESS. Until renowned geophysicist Tanya Atwater came aboard near the end of the project, the group of senior scientists did not include a prominent geoscientist and I feared that the committee recommendations would ignore the geosciences. My fears were allayed when Helen Quinn ran a
group exercise to help identify the Big Ideas of science that we should all focus on. A large goal of the Framework was to stop the “mile wide, inch deep” approach to science education, where every topic is briefly covered with little time for students to delve deeply into anything. We set a goal of having state standards reduce the total volume of content by 10% to allow more time for deeper student investigations. We went around the room and each person got to pick one Big Idea. To my great surprise and glee, the list of topics read like something out of our Earth Science Literacy Framework: climate change, pollution, severe weather, human impacts on the biosphere, water security, energy resources, forecasting natural hazards, and so on.

This was the first moment where I thought that we had a chance of getting substantial ESS into high school. Although it was still very much the case that high school teachers of biology, chemistry, and physics, as a whole, poorly understood and inadequately valued the geosciences, this was not the case for the leading biologists, chemists, and physicists who were in that room. They understood the importance of the scientific relationship between humans and their planet, and this relationship largely fell within the ESS domain. From this point onward, the three silos of Life Science, Physical Science, and ESS were treated as equals within the Framework.

Our Design Team’s work consisted of establishing the “Big Ideas” of ESS and then laying out grade-banded progressions of what students needed to understand at what grades. The first step was fairly straightforward. We had three Big Ideas: (a) Earth’s Place in the Universe (big space and deep time, with the marvels of space and planetary exploration and the fascination with fossils and historical geology); (b) Earth’s Systems (essentially Earth System Science), and (c) Earth and Human Activity. It was clear that our equal footing with Life and Physical was because of Big Idea #3, which addressed natural resources, natural hazards, human impacts on Earth systems, and global climate change.

More difficult was the task of determining what it was that students should be expected to understand about ESS at different developmental stages, based on research into learning progressions, a field that uses the psychology of child development to determine how scientific understanding should be sequentially scaffolded. Unfortunately, very little of this research had been done in the geosciences, so we went with our best guesses as to what students should be expected to understand in 12 Big Idea subtopics by the ends of second grade, fifth grade, middle school, and high school.

Tanya Atwater joined the committee and had a major focus on the human contributions to climate change, so these grade-band expectations grew to be quite substantial, but soon had the problem that the human impacts and global climate change sections read like long laundry lists of human evils. Given the dominant role that humans now have as the largest agent of geologic change on the planet, with devastating effects to the biosphere (World Wildlife Foundation [WFF], 2020), it is easy to dwell on the many large-scale problems that result from human activities. However, it is also important for students to maintain a sense of hopefulness when studying these topics. Cary Sneider, from the engineering group, helped tremendously here by suggesting that we use the design principles of engineering to take a more solutions-minded approach to developing student understanding about human impacts and climate change. This approach carried through to the writing of the actual NGSS standards, and the educational results have been much better for it. The result was substantial ESS, with a strong focus on mitigating human impacts, recommended for students in high school as well as middle school.

Of course, the lessons of the 1996 NSES reminded us that this was not sufficient. Just having recommendations in a National Academy report did not necessarily change classroom teaching for the better. The NRCS’s (1996) NSES had also recommended substantial high school ESS. In fact, the NSES had most of the same pedagogical recommendations that we had, only 15 years earlier. However, all of the various NSES standards— for the science content, practices, crosscutting themes, and even for educational systems, professional development, and assessments—were all in separate chapters and the important human-critical geoscience topics were separated from the rest of ESS in a vaguely identified section called “Science in Personal and Social Perspectives.” The NSES did indeed have a large impact on state K-12 science standards. About two-thirds of U.S. states went on to revise their state science standards based on the 1996 NSES. (The other third of U.S. states revised their science standards based on the 1993 Benchmarks for Science Literacy report and associated 1989 Science for All Americans report by the American Association for the Advancement of Science, which both came out of the AAAS Project 2061 program [American Association for the Advancement of Science [AAAS], 1989, 1993]) However, most states went in to these benchmarks, picked out what they were interested in, and left the rest. State science
standards largely ended up as lists of facts for students to memorize, assessed with multiple-choice tests of memory recall, and divorced from ideas of actually doing science.

This was where Helen Quinn and the Framework organizing committee did something very clever and impactful, ingenious in its simplicity. They decided to weave together the science content, science practices, and science themes in such a way that no one part could be pulled away from the others. The idea was that the science content (the disciplinary core ideas, or DCIs) would be parsed into individual performance expectations (PEs) with minimal overlap, and that each PE would include part of the eight science and engineering practices (SEPs) and part of the seven scientific cross-cutting concepts (CCCs) in ways that could not be broken out (Table 1). This was called “three-dimensional learning,” and the hope was that states would not be able to pick and choose which parts of the standards they wanted, but would instead have to take all of it together. In the NGSS process, this became known as “All standards, all students,” meaning that not only were the NGSS standards designed to apply to all students (these were not just for accelerated “honors” students) but states were expected to adopt all of the standards for all of the students, and not just a subset of them.

### Table 1

Two of the “Dimensions” of the Next Generation Science Standards, the Practices and Concepts, Showing the Eight SEPs (Science and Engineering Practices) and Seven CCCs (Cross-Cutting Concepts) as Well as the Connections to Nature and Science (CNS) and to Engineering, Technology, and Applications of Science (CETAS)

| Practices | Concepts |
|-----------|----------|
| SEP1. Asking questions (for science) and defining problems (for engineering) | CCC1. Patterns |
| SEP2. Developing and using models | CCC2. Cause and effect: Mechanism and explanation |
| SEP3. Planning and carrying out investigations | CCC3. Scale, proportion, and quantity |
| SEP4. Analyzing and interpreting data | CCC4. Systems and system models |
| SEP5. Using mathematics and computational thinking | CCC5. Energy and matter: Flows, cycles, and conservation |
| SEP6. Constructing explanations (for science) and designing solutions (for engineering) | CCC6. Structure and function |
| SEP7. Engaging in argument from evidence | CCC7. Stability and change |
| SEP8. Obtaining, evaluating, and communicating information | CNS5. Science is a Way of Knowing |
| CNS1. Scientific Investigations Use a Variety of Methods | CNS6. Scientific Knowledge Assumes an Order and Consistency in Natural Systems |
| CNS2. Scientific Knowledge is Based on Empirical Evidence | CNS7. Science is a Human Endeavor |
| CNS3. Scientific Knowledge is Open to Revision in Light of New Evidence | CNS8. Science Addresses Questions About the Natural and Material World |
| CNS4. Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena | CETAS1. Interdependence of Science, Engineering, and Technology |
| | CETAS2. Influence of Science, Engineering, and Technology on Society and the Natural World |

Note. Four of the nature of science topics are part of the practices and four are part of the concepts. So, although the NGSS is described as being “three-dimensional” learning, there are really more than three dimensions, as aspects of metacognition are included with the Nature of Science topics (how we know what we know) and aspects of character and morality are included with the CETAS (what we should do with the science). SEP = Science and Engineering Practices; CCC = Cross-Cutting Concepts; CNS = Connections to Nature of Science; CETAS = Connections to Engineering, Technology, and Applications of Science.

6. The Next Generation Science Standards (NGSS)

The work of the NRC Framework went straight into the writing of the NGSS. We knew that our work would not be implemented without a clearer interpretation of what was meant by “three-dimensional learning.” We would have to write the actual PEs, which were only hinted at in the Framework, and so began the great balancing tightrope walk of the NGSS, led by the curriculum specialist Stephen Pruitt. Stephen with his relaxed charm, cheerful Georgia drawl, and keen political acumen was the perfect choice to lead the writing of the NGSS, much the way that the scientific visionary Helen Quinn was perfect to lead the NRC Framework.

The NGSS were all about balance because we wanted the standards to be rigorous but still widely adopted, and we had no carrot and no stick to make the states adopt them. We needed to give sufficient guidance for the
development of NGSS-derived K-12 science curricula but also be clear that the NGSS were not a curriculum (which would be, after all, illegal). We saw the pushback that the Common Core had received and made sure that the federal government said nothing about us. Not only were there no “Race to the Top” billions of dollars but not a single penny of federal funds went to the writing of the NGSS; it was funded by the Carnegie Foundation of New York with some additional philanthropic support. There were no big announcements by President Obama and Secretary of Education Arne Duncan, as there had been with the Common Core, so we largely flew under the political radar: at least, that is, until we were finished and people saw what we had written about climate.

The writing of the NGSS was facilitated by the governor’s association Achieve, just as the Common Core had, but the similarities stopped there. The Common Core had gotten some initial public input, but the writing team then worked mostly in private and emerged from seclusion with the finished standards. Stephen Pruitt decided that the NGSS would have a greater chance of being adopted if more people had a share in its creation and if the process was more open. He first assembled an extremely large writing team, more than 50 people, from all corners of the science and education worlds and from a large number of states, including some (such as Texas and Virginia) that had announced in advance that they would have nothing to do with the NGSS. The ESS writing team for middle and high school that I chaired included a fabulous mix of people from primary, secondary, and higher education (Mary Colson, Rick Duschl, Ken Huff, Paula Messina, and Paul Speranza).

We also wanted to have some states officially participate, to add more credibility and buy-in to the standards, and hoped that a few would volunteer. We were surprised when a half-dozen states immediately volunteered, and Stephen soon cut off the number of volunteers at 26 states. It was nice to be able to say that more than half of the U.S. states were directly involved with the writing of the NGSS, and even nicer that (at that time) half had Democratic state legislatures and half had Republican ones. This really was a bi-partisan states-led effort, which lessened the danger of perceived threats to states' rights. A total of 35 states were represented either as part of the writing team, as a lead state partner, or both. Unlike with the Common Core, the NGSS went out for two public reviews (May 2012 and January 2013), as well as multiple internal versions for lead state partners and other groups such as college and career readiness. In fact, version control became a significant organizational problem when multiple versions were circulating simultaneously; I lost count somewhere after version 12.

In retrospect, one of the most important allies for the NGSS had emerged in the form of high-tech businesses, which had been struggling to find enough U.S. employees to fill vacant jobs in fields related to STEM (Science, Technology, Engineering, and Mathematics). These businesses were going to their governors, even in “red” states, and saying that they would have to leave their states and relocate if they couldn’t find enough qualified local employees. Their message was essentially that they did not care what their governors’ views of climate change or evolution were; if the STEM education in their states did not improve, tech companies would have to leave.

This turned out to be a very good thing for the NGSS, which, in another important change from the 1996 NSES, incorporated math and engineering at all levels. The NGSS were very much a STEM program, with the “TEM” parts of technology, engineering, and math built in from the start. For example, four of the SEPs (#2–#5 in Table 1) are strongly connected to mathematics skills (the other four are connected with English language skills), and two of the SEPs (#1 and #6 in Table 1) have separate provisions for both science and engineering. In fact, engineering appears in all three of the NGSS dimensions, with specific DCIs related to engineering design and the Concepts dimension (CCCs) including principles associated with “Connections to Engineering, Technology, and Applications of Science” (Table 1). States had made it very clear that they were looking for STEM curricula, and the Framework and NGSS provided the basis for them.

The NGSS were completed just in time for the April, 2013, annual meeting of the NSTA (National Science Teachers Association) in San Antonio, TX, where they were first unveiled, but not without some drama that began with what I called the Valentine’s Day Massacre. By the date of our last NGSS committee meeting (February 14, 2013) we thought that everything was finished. We had worked to make sure that all the DCIs were covered and that all of the different SEPs and CCCs were implemented at all grade levels (the goal was for a student to be able to experience all 8 practices and reinforce all 7 cross-cutting concepts each year). However, when the meeting started, Stephen Pruitt told us that that there were too many PEs and that some lead states were threatening to drop out unless we cut the PEs back. We asked how much had to be cut. He said a third to a half.
The next 2 months were the worst of my professional career. Not only did all of the standards have to be rewritten, with all the three dimensions rebalanced, but what began was a steady erosion of the Earth and space standards that we had fought so hard to get into middle and high school. The other areas got cut too, but my concern was with the ESS. There is a gut-wrenching passage in Hemingway’s “The Old Man and the Sea” when the old man first sees the sharks that will gradually and methodically tear away all of the flesh from the large fish he has caught. That was how I felt. Before that day we had 35 ESS PEs in middle school and 29 in high school. By the April NSTA meeting that was down to 15 in middle school and 19 in high school: a 50% reduction. But maybe Sophie’s Choice would be a better analogy, because I was the one responsible for having the final word on which of our “children” the ESS writing team cut out.

Some standards we were able to merge, retaining the scientific topics. For others the reinforcing repetition across different disciplines (ESS, Life, and Physical) and different grade bands got cut, but the ideas remained somewhere within the standards. For example, climate was initially in both middle and high school, but we had to limit weather to middle school and climate to high school (which does not make scientific sense), but at least the concepts remained. But then we had to start real cutting. With each successive removal, I knew that the “teach to the standards” mentality of most states meant that there would now be important ESS concepts that would not be taught in American K-12 schools. There were late nights where I was on the phone with Stephen Pruitt, begging and pleading to keep certain ESS standards that were on the chopping block. Some of those battles I won. Most I lost. I totally agreed with the goals of the decimation; the NGSS would fail if they were too large to be implementable. I just did not want any of our hard-fought geoscience to get cut. In the end, the amount of ESS was still substantial, and had the appropriate emphasis on developing solutions that reduced and mitigated human impacts (an example of one of the high school ESS PEs is shown in Figure 2 and the rest can be found at Next Generation Science Standards [NGSS] (2022)). Maybe in a future revision some of the cut geoscience will make its way back into curricula.

7. State-Wide Reception of the NGSS

We were caught a bit off-guard by the pushback to the climate standards. Based on previous experiences, we were expecting resistance to the evolution standards, so we sought assistance in advance on how to prepare for this from experts such as Eugenie Scott, of the National Center for Science Education, and Ken Miller, a biology professor at Brown University who successfully argued against “intelligent design” in the Dover, PA, court case (Miller, 2008). However, and fortunately, very little resistance to evolution came. Where significant resistance did arise, however, was concerning the climate-related standards. Climate plays a role in 9 of the 19 high school ESS PEs. More significantly, in the middle school standards we had a PE that stated “Students who demonstrate understanding can ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century,” and explicitly added in the Clarification Statement that “Emphasis is on the major role that human activities play in causing the rise in global temperatures.” We spent a lot time agonizing over those sentences, because although they were true and important, we feared that we might lose some states because of them, and, initially, we did.

Wyoming and West Virginia, the two leading coal producers in the U.S., were both initially enthusiastic about the NGSS but dropped out when they saw the emphasis on climate. Other states took a similar stance. We were not surprised and even took it as a sign that we were doing the right thing when the Heritage Foundation, an influential conservative public policy organization, criticized our climate standards, but we were frustrated to have lost states. In the end, however, the groundswell of support for the NGSS from teachers caused these states to adopt the NGSS anyway, but with a compromise. The pedagogy was usually fully NGSS but the scientific content of the standards was altered slightly. These states became known as “adapting” states, as opposed to “adopting” states. In some cases the adaptations were large: in Oklahoma the enthusiasm for the pedagogical advancements of the NGSS was high, but the Oklahoma state natural gas pipeline licensing board got to edit out much of the climate content. In other cases the adaptations were small: in West Virginia, the only substantial change was in the middle school PE mentioned above, altering the “rise in global temperatures” to “change in global temperatures,” but this was enough for the other adopting states to kick West Virginia out.

The option of adapting the NGSS ended up being a good thing in that it has brought the foundational ideas of the NGSS to many states that were initially dismissive of them. My own state of Missouri initially rejected the NGSS.
However, in town after town, K-12 science teachers started adopting its teaching methods anyway. Eventually, Missouri had no alternative but to redo their standards to align with the NGSS. The Missouri state science standards go by a different name (“Missouri Learning Standards”), but they are 99% NGSS. As of the start of the year 2022, 20 states and the District of Columbia have adopted the NGSS and 25 states have adapted them (https://ngss.nsta.org/about.aspx). That leaves only Florida, North Carolina, Ohio, Texas, and Virginia as holdouts, but even these states have embraced many of the principles of the NRC Framework such as three-dimensional learning, the eight SEPs, and PhBL. This high level of implementation was far beyond our hopes when we both began and completed the NGSS project.

8. NGSS-Designed Curricula

Just because we had to make sure that the NGSS were not a curriculum does not mean that we did not provide advice on what an NGSS-based curriculum might look like. Appendix K of the NGSS (NRC, 2013: https://www.nextgenscience.org/sites/default/files/Appendix%20K_Revised%208.30.13.pdf) was our attempt to map out how the PEs should be organized within a school system. The NGSS were released as year-by-year standards for...
elementary school but in 3-year grade bands for middle and high school. In Course Map A of Appendix K, the “Conceptual Progressions” Model, all of the science is integrated into three courses (for both middle and high schools) in a way that most efficiently uses a progression of concepts. This is similar to the “Physics First” approach of some high school curricula, where you teach the sequence of physics→chemistry→biology because the chemistry builds upon the physics and the biology builds upon them both. For the NGSS, where physics and chemistry are merged together into “physical science” and not separately discussed, our 3-course progression was primarily physical science in the first course (sixth and ninth grades), primarily life science in the second course (seventh and tenth grades), and primarily geoscience in the third course (eighth and eleventh grades), because the geoscience builds upon both the physical and life systems. This model has been heavily adopted by middle schools across the country, but not very much at high school, where geoscience is rarely taught at higher grades.

The simpler way to organize high school science (the “Science Domains” model, Course Map #2 of Appendix K), is to have a year each of Physical, Life, and ESS (or, if you have 4 required years of high school science, as some states do, a year each of biology, chemistry, physics, and ESS). I pushed hard for this model because I wanted to see a dedicated high school geoscience course adopted nationwide. The common high school science curriculum of biology, chemistry, and physics dates back to the recommendations of the Committee of Ten Report of 1893, chaired by Harvard University president Charles Eliot (NEA, 1893; Wysession, 2014). At that time, the science courses of any given high school could consist of a seemingly random set of electives. The Committee of Ten, frustrated by the lack of standard science backgrounds of incoming college students, suggested that science be 25% of a high school curriculum and that grades 9–12 consist of, in sequence, Physical Geography, Biology, Chemistry, and Physics (Lewis, 2008; NEA, 1893).

This report did have some impact on the confusing jumble of state science standards, and a ninth-grade Physical Geography course did gain traction in high schools in the early 1900s. However, even ninth-grade physical geography began to lose ground as the twentieth century progressed, largely for two reasons: (a) many influential educators advocated for student understanding of “the scientific method” and of the experimental sciences of chemistry and physics (as opposed to the observational geosciences) as the best way to do it (Dewey, 1944); and (b) national security became an increasingly important part of science curricula following the two World Wars, favoring chemistry and physics because of their increasing roles in modern warfare (Bybee & DeBoer, 1994). By the start of the 21st century, only 7% of U.S. students were getting any geoscience education in high school (Barstow & Geary, 2002).

Sadly, although the ESSs have blossomed into vibrant areas of scientific research in the 130 years since the Committee of Ten report, there is little way that high school students would know this. Incoming college students are often amazed that the annual NSF research funding for the geosciences is greater than any of biology, chemistry, or physics. There is tremendous inertia in public education systems and change is very difficult. In this case, very few schools will add a dedicated high school ESS course because there are not enough high school-certified geoscience teachers available and it takes a long time to build a pipeline to get them. It is a cruel chicken-and-egg dilemma: you can’t build geoscience courses in high school because there aren’t enough certified teachers, but there aren’t enough high school geoscience teachers because there are so few high school geoscience courses for them to teach.

As a result, most U.S. high schools are opting for Course Map #3 (“Modified Science Domains” model), where you keep the traditional biology, chemistry, and physics courses and insert the chopped-up ESS content into each course. Geobiology goes into the biology course, geochemistry into the chemistry course, and geophysics into the physics course, with geology stuffed in wherever it can fit, which is mostly into chemistry because there are only 9 chemistry NGSS PEs for high school, compared to 19 for ESS. It seemed ridiculous to me that chemistry should get its own course when there are twice as many NGSS PEs for ESS than for chemistry, but this kind of curriculum works best with existing school staffs in many U.S. schools because they already have the biology, chemistry, and physics teachers.

9. Phenomenon-Based Learning

It is somewhat ironic, therefore, that the high school textbook programs for both chemistry (“Experience Chemistry”) and physics (“Experience Physics”) (Cochran et al., 2021; Moore et al., 2020) that I have coauthored have followed Course Map #3, of which I was so scornful. What sold me on this model was the elegance of a
curriculum model developed by the state of California: the “3-Course Integrated High School Science” model (California Department of Education [CDE], 2016). This curriculum used ESS phenomena as the basis for the storyline investigations that served as the glue that held the units of instruction together (Achieve Inc., 2016). ESS was not only integrated into the biology, chemistry, and physics courses, but it served as the motivation for learning the material. When I saw this, I realized that this was likely to be the best way at this point in history to get sufficient ESS into high school.

The NGSS were heavily influenced by a theory of student learning called phenomenon based learning (PhBL). This approach to teaching science began in Finland, spread throughout Scandinavia, and is now being implemented around the world. The idea is that students learn best through the method of storytelling and that scientific phenomena can serve as the anchoring foundations for compelling storylines of instruction that allow students to learn as they investigate the topic. These phenomena are best when they are intriguing to students and relevant to their lives. Teachers motivate students to continually ask questions about a phenomenon, and student questions then drive the sequence of investigations through their own experiences with the different SEPs. Additional practices and content are brought in as needed and students never have the excuse to ask “why do we need to know this?” because the investigations are always addressing their own questions. For example, a phenomenon-based question could be “Where did my body come from?” or “How old is my body?” which would integrate questions not only of biology but also physics, chemistry, and ESS (nucleosynthesis, radioactivity, supernovae, the Big Bang, etc.). A good description of how phenomena are used in the NGSS is in the PEEC (Primary Evaluation of Essential Criteria) document largely written by Roger Bybee (the chair of Life Sciences for the NGSS) (Achieve Inc., 2017).

The California model not only used ESS topics as the anchoring phenomena for their high school science curriculum, but used the kinds of compelling and relevant phenomena that are important to students. Their Chemistry course would present chemical reactions using the example of the combustion of hydrocarbons combined with the phenomenon of the rise in atmospheric carbon dioxide and its connection to climate change and resulting severe weather in California (e.g., droughts and forest fires). Students would learn about acids and bases through the storyline of the acidification of the ocean and its increasing harm to coral reefs. The model looked great, but there were not yet any complete educational programs that did this. So, we wrote a Chemistry program for California. Chris Moore (University Nebraska, Lincoln) and Bryn Lutes (Washington University) wrote the chemistry and I wrote the integrating geoscience. The book was produced by Savvas Learning, with some of the same editors I had worked with back when I did the Prentice-Hall Physical Science book (in the interim, Pearson had bought up Prentice-Hall and merged it with Scott-Forsman, but finally realized it had no idea what to do with K-12 education and sold off the division in 2019, which became Savvas). The program, Experience Chemistry, ended up being well-enough received that we soon made a national version that is now being adopted within many other states.

The program was an enormous amount of fun to write. It wasn’t a textbook in any traditional sense. Yes, there is a student workbook, with questions on every page (looking at graphs, analyzing data, doing calculations, etc.), but the foundations of the program were multiple sets of activities (physical and digital laboratory experiments, class demonstrations, discussions, etc.) that spiraled around the phenomena using a repeating “5E” approach (Engage, Explore, Explain, Elaborate, Evaluate), which had also been developed by Roger Bybee (Bybee, 2009). I am elated that the student handbook is able to include ~150 pages related to climate science and climate change (in a national Chemistry program!), but the success of the program, as seen in assessments of pilot studies, is basically because this way of learning is more fun for both teachers and students.

There was an analogy that bounced around the NGSS meetings concerning the importance of having students enjoy doing science. Suppose you had to design a curriculum to teach students how to play baseball and softball. One approach would be to sit students down in a classroom, have them read a heavy textbook and memorize the rules of the game, dimensions of the field, etc., and then take a high-stakes multiple-choice test on it. Students that did well on the test would go into an honors course where they would learn the more advanced and confusing rules (like the infield fly rule, or why the ball is fair if it hits the foul pole), the statistics of professional teams, etc. At the end of a year, how well would the students be able to play baseball or softball? Not very well, nor would they enjoy it. Unfortunately, this is what we have done with public science education for many decades, with the result that the majority of high school students find science classes to be boring and tedious.
Science, as recommended back in the 1893 Committee of Ten Report, was all about doing science; standards were largely based on the laboratory experiments that students would do, not the facts they would memorize. Somehow U.S. science education lost its way over the 125 years that followed and standards became more about memorizing facts for multiple-choice assessment tests. The way that children learn to play baseball and softball is that you give them a ball and a bat and they go out and get their knees dirty and have fun because baseball and softball are fun. In the process, however, children do end up learning the rules of the games and even the statistics of their favorite teams, but only because they learned to enjoy them first. More importantly, they will follow the game and root for their favorite teams for the rest of their lives. We need to have this approach to teaching science. Science is fun to do, so we need to make sure that students love to do it first. They will eventually “learn the rules” and even continue to follow it for the rest of their lives, but only if it is something that they first learn to love.

And, surprisingly, research shows that students who learn science by actively and deeply investigating a smaller number of topics end up scoring better on those same multiple choice tests than students who cover all of the material on the test through passive instruction. NGSS is a progressive program, ironically, by bringing American science education back to its nineteenth-century roots in terms of emphasizing the practices of science. It is partly for this reason, because it is more enjoyable for both students and teachers, that the NGSS is being widely adopted across the U.S. in both liberal and conservative states at a time in this country’s history where unprecedented political polarization has prevented agreement on very many things. The inclusion of ESS was not the reason why the NGSS has been embraced, but it has been carried along for the ride (which is fine by me!), and advanced ESS is now being incorporated into a large number of high schools across the country. There is much work to be done, and many school districts that have adopted the NGSS still have not integrated ESS into their high schools, but as a nation, we are going in a good direction toward creating a citizenry with a geoscience literacy sufficient to address the important Earth-related challenges that face us.

One area that remains a significant problem for the ESS is the continuing lack of diversity, equity, and inclusion (DEI) within the geosciences. Although the representation of women within the geosciences has improved over the past several decades, the geosciences remain the least ethnically diverse of all the STEM fields (National Science Foundation [NSF], 2017). Even worse, although there have been many attempted initiatives, there has been no progress in diversifying the geosciences over the past 40 years (Bernard & Cooperdock, 2018). Aspects of DEI were an important area of concentration during the construction of the NGSS, brilliantly led by Okhee Lee. The main aspects of these efforts appeared in Appendix D of the NGSS as a general set of guidelines for implementing “All Standards, All Students” (NRC, 2013: https://www.nextgenscience.org/sites/default/files/Appendix%20D%20Diversity%20and%20Equity%206-14-13.pdf) as well as a set of case studies for addressing issues of equity in the specific areas of economic disadvantage, race and ethnicity, students with disabilities, English language learnings, gender, alternative education, and gifted and talented students (NRC, 2013: https://www.nextgenscience.org/appendix-d-case-studies). These ideas were also expanded upon and published as a stand-alone document by the NSTA (National Science Teachers Association) (Lee et al., 2015).

Educational research has continued to show that student-centered active learning as advocated by the NGSS helps to improve learning by underrepresented minorities and students from underserved backgrounds. There are certain views that hold that standards-based performance expectations are fundamentally inadequate for supporting the kinds of teaching methods that would be more effective for minoritized and other non-mainstream students (e.g., Ault, 2021). However, other studies are showing that the flexibility of the NGSS in the examples that can selected for performance expectations and the ability to bundle performance expectations into regionally specific storylines can allow for culturally inclusive place-based learning that can effectively engage regional communities (Semken & Garcia, 2021). Clearly, this is an area that will require significant continued research and outreach.

10. Appendix I: Career Choices and Service Work

In the spirit of having this Perspectives article contain some career perspectives for younger scientists, from the vantage point of someone now in his 60s, I will say a few words about my career choices concerning service work, particularly, in my case, in participating with writing science textbooks. For many years my department role was chairing the recruitment of graduate students, and when asked for advice on choosing research programs and advisors I would tell students that the most important thing they could do early in their career was to (a)
figure out what they liked to do, (b) figure out what they were good at, and (c) follow the overlapping part of that Venn diagram. Scientific research involves many different kinds of work (theory, hardware, software, data collection, data management, etc.). You might love the theoretical side of your research but not be very good at math, which could lead to frustration. And when I say “like” to do, I mean both what you enjoy doing on a daily basis (e.g., I love writing computer code, much the way I love doing the daily NY Times crossword puzzle) and what rewards your life with meaning and fulfillment.

I later discovered that there were whole philosophies devoted to this kind of Venn-diagram approach to evaluating and determining human actions. One of the most elegant of these is the concept of ikigai, or “reason for being,” which is a long-standing principle of Japanese tradition that was popularized in the 1960s by the psychologist Mieko Kamiya (Kamiya, 1966). Here, the “what you are good at” and “what you like to do” of my graduate student advice are joined by “what the world needs” and “what you can be paid for” (Figure 3). The intersection of any two of these is the root of concepts such as passion, mission, profession, and vocation. The intersection of three of these can provide satisfaction, delight, excitement, or comfort, but also uselessness, emptiness, uncertainty, or a lack of wealth. Only by combining all four can you discover the deeper meaning of your “reason for being.” This approach is a helpful way to think about professional service work.

I haven’t said much here about my wonderfully enjoyable nearly 4 decades using teleseismic waves to map out 3D variations in Earth’s deep structure, composition, and temperature [including research done with my fabulous mentors Don Forsyth (Brown U) and Emile Okal (Northwestern U)]. It is research I enjoy to do and am reasonably good at. Along the ikigai approach, this is the root of much my professional “passion,” and because I have managed to get paid for doing it, also the root of much of my professional “satisfaction.” However, what has distinguished my career from that of many of my seismological collaborators over the decades has been my focus on contributing to public science literacy and education. In alignment with the ikigai career-choice rubric, it is the communication of science that I both am best at and find the most rewarding. My research on core-mantle boundary structure, mantle attenuation and anisotropy, intraplate earthquakes, the Mid-Continent Rift, the thermal structure of Madagascar, etc., has brought me great satisfaction, but my greatest reward and ikigai have come from my E&O in playing a role in improving the general public’s understanding and appreciation for the geosciences.

The choice wasn’t easy, and I fought it for many years, like trying to swim upstream. Writing the popular articles (For Scientific American, American Scientist, Earth, etc.) and textbooks (>35 separate volumes from 8 different programs) came easy to me, as did the lectures for the “Great Courses” series, but there was a price to pay. There are only so many hours in the day, so this “service work” meant less time on research, which was both the major part of my self-identity and pride and also the means by which I was evaluated by my university. In fact, I received criticism from parts of my university’s administration for this work outside of my research and it was only when I began to be professionally recognized with awards for my service work (from AGU, SSA, and AAPG) that I was promoted to full professor.

There is a broader issue here concerning the need for scientists to be involved with societally important service work and therefore the need for such work to be recognized and rewarded. In fact, there is a need for academics across all disciplines to take more active roles in societal service. There seems to be no shortage of challenges facing humanity at the present time, and not just in the area of the geosciences: racial injustice, international conflict, fracturing of political discourse, lack of confidence in political leaders, global economic and trade instabilities, and complex systems of misinformation and disinformation all are troubling issues.

Figure 3. Intersecting Venn-diagram circles representing the traditional Japanese concept of ikigai, which means “reason for being.” The concept of ikigai emerged in the 1960–1980s as a guide to personal choices that could lead toward both the improvement of oneself and the betterment of society, largely through the popular publication Kamiya (1966), and has since been used as a rubric for guiding professional choices. The inclusion of the right-hand circle, “what the world needs,” supports the commitment of professional service work for the betterment of society as a means of attaining a deeper sense of reward from one’s profession. For geoscientists, this public service work can take many forms, especially in the support of public education and geoscience literacy.
While the current world climates (literally and colloquially) are certainly in worse shape than they have been in preceding decades, it is important to remember that this is not the first time that this has happened in the past. Abraham Lincoln said “The dogmas of the quiet past are inadequate to the stormy present,” and during the Renaissance, scientists faced misinformation to such a degree that a belief in heliocentrism was considered heresy. However, scientists have repeatedly stepped forward in the past to help during times of crisis. For these examples, the National Academy of Sciences was formed during the Civil War, approved by President Lincoln in 1863, as a means of using science and technology to help hold the Union together, and Galileo Galilei is known as much for his scientific brilliance as he is for his bravery in refusing to recant his heretical public statements that Earth revolved around the sun and his willingness to live the rest of his life imprisoned under house arrest.

As with the creation of the National Academy of Sciences during the Civil War, there is a great current need for the construction of bold new systems through which the wealth of academic understanding and skill can be channeled to ensure the survival of not just the Union but society as a whole. And, as during the Renaissance, today’s scientists need to stand up and denounce the onslaught of misinformation and disinformation, not only toward flashpoints such as evolution and climate change, but toward the validity of science as a whole. This cannot just be limited to academic treatises in erudite journals such as this one. We need to get out and speak in town halls, high schools, school board meetings, science centers, meetings with politicians, and through editorials, op-eds, blogs, and vlogs. And we must do this knowing that, as with Galileo, there may be repercussions [I feel a certain connection with Galileo. When I received the Frank Press Service Award from the Seismological Society of America I learned that Frank’s PhD advisor’s advisor’s advisor, going back 17 generations, was Galileo (with some other notable names such as Isaac Newton and James Maxwell along the way). And, because the advisor (David Harkrider) of my PhD advisor (Emile Okal) was Frank Press, that made me a twentieth-generation academic descendant of Galileo. There is a certain degree of responsibility and obligation that comes with this, not only scientifically but in terms of service to society.]

There has been, at the same time, a recent growing lack of public support for not only science but higher education as a whole. I think that this is not unrelated to the public’s frustration with the great challenges currently facing humanity and the inadequate assistance from those considered to be most trained and prepared to address them. Academics, particularly in the sciences, too often avoid participating in societal service. This seems to happen for many reasons that include suffering from a delusion of objectivity (that our “pure research” is wholly independent from social issues), a sense that service work is beneath us or not worth our time, an ignorance of how and where to apply our efforts, or simply the lack of a system of recognizing and rewarding such work. This lack of societal engagement seems to be much greater in the U.S. than in many other countries. Somewhere between the construction of the U.S. National Academy in order to win the Civil War and its snub of Carl Sagan, for his brilliant societal outreach and education, we took a wrong turn. However, our avoidance of public service cannot persist if academia expects to continue to receive the respect and financial support it has in the past.

At the 2021 Fall AGU meeting I spoke about the significant need for systemic changes across all institutional levels to support and encourage service work (Wysession, 2021):

- For professional organizations, there need to be more more avenues such as AGU’s Ambassador Award and SSA’s Frank Press Award to recognize commitments to service work.
- National leadership needs to value geoscience research in its decision-making processes and foster symbiotic partnerships that allow geoscientists to be more engaged with politics and politicians to be more engaged with geoscience.
- Funding agencies should continue to guide research into societally important areas (such as climate change) through a combination of access to funds and the expertise to disburse it wisely, and should also continue to fund and foster the development of science literacy frameworks.
- Universities need to revisit and revise their promotion and retention metrics to move away from overly simplistic indices such as h-factors and adopt broader measures of “impact” and “distinction” that include service to society.

Individual scientists ultimately bear the responsibilities for their career choices, particularly in academia where great freedom is granted in how individuals spend their professional time. However, systemic changes are needed at all levels to promote and encourage participation in societally beneficial activities. The very survival of modern academia as we know it may depend upon it.
For my part, I do not regret any of my professional choices. Trying to maintain parallel careers in both seismological research and in science literacy and education has been challenging, but the high quality of the textbooks and video lectures was not possible without the deeper understandings that came with my research, and the leadership opportunities with projects such as the Earth Science Literacy Initiative, NRC Framework, and NGSS would not have arisen without the successes of my research. Also, learning to write well certainly improved my NSF proposal success rate.

11. Appendix II: Career Choices and Writing Textbooks

Several scientists have asked my advice on whether or not they should get involved with writing a textbook. If doing so falls within your ikigai Venn diagram overlap then I would recommend it, but know that the time required to write textbooks follows a $t_n$ relationship, where $t_n$ is the time you think it will take and $n$ is a number that, like a non-Newtonian rheology, is largely unpredictable but definitely larger than 1. The first textbook I coauthored was Seth Stein’s Introduction to Seismology (Stein & Wysession, 2003). I thought that Seth’s notes were brilliant and near completion when I joined the project, having learned from them in seismology courses both as an undergraduate (from Don Forsyth) and graduate student (from Seth). However, it took 5 years for us to finish the book, with my part taking 10–20 hr per week, but it was a fabulous experience and I developed an understanding of seismology that I could not have gained in any other way. I would do it all over again, but I was very glad that I waited until I had tenure to start it!

My K-12 textbooks were a very different kind of experience. Major textbook companies are large machines with many moving parts that include sales, marketing, art, digital platforms, assessment, and professional development, in addition to editorial. The writing of the text is only one small part. With Intro to Seismology, Seth and I did everything ourselves – the text, equations, figures, homework problems and solutions, website, etc. – but with my early books with Prentice Hall (high school Physical Science: Concepts in Action, and the geoscience books of the middle school Science Explorer series) I wrote from an outline I was given and the editors took care of the rest. This was usually OK because the Prentice Hall editors were competent and careful and we had sufficient time to develop the books. However, the editors were not scientists and I found I had to check carefully everything they did. Art figures were often hand-drawn with the scientific proportions wrong; homework problems sometimes described impossible situations; and their content could be outdated and incorrect.

For example, I had to battle with the editors to replace “the Richter scale,” which was indiscriminately used to describe any earthquake magnitude, with “moment magnitudes.” I informed them that the Richter scale, and the more general local $M_L$ magnitude scale that it inspired, only worked for smaller ($M_L < 6$) earthquakes measured at nearby distances, and not the M8 earthquakes being described. They said that they had always written it this way. I informed them they had always been wrong. They said that their competitors all did the same. I informed them that the competitors were wrong too. They said that this was in the state standards. Ah, well, they had me on that one. We had to write the text so as to include “the Richter scale” in order to meet the standards, but then go on to say that magnitudes of large earthquakes were measured using a different scale called the moment magnitude scale. Many conversations like this one played out over the years and showed me the necessity of having good state education standards.

The accuracy of the textbooks I worked with got worse when Pearson began to influence editorial decisions. In 1998, the large company Pearson purchased Prentice Hall (with middle and high school books) and merged it with Scott Foresman (with elementary books) to create a full K-12 textbook division, and although I started working with Prentice Hall in 2001, the heavy hand of Pearson did not show up until a few years later. Pearson’s desire to sell books increasingly replaced their interest in making good books, and timelines got shorter and budgets got tighter. I was initially recruited to create their high school Earth Science book, but then heard nothing for almost a year and assumed the project was off. I was then informed that they wanted the book created in a month for a statewide adoption competition in North Carolina. I told them I couldn’t write a book in a month, so I was given a team of seven science writers that I would supervise and edit, and in little more than a month we converted a college book to one at a high school level (Tarbuck & Lutgens, 2005).

I later coauthored two full K-8 national science programs with Pearson: Investigate Science (Padilla et al., 2011, 2012) and Elevate Science (Miller et al., 2017), each with multiple separate grade-level volumes. Instead of hiring additional editors to help with the writing of laboratory experiments, worksheets, and artwork,
Pearson outsourced the work to the lowest-bidding vendors, and the materials we got back were often terrible, requiring multiple revisions. One project was put on hold for 3 years, for no apparent reason, and then put on an accelerated schedule to meet state-wide textbook adoptions, forcing the writing to be hurried and rushed.

After recently seeing the movie remake of Frank Herbert’s novel *Dune*, I was struck by the analogy of writing textbooks with a large textbook company such Pearson to what it would be like to ride the giant sandworms. These giant powerful creatures are an important part of the climate and environment of the planet, but they can destroy everything in their path in a blind frenzy to find food. However, if you are clever and experienced, you can not only climb up onto the creatures but even steer them for a while in a direction you want to go. Because of the outsourcing of program materials, working with Pearson in the development of these K-8 programs was often frustrating and unnecessarily time-consuming, but I felt that I was able to help guide them to make some good decisions and that the ESS and physical science that appeared in the resulting K-8 programs, which have reached many tens of millions of children, were significantly more accurate, intuitive, and engaging than they would otherwise have been.

More significantly, I was able leverage my role as a national STEM leader to help convince Pearson to allow us to make a high school chemistry program that incorporated ESS along the lines of the California Integrated model, which became *Experience Chemistry*. Soon after this program began, Pearson finally conceded that they really did not know what to do with K-12 instruction and sold off the K-12 textbook division, which became the start-up company Savvas Learning. However, we got to keep going with *Experience Chemistry* and even go on to develop the *Experience Physics* program (both brilliantly coordinated by lead editor Maria Stamm), and the company (still with some of the same editors from my early Prentice Hall days, such as Ros Kane and Ken Chang) is now smaller with a less-corporate feel once again, with more autonomy on the part of the writers and editors. So, I do think that more geoscientists should get involved with K-12 education, particularly in the way of creating educational materials. Working with established textbook companies can allow your work to reach very large numbers of students (scoring high on the “what the world needs” circle of the ikigai rubric). However, not all companies are the same.

Helping to create the national high school *Experience Physics* program has also brought my work back around, full circle, to the start of my career. When I taught high school physics in Staten Island, New York, right out of undergraduate school, it was because there were no available high school jobs teaching geoscience. At that time, the high school physics textbook I was told to teach from was terrible, mostly just a compendium of facts, some of which were even wrong and misleading. I have now helped to create multiple opportunities across the country for teaching geology in high school through the construction of a physics program that integrates geoscience in with the physics. There is a certain satisfaction that comes with a story that connects back to its start. That applies to a career as well. This has been my ikigai. Helping to create a progressive high school physics program, based on the NGSS that I played a part in creating, after starting my career as a high school physics teacher, has brought to a career as well. This has been my ikigai. Helping to create a progressive high school physics program, based on the NGSS that I played a part in creating, after starting my career as a high school physics teacher, has brought me a level of professional “reason for being” that is greater than for any other work I have done up to this point.

Data Availability Statement

This manuscript involves no data, so there is no need for data access.

References

Achieve Inc. (2016). Using phenomena in NGSS-designed lessons and units. Retrieved from https://www.nextgenscience.org/resources/phenomena

Achieve Inc. (2017). Primary evaluation of essential criteria. (PEEC) for next generation science standards instructional materials design. Retrieved from https://www.nextgenscience.org/peec

American Association for the Advancement of Science. (1989). *Science for all Americans*. Project 2061. Oxford University Press. Retrieved from http://www.project2061.org/publications/sfaa/online/sfaatoc.htm

American Association for the Advancement of Science. (1993). *Benmarks for science literacy*. Project 2061. Oxford University Press.

Attl, C. R. (2021). *Beyond science standards: Play, art, coherence, community*. Rowman and Littlefield.

Barstow, D., & Geary, E. (Eds.) (2002). *Blueprint for change: Report from the national conference on the revolution in earth and space science education*. TERC. Retrieved from www.EarthScienceEdRevolution.org

Bernard, R. E., & Cooperdock, E. H. G. (2018). No progress on diversity in 40 years. *Nature Geoscience*, 11, 292–295. https://doi.org/10.1038/s41561-018-0116-6

Bybee, R. W. (2009). *The BSCS 5E instructional model and 21st century skills*. BSCS.
Bybee, R. W., & DeBoer, C. E. (1994). Research on goals for the science curriculum. In Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 357–387). National Science Teachers Association.

California Department of Education. (2016). 2016 science framework. In Chapter 7: High school three-course model. Retrieved from https://www.cde.ca.gov/ci/sc/cf/cascienceframework2016.asp

Cochran, G., Moore, C., Sterlace, J., & Wysession, M. E. (2021). *Experience physics*. Savvas Learning Company.

Dewey, J. (1944). *Democracy and education: An introduction to the philosophy of education*. The Free Press.

Earth Science Literacy Initiative. (2009). *Earth science literacy principles: The big ideas and supporting concepts of earth science*. National Science Foundation. Retrieved from http://www.earthsclieliteracy.org/

Kamiya, M. (1966). *What makes our life worth living*. Misuzu Shobō.

Lee, O., Miller, E., & Januszky, R. (Eds.) (2015). *NGSS for all students*. (pp. 210). National Science Teachers Association Press.

Lewis, E. B. (2008). Content is not enough: A history of secondary earth science teacher preparation with recommendations for today. *Journal of Geoscience Education*, 56(5), 445–455. https://doi.org/10.5408/jge_nov2008_lewis_445

Miller, K. (2008). *Only a theory: Evolution and the battle for America's soul*. Penguin Group.

Miller, Z., Padilla, M., & Wysession, M. E. (2017). *Elevate science* [9 Volumes, for elementary and middle school]. Pearson Education.

Moore, C., Wysession, M. E., & Lutes, B. (2020). *Experience chemistry* [A high school chemistry program, national version]. Two volumes. Savvas Learning Corporation.

National Educational Association. (1983). *Report of the committee on secondary school studies (commonly known as the Committee of ten report)*. Government Printing Office.

National Geographic Society. (2006). Ocean literacy: The essential principles of ocean science K-12. Retrieved from http://www.coexploration.org/oceanliteracy/documents/OceanLitChart.pdf

National governors association center for best practices & Council of chief state school Officers. (2010). *Common core state standards for English language arts and mathematics*. Washington, DC: Author. Retrieved from http://www.corestandards.org/the-standards

National Research Council. (1996). *National science education standards*. The National Academies Press. https://doi.org/10.17226/9462

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. https://doi.org/10.17226/13165

National Research Council. (2013). *Next generation science standards: For states, by states*. The National Academies Press. https://doi.org/10.17226/18290

National Science Foundation. (2017). Women, minorities, and persons with disabilities in science and engineering: 2017 NSF 17. (pp. 310). Retrieved from https://go.nature.com/2lp266A

Next Generation Science Standards. (2022). NextGenScience, WestEd. Retrieved from https://www.nextgenscience.org/search-standards

Padilla, M., Buckley, D., Miller, Z., Thornton, K., & Wysession, M. E. (2011). *Interactive science* [12 volumes, for middle school]. Pearson Education.

Padilla, M., Buckley, D., Miller, Z., Thornton, K., & Wysession, M. E. (2012). *Interactive science* [7 volumes, for elementary school]. Pearson Education.

Schoedinger, S., Tran, L. U., & Whitely, L. (2010). From the principles to the scope and sequence: A brief history of the ocean literacy campaign. *Journal of Marine Education, Special Report #3 (The Ocean Literacy Campaign)*, 3–7.

Semken, S., & Garcia, A. A., Jr. (2021). Synergizing standards-based and place-based science education. *Cultural Studies of Science Education, 16*(2), 447–460. https://doi.org/10.1007/s11422-021-10020-4

Stein, S., & Wysession, M. E. (2003). *An introduction to seismology, earthquakes, and earth structure*. Wiley-Blackwell.

Taber, J., Hubenthal, M., & Wysession, M. E. (2009). Review of IRIS education and outreach. (pp. 32). Incorporated Research Institutions for Seismology.

Tarbuck, E., & Lutgens, F. (2005). *Earth science*. In M. Wysession (Ed.), For 9th grade. Pearson Education.

University Corporation for Atmospheric Research. (2008). Atmospheric science literacy: Essential principles and fundamental concepts of atmosphericscience. Retrieved from http://eo.ucar.edu/asl/pdfs/ASLbrochureFINAL.pdf

U.S. Global Change Research Program/Climate Change Science Program. (2009). Climate literacy: The essential principles of climate sciences. World Wildlife Foundation. (2020). Living planet report 2020. Retrieved from https://livingplanet.panda.org/en-us/

Wysession, M. E. (2008). *How the earth works*. Savvas Learning Company.

Wysession, M. E. (2014). The next generation science standards: A potential revolution for geoscience education. *Earth's Future, 2*, 299–302. https://doi.org/10.1002/2014EF000237

Wysession, M. E. (2021). *The legacy of Galileo: Incentivizing scientific service*. Abstract U52A-02, presentation at the 2021 Full Meeting, New Orleans, LA: AGU.

Wysession, M. E., Budd, D. A., Campbell, K., Conklin, M., Kappel, E., Karsten, J., et al. (2012). Developing and applying a set of earth science literacy principles. *Journal of Geoscience Education, 60*(2), 95–99. https://doi.org/10.5408/11-248.1

Wysession, M. E., Frank, D., & Yancopoulus, S. (2004). *Physical science: Concepts in action, with earth and space science*. Prentice-Hall.

Wysession, M. E., & Rowan, L. (2013). *Geoscience serving public policy*. In M. E. Bickford (Ed.), (Vol. 501, pp. 165–187). The Impact of the Geological Sciences on Society: Geological Society of America Special Paper. https://doi.org/10.1130/2013.2501(07)