The Nature of Science

For the first 15 years of my teaching career, I served as our rural school's ONLY freshman Physical Science teacher, introducing about 40 students per year to the rigors and excitement of high school level science. Being this "gatekeeper" for science in my school gave me a unique opportunity to be sure that all students started out learning strong and consistent fundamentals. Although it sounds old-fashioned in an era where teachers are cautioned against overemphasizing "the" scientific method, I always opened my Physical Science year with several weeks of instruction and application of what NGSS now calls Science and Engineering Practices. It was important to me to have students practice fundamental investigation skills and learn how to apply key process terminology (such as hypothesis, law, and theory) before we dove into specific content lessons. However, these initial lessons did not stand alone; the skills learned were threaded into investigations through all of high school science.

These initial lessons also provided me a platform to directly address many of the fundamental ideas of the Nature of Science (NOS), and some of the misconceptions that students had about how science works. The NGSS Appendix H lists eight fundamental NOS tenets, painting a picture of science as a human construct for knowing about a predictable natural world. The tenets also emphasize the reliance that science has on investigations that provide evidence, and how new evidence can change the models, laws, and theories that communicate scientific knowledge (NGSS Lead States, 2013). In my years with high school students, I have learned that the NOS should not simply be described, but must be experienced, if it is to become a part of students' long-term framework for understanding. For this reason, NOS ideas are embedded into lessons that primarily emphasize the Science and Engineering Practices. The examples below illustrate how NOS is addressed when student practice writing quality hypotheses statements.

- A quality hypothesis must be "testable". This leads to discussions about how we can not write supernatural phenomena into scientific studies, because science focuses on the natural world. I am careful in this discussion to acknowledge that science is one evidence-based way of knowing, but that there are other ways (such as religion and emotion) that are also valid, even if they are outside the realm of science.
- To emphasize that investigations are not always experiments, we discuss unethical and impractical hypotheses, such as "If I give John 3,000 g of caffeine, he will die," and "If I move the moon, then the tides will stop". These examples help students understand why it is sometimes necessary to use models and field studies as valid parts of scientific investigation.

Another of my favorite NOS lessons addresses the nature of evidence and arises when a student announces that they refuse to believe in something that they cannot see, such as an atom or electron. I accept their statement then ask "Are you SURE you have a stomach?" This always leads into an energetic class discussion with me taking the position that

none of us have seen our stomachs, so none of us can be sure. The value of indirect scientific evidence becomes clear as the students make their arguments, and the NOS tenet that nature is consistent and predictable also plays a big role. Eventually, I steer the conversation to the possibility that maybe tomorrow, a surgeon will discover a new type of human without a stomach, in which case new evidence leads to new scientific knowledge and the medical books are rewritten. I have found that these types of discussions, which challenge students to think deeper about something that is relevant to them, are more helpful in teaching the NOS than introducing a list of tenets and vocabulary words.

Many of the conversations that serve as mini-NOS lessons in my classroom seem adequate. They involve underlying ideas about science that are not complex or hard to understand, so there is no need to practice them with extended lesson experiences. However, other NOS tenets, such as using a variety of investigation methods, developing models, and basing knowledge on empirical evidence, do take practice for students to fully appreciate them. NGSS Appendix H goes on to explain how implementing inquiry-based instruction that's centered around phenomena serves a dual purpose. It not only utilizes 3-dimensional structures to accomplish content learning objectives, but also reinforces the Nature of Science through the doing of science by students (NGSS Lead States, 2013).

Providing more frequent and more complex opportunities for my students to engage in NOS-rich NGSS-style investigations is one area in which I have room to grow. My teaching career started long before NGSS guidelines established the new gold standard for science instruction, so many of my teaching practices may seem "traditional" in comparison. I suspect I rely on direct instruction with whole class demonstrations and discussions more often than teachers who have fully adopted NGSS methodologies. But, since my students have been relatively successful and my rural school district has not made the transition to the NGSS a priority, it is difficult to overcome existing momentum and overhaul our curriculum and instructional systems. I foresee a more gradual shift in my teaching practice, where each course is progressively shifted to more NGSS-style pedagogies, perhaps by 1 or 2 units a year versus all at once. I know that students will engage in more authentic science experiences as this transition progresses, which will naturally deepen their understanding of the Nature of Science.

Although I have only taught high school students, I am transitioning into a teacher-leader role where I will be mentoring elementary teachers, so I am curious about how NOS instruction changes as students grow through elementary to secondary school. It seems, on the surface, that elementary science is more focused on scientific processes while secondary science shifts to more complex disciplinary content knowledge. Young students cannot get too deep in science

content since they do not yet have abstract thinking, complex language, or mathematical thinking abilities that support traditional science content. They are capable, however, of asking questions, engaging in hands-on experiences, finding patterns, and developing simple models to use as their own evidence for refining their personal understandings of the world. These youngest children, guided through high quality NGSS-inspired experiences, are learning about the Nature of Science first hand, discovering "how science works" while developing their early science conceptions. As students get older and more capable of complex thinking, much of this authentic discovery is traded for a focus on scientific theories and laws that were developed by others long ago. There is a danger that students may lose sight of the real Nature of Science as they are inundated with the accelerating pace, new vocabulary, and complex mathematical models that fill secondary science courses. Hopefully, their early experiences about how science works will not be forgotten and can serve as context to tie their later learning together.

One final tenet of the NOS identifies it as a human endeavor, socially developed and situated among other disciplines as we develop our knowledge base and solve human problems (NGSS Lead States, 2013). Interdisciplinary STEM provides an excellent vehicle for teaching this part of the NOS as students purposefully combine knowledge from multiple contents in real world contexts. As we blend disciplines, Kelley and Knowles (2016) remind us that there is still value in teaching stand-alone background knowledge before expecting students to access that knowledge for an integrated STEM experience. It stands to reason that the individual Natures of Science, Math, Engineering, and Technology should be included in these disciplinary foundations, since each subject brings its own "way of knowing" and students need to learn which subject's tools best fit a given problem. In addition, noting the overlaps between the tenets of each discipline helps to reinforce them as interrelated tools for STEM learning rather than isolated subjects taught in school silos. For example, when comparing the Common Core Math Standards (2021) to the NGSS, many similarities are evident. Both math and science are driven by a human "need to know", whether it's a problem to solve (as outlined in Math Practice 1) or a question about the natural world. Both disciplines likewise rely on a wide menu of investigation and computational tools that can be applied systematically and creatively to discover answers. Models serve a key role in representing and communicating thinking in both science and math, and both NOS and NOM tell us to expect reliable patterns and predictability, whether in mathematical structures or in the consistent behaviors of the universe. When students understand the tenets of the individual STEM disciplines, they are more able to leverage the synergies between the fields and avoid working outside the boundaries that define them.

References

Standards for Mathematial Practices. (2021). Common Core State Standards Initiative. http://www.corestandards.org/Math/Practice/

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States (Appendix H)*. The Next Generation Science Standards: APPENDIX H –Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards. https://www.nextgenscience.org/sites/default/files/resource/files/Appendix%20H%20-%20The%20Nature%20of%20Science%20in%20the%20Next%20Generation%20Science%20Standards%204.15.13.pdf