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## Nature of Science

The nature of science is best described by this quote from James B. Conant: "Being well informed about science is not the same thing as understanding science" (Conant, 1951, as cited in Next Generation Science Standards Appendix H, 2013, page 3). Students simply learning science content is not sufficient. They must understand what science is; that it is dynamic, observation-based, inferential, subjective, and culturally influenced. While some of these tenets I am already implementing in my classroom, others leave areas of improvement.

One of the tenets I address in my classroom is the tentative nature of science- scientific knowledge is not set in concrete and is subject to change ("Tenets of the nature of science," 2011). This is also noted as an understanding of the nature of science in the Next Generation Science Standards (NGSS): scientific knowledge is open to revision in light of new evidence (NGSS Appendix H, 2013, page 5). When teaching about the Big Bang, I describe the meaning of "theory" as a scientific idea that has not been proven to be true but has not been disproven. We discuss that while the Big Bang is supported by evidence, it could change or be disproven some day based on new evidence. I compare this with the demotion of Pluto as a planet after the discovery of Eris. This discovery led to the clarification of the criteria to be considered a planet, and classified Pluto as a dwarf planet. Similarly, the recognition of dark matter and dark energy changed the beliefs on what comprises our Universe. Dark matter and dark energy are now believed to be 95% of the universe, while all known objects (planets, stars, etc.) make up only 5%. We also discuss how it was once thought that Earth was the center of our solar

system before the Heliocentric model was developed. These examples of the tentative nature of science are just from one unit, and many more are discussed throughout the course of the school year.

Several tenets of science could be addressed in the same lesson. When studying gravity, my students do a lab in which they drop two balls of different weights from the same height at the same time. My students make observations on when they land, collect data for multiple trials, and make inferences based on their observations. This addresses the understanding that scientific knowledge is based on empirical evidence. My students also observe similar experiments in videos to see if the results support or negate their findings, such as objects being dropped from the Leaning Tower of Pisa to recreate Galileo's experiment. This is also an example of the tentative nature of science since it was once believed that a heavier object would land first, but Galileo demonstrated that they land at the same time. Another video shows a bowling ball and feather being dropped. Of course the bowling ball lands first, but when the objects are dropped in a vacuum they fall at the exact same rate! This introduces the idea of air resistance. My students then started dropping random objects in the classroom, such as a paper and a pencil. They observed that the pencil landed first, but when the student crumpled the piece of paper and dropped them again they landed at the same time. My students creating their own experiments based on their questions and observations addresses the tenet that scientific investigations use a variety of methods.

In the article "I Used to Love Science... And Then I Went to School," Gloria Ladson-Billings describes a classroom in which the students settle on a small set of questions that become the basis for the curriculum (Ladson-Billings, 2003). If there were no constraints of pacing and curriculum, I would focus my instruction more on students' questions about life. If students are investigating their own questions, constructing arguments, and having meaningful discussions with classmates, this would increase their engagement and understanding of science. This describes one of the tenets that would enhance my science instruction- the

inferential, imaginative, and creative nature of science. While my students do make inferences, I feel like I often guide them towards a conclusion when it should be more student-led. One way I could improve my pedagogy is through the use of phenomena. I teach about the effects of mountain ranges on climate- the rain shadow. We discuss the vastly different climate on each side of the Sierra Nevada mountain range, the Redwood forests and Death Valley. I could introduce this lesson using the phenomenon “The Driest Place on Earth” (The Wonder of Science, 2018). This phenomenon prompts students to think about why the Atacama desert is the driest place on earth. It provides opportunity for questions and inference, and students could then collect data about rainfall or study wind patterns to support their inferences. I recently discovered Mosa Mack Science which could help make my lessons more inference-based and student-focused. The lessons are broken into 3 parts: the solve (phenomena), a lab on the topic, and an engineering challenge (Mosa Mack Science, 2005). I am always seeking new resources and adjusting instruction to improve students’ interest and scientific knowledge.

Another tenet that I could include more in my lessons is the subjective nature of science- that different scientists can interpret the same datasets differently (“Tenets of the nature of science,” 2011). After my students make observations and develop explanations individually, I should encourage discussion with classmates because their inferences may differ. Constructive arguments could lead to new theories or change students' way of thinking about a topic. As stated in the NGSS, science is a human endeavor, meaning that all different types of people can work in science and often work in teams (NGSS Appendix H, 2013, page 6). By having my students collaborate more often in the classroom, it is preparing them for future STEM careers in which they may need to work with different types of people to accomplish a goal. This subjectivity also ties into the socially and culturally embedded nature of science (such as politics and religion) that “will affect the science knowledge produced and how it is accepted” (“Tenets of the nature of science,” 2011). When I teach about the Big Bang and evolution, I talk about the

belief that God created everything. While discussing global warming, I mention that some politicians don't view climate change as a priority. I would like to incorporate more of this discussion, specifically based off my students' culture and beliefs.

As a science and math teacher, my knowledge of both subjects is beneficial to integration in the classroom. The nature of mathematics overlaps with science by its principles, the practice standards, and specific content standards. After reviewing the Principles for School Mathematics, I believe that each of these principles could be applied to science instruction. For example, the principle on curriculum states, "A curriculum is more than a collection of activities; it must be coherent, focused on important mathematics, and well articulated across the grades." The NGSS are also designed to articulate across the grades, learning the same content but diving deeper into each topic so that it is grade-level appropriate. The principle on learning mentions, "Students must learn mathematics with understanding, actively building new knowledge from experience and previous knowledge" (Executive Summary: Principles and Standards for School Mathematics, 2000, page 2). Students also build upon prior knowledge in science by making observations and inferences to gain a better understanding of the world. Both of these principles for mathematics, if applied to science, support the idea that scientific knowledge is cumulative (NGSS Appendix H, 2013, page 6).

There are many Standards for Mathematical Practice that align with science instruction. The first, MP.2. Reason abstractly and quantitatively, is about manipulating symbols abstractly and attending to the meaning of those symbols while doing so (NGSS Appendix L, 2013, page 3). Science often uses equations, such as Einstein's famous equation relating mass and energy. Students will need to make sense of these equations and understand the symbols that are used (e.g. exponents), and those skills stem from mathematics. Another practice standard, MP.4. Model with mathematics, focuses more on the mental process involved with solving a problem than the answer itself. The nature of science also focuses more on understanding and practicing science than the content being taught. Lastly, MP.5. Use appropriate tools

strategically, refers to drawing diagrams and using the coordinate plane. In science we often need to use diagrams to represent an idea, display data in graphs, or interpret diagrams and graphs.

The NGSS writers worked with the Common Core State Standards of Mathematics (CCSSM) to ensure the standards are aligned and on pace with one another. There are several connections between the two as noted in reference table 1 from NGSS Appendix L. Many of these math concepts are used by my sixth graders in science class. When my students study the effects of increased edges around fragmented habitats, they write ratios (area effected/area of habitat), calculate the percent exposed to edge effects, and graph the proportional relationship on a coordinate plane. My students also use mathematics for a climate project in which they study how temperatures have changed over the years in different parts of the world. They find mean and median temperatures, make a graph of the data collected, and calculate rate of change. Outliers can promote great discussion and encourage students to make inferences.

Through an understanding of the nature of mathematics, the nature of science, and a thoughtful integration of these subjects (as well as technology and engineering), we can achieve a nature of STEM in our classrooms. As education currently stands, we have a long way to go but I believe we are headed in the right direction. By addressing the tenets discussed, we can give our students quality instruction setting them up for a successful future in STEM careers- possibly changing the world.

## Resources

Appendix H – Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards. *Next Generation Science Standards*, Apr. 2013

“Tenets of the Nature of Science” *Science Learning Hub*, 7 Oct. 2011,

<https://www.sciencelearn.org.nz/resources/413-tenets-of-the-nature-of-science>

“The Driest Place on Earth” *The Wonder of Science*, 15 June 2018,

<https://thewonderofscience.com/phenomenon/2018/6/15/the-driest-place-on-earth>

“Photosynthesis” *Mosa Mack Science*, 2022,

<https://mosamack.com/home/photosynthesis/lessons/live>

Executive Summary: Principles and Standards for School Mathematics. *National Council of Teachers of Mathematics*, 2000

Appendix L – Connections to the Common Core State Standards for Mathematics. *Next Generation Science Standards*, May 2013