

The Nature of Science

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Methods of STEM Education - Secondary

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February 23, 2020

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James B. Conant wrote “Being well informed about science is not the same thing as understanding science, though the two propositions are not antithetical. What is needed is methods for importing some knowledge of the tactics and strategy of science to those who are not scientists” (Conant, 1951, p. 4, as cited in “Appendix H”, 2013). Many scientists and science educators would agree that science explains the world around us, but, that to truly understand science, students must understand the concepts, practices, and nature of science (“Appendix H”, 2013). This understanding, as described by the Next Generation Science Standards, is built by “wondering, investigating, questioning, data collecting and analyzing” (“Appendix H”, 2013).

The next generation science standards describe the nature of science using a matrix. This matrix describes eight major themes, four discussing the science and engineering practices and four discussing the crosscutting concepts, that deconstruct the understanding of the nature of science according to grade level (“Appendix H”, 2013). See figure 1 and figure 2 (“Appendix H”, 2013). “Tenets of the Nature of Science” describes the foundational principles more simply in five tenets which commonly overlap with the themes identified in the NGSS nature of STEM matrix. This analysis will focus on the complexity of these themes seen at the high school level.

Biology content lends itself to many inquiry-based science investigations, however with a lack of funding and resources, utilizing a variety of diverse methods and new technologies to advance scientific knowledge is not always feasible. This does not stop me from engaging my students in experiences that require them to utilize critical and logical thinking, complete investigations with precision, approach situations with open-mindedness and objectivity, and present their findings honestly and ethically. One method I use to address students completing “scientific investigations using a variety of methods” is introducing a variety of experimental methods throughout the semester in the form of organized lab experiences, then engaging

students in an experimental design capstone experience (“Appendix H”, 2013). This capstone experience requires students to ask their own question, develop their own scientific investigation, complete their trials utilizing one of the presented methods, analyze their data, revise their original ideas, redo trials and data analysis as necessary, then report their findings to their peers and the public in a showcase.

I address the idea of science knowledge being “based on empirical evidence” in many of the units I teach as my summative assessments include claim-evidence-reasoning written responses (“Appendix H”, 2013). My students support their claims about biological systems using empirical evidence collected during in-class investigations as well as empirical evidence in the form of data from outside sources. By analyzing and interpreting the meaning of this data and choosing which pieces support their scientific claim, my students are gaining not only a deep, conceptual understanding of content, but also a better understanding of how to support a claim using the “empirical nature of science” (Tenets of the nature of science, 2011).

When studying the theory of evolution, I address with my students that “scientific knowledge is open to revision in light of new evidence,” or the “tentative nature of science” as described in “Tenets of the Nature of Science” as we discuss the timeline of development for the theory of evolution (“Appendix H”, 2013; Tenets of the nature of science, 2011). I engage my students in creating a physical timeline of key events and publications showcasing how thoughts on evolution have changed over time. In doing so, students realize interpretations and explanations in science often change due to new evidence.

My photosynthesis unit is the perfect time to discuss using “scientific models, laws, mechanisms, and theories [to] explain natural phenomena” (“Appendix H”, 2013). The laws of conservation of mass and conservation of energy play an intricate role in explaining the input and output relationships of photosynthesis, seen particularly the “phenomena” of Joseph

Priestley's experiment using a mouse, a plant, and a candle. By analyzing this phenomena and performing additional experiments, as well as developing an understanding of how scientific laws developed and are used to explain their observations, students gain a better conceptual understanding of how scientific observations lead to scientific theories, in the case of explaining "some aspect of the natural world", or scientific laws, in the case of describing "relationships between observable phenomena" ("Appendix H", 2013).

Helping students develop their understanding of science as "a way of knowing" is quite difficult in that science is complex in the way it utilizes all other subjects, such as math, history, and literacy, to explain current understandings of the world around us ("Appendix H", 2013). One key aspect I focus on is the idea of questioning and revising ideas in order to gain better understanding. One way I do this is by having my students reflect on what they know before we start a new unit, ask questions about what they would like to know, then, at the end of the unit, adjust and revise their initial thoughts based on what they learned. This practice, while seemingly simple, engages students in the thoughts of real scientists as it allows them to reflect on current thoughts then adjust those thoughts after further exploration of their guiding questions.

When addressing the difference between the concepts of observations, hypotheses, scientific theories, and scientific laws, my students often struggle with the idea that scientific laws always have been, are, and always will be consistent in what they describe. In order to teach my students that "scientific knowledge assumes an order and consistency in natural systems," my students research the development of scientific laws and describe examples of these laws in action in order to see that these laws are consistent across all real-world phenomena ("Appendix H", 2013).

I try to incorporate the concept that “science is a human endeavor” into each and every unit we study in my Biology class by choosing a new “scientist of the week” every week (“Appendix H”, 2013). At the beginning of the semester, I ask my students, “Who are scientists? What image comes to mind when you think of a scientist?” I am always disappointed to hear when students say “scientists wear lab coats and goggles” and “scientists are people like [insert old white male].” I hope to change those mental images by choosing a wide variety of scientists for the “scientist of the week” not only so more of my students are able to relate to science through commonalities like gender and nationality, explain how scientists’ social cultural backgrounds influence their studies described as the “socially and culturally embedded nature of science” and showcase the “imaginative and creative nature of science” due to the unique and creative aspects of every scientists’ work (Tenets of the nature of science, 2011) .

When studying evolution through natural selection, I also incorporate the study of artificial selection to explain how humans can impact the appearance of traits over time, as this explains the idea that “science addresses questions about the natural and material world” (“Appendix H”, 2013). I divide students into a few groups (based on class size), and allow them to choose a debate topic: designer babies, GMO foods, and cloning, just to name a few. Students are then tasked with doing research to support their argument. Many students soon come to realize that not all questions can truly be answered by science, that many decisions involve the ethics and values of scientists, described as the “subjective and theory-laden nature of science”, and rely on society to make choices (“Appendix H”, 2013; Tenets of the nature of science, 2011). I love this activity as it truly brings science into the context of the real world and shows students that science isn’t just petri dishes and microscopes, it is the important, educated choices that affect the world around us.

In the future I hope to more effectively utilize historical and modern case studies to develop my students' understanding of the nature of science, as I recognize that placing science in the context of the real-world through determining trends, analyzing and interpreting data, and supporting scientific claims with empirical evidence is invaluable to the learning of my students ("Appendix H", 2013). In addition, instead of incorporating these tenets of science in individual lessons, I hope to integrate these tenets across units through looking at the larger context of scientific models, laws, phenomena, and theories we study in class by viewing them through sociocultural lenses by studying how the scientists' background or societal views may have affected research of the time and the effect that the improvement of scientific tools had on the empirical evidence collected over time. I hope that in making deliberate choices to build students' understanding of science through these tenets, such as by incorporating grounding phenomena into my units and the integration of real-world data into my curriculum, instead of seizing the opportunity when it arises, as I do now, and through engaging students in critical reflection on their own investigations, my students will gain a better understanding of what it means to "do" science.

My understanding of the nature of science has most grown and developed over time. As a student, my understanding was limited as many of my science classes were presented as concrete examples and definitions to memorize and retain. As a pre-service teacher, my understanding grew as I learned that students "learn science better" when they are engaged in inquiry, perhaps through problem-based instruction or through introduction of real-world examples. As a teacher now a part of this course, I have again learned more about the nature of science; I now realize students need to think like a scientist, form questions about phenomena like a scientist, investigate like a scientist, analyze data like a scientist, and support their ideas with evidence like a scientist in order to truly understand science.

Unsurprisingly, the nature of science and nature of engineering share many areas of overlap. Just as there could be many hypotheses about the outcome of a chemical reaction or other investigation, as described in “Engineering in K-12 Education: Understanding the Status and Improving the Prospects” there are also many possible solutions to an engineering challenge or problem (Katehi, L., Pearson, G., and Feder, M., (2009). One must test these possibilities in order to determine the best solution, just as one should perform many trials and evaluate the results of these trials in order to support or refute a hypothetical answer to a research question. Another area overlap is the idea that both engineering and science must “encourage the consideration of social, environmental, and other impacts” of experiments or design solutions (Katehi, L., et al., (2009). For example, genetically modified foods are a hot topic in society; many think of these modifications as something that is completed in the lab setting, when this is actually a form of engineering in that scientists are working to solve problems like short shelf life or low fruit production. Yet another overlap between engineering and science is the need for the “habit[s] of mind,” creativity and critical thinking (Katehi, L., et al., (2009). Many of my students hold the common misconception that scientists do not use creativity because they have to follow steps or procedures, but believe engineers do use creativity because they solve problems when, in reality, creativity and critical thinking are inherent to the nature of engineering and science.

REFERENCES

- APPENDIX H – Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards. (2013). Retrieved February 22, 2020, from <https://www.nextgenscience.org/sites/default/files/Appendix H - The Nature of Science in the Next Generation Science Standards 4.15.13.pdf>
- Katehi, L., Pearson, G., and Feder, M. (Eds.). (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Retrieved from https://www.nsf.gov/attachments/117803/public/1b--Eng_in_K-12_Ed.pdf
- Tenets of the nature of science. (2011, October 7). Retrieved February 22, 2020, from <https://www.sciencelearn.org.nz/resources/413-tenets-of-the-nature-of-science>

Figure 1.

Understandings about the Nature of Science relating to science practices (“Appendix H” 2013).

Understandings about the Nature of Science				
Categories	K-2	3-5	Middle School	High School
Scientific Investigations Use a Variety of Methods	<ul style="list-style-type: none"> Science investigations begin with a question. Scientists use different ways to study the world. 	<ul style="list-style-type: none"> Science methods are determined by questions. Science investigations use a variety of methods, tools, and techniques. 	<ul style="list-style-type: none"> Science investigations use a variety of methods and tools to make measurements and observations. Science investigations are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings. Science depends on evaluating proposed explanations. Scientific values function as criteria in distinguishing between science and non-science. 	<ul style="list-style-type: none"> Science investigations use diverse methods and do not always use the same set of procedures to obtain data. New technologies advance scientific knowledge. Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.
Scientific Knowledge is Based on Empirical Evidence	<ul style="list-style-type: none"> Scientists look for patterns and order when making observations about the world. 	<ul style="list-style-type: none"> Science findings are based on recognizing patterns. Scientists use tools and technologies to make accurate measurements and observations. 	<ul style="list-style-type: none"> Science knowledge is based upon logical and conceptual connections between evidence and explanations. Science disciplines share common rules of obtaining and evaluating empirical evidence. 	<ul style="list-style-type: none"> Science knowledge is based on empirical evidence. Science disciplines share common rules of evidence used to evaluate explanations about natural systems. Science includes the process of coordinating patterns of evidence with current theory. Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
Scientific Knowledge is Open to Revision in Light of New Evidence	<ul style="list-style-type: none"> Science knowledge can change when new information is found. 	<ul style="list-style-type: none"> Science explanations can change based on new evidence. 	<ul style="list-style-type: none"> Scientific explanations are subject to revision and improvement in light of new evidence. The certainty and durability of science findings varies. Science findings are frequently revised and/or reinterpreted based on new evidence. 	<ul style="list-style-type: none"> Scientific explanations can be probabilistic. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	<ul style="list-style-type: none"> Scientists use drawings, sketches, and models as a way to communicate ideas. Scientists search for cause and effect relationships to explain natural events. 	<ul style="list-style-type: none"> Science theories are based on a body of evidence and many tests. Science explanations describe the mechanisms for natural events. 	<ul style="list-style-type: none"> Theories are explanations for observable phenomena. Science theories are based on a body of evidence developed over time. Laws are regularities or mathematical descriptions of natural phenomena. A hypothesis is used by scientists as an idea that may contribute important new knowledge for the evaluation of a scientific theory. The term “theory” as used in science is very different from the common use outside of science. 	<ul style="list-style-type: none"> Theories and laws provide explanations in science, but theories do not with time become laws or facts. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. Laws are statements or descriptions of the relationships among observable phenomena. Scientists often use hypotheses to develop and test theories and explanations.

Figure 2.

Understandings about the Nature of Science relating to crosscutting concepts (“Appendix H” 2013).

Understandings about the Nature of Science				
Categories	K-2	3-5	Middle School	High School
Science is a Way of Knowing	<ul style="list-style-type: none"> Science knowledge helps us know about the world. 	<ul style="list-style-type: none"> Science is both a body of knowledge and processes that add new knowledge. Science is a way of knowing that is used by many people. 	<ul style="list-style-type: none"> Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. Science knowledge is cumulative and many people, from many generations and nations, have contributed to science knowledge. Science is a way of knowing used by many people, not just scientists. 	<ul style="list-style-type: none"> Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. Science is a unique way of knowing and there are other ways of knowing. Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	<ul style="list-style-type: none"> Science assumes natural events happen today as they happened in the past. Many events are repeated. 	<ul style="list-style-type: none"> Science assumes consistent patterns in natural systems. Basic laws of nature are the same everywhere in the universe. 	<ul style="list-style-type: none"> Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. Science carefully considers and evaluates anomalies in data and evidence. 	<ul style="list-style-type: none"> Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. Science assumes the universe is a vast single system in which basic laws are consistent.
Science is a Human Endeavor	<ul style="list-style-type: none"> People have practiced science for a long time. Men and women of diverse backgrounds are scientists and engineers. 	<ul style="list-style-type: none"> Men and women from all cultures and backgrounds choose careers as scientists and engineers. Most scientists and engineers work in teams. Science affects everyday life. Creativity and imagination are important to science. 	<ul style="list-style-type: none"> Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination and creativity. Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. Advances in technology influence the progress of science and science has influenced advances in technology. 	<ul style="list-style-type: none"> Scientific knowledge is a result of human endeavor, imagination, and creativity. Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. Technological advances have influenced the progress of science and science has influenced advances in technology. Science and engineering are influenced by society and society is influenced by science and engineering.
Science Addresses Questions About the Natural and Material World.	<ul style="list-style-type: none"> Scientists study the natural and material world. 	<ul style="list-style-type: none"> Science findings are limited to what can be answered with empirical evidence. 	<ul style="list-style-type: none"> Scientific knowledge is constrained by human capacity, technology, and materials. Science limits its explanations to systems that lend themselves to observation and empirical evidence. Science knowledge can describe consequences of actions but is not responsible for society's decisions. 	<ul style="list-style-type: none"> Not all questions can be answered by science. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.