The Nature of Science
in The Next Generation Science Standards

Scientists and science teachers agree that science is a way of explaining the natural world. In common parlance, science is both a set of practices and an accumulation of knowledge. An essential part of science education must include developing both the abilities and knowledge of the practices and the science concepts that are foundational to specific disciplines. Further, students should develop an understanding of the enterprise of science as a whole. This final statement establishes connections to the nature of science as a domain of learning outcomes for K–12 science education. The Next Generation Science Standards (NGSS) offer an opportunity to significantly impact science education. The purpose of this paper is to address the importance of understanding the Nature of Science and how students can build that knowledge through the NGSS.

The NRC Framework

The Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) acknowledges the importance of the nature of science in the statement "… there is a strong consensus about characteristics of the scientific enterprise that should be understood by an educated citizen" (NRC, 2012, page 78). The *Framework* continues with reflections on the practices of science and returns of the nature of science in the following statement. "Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim and be able to distinguish among them" (NCR, 2012, page 79). This quotation presents a series of concepts important to understanding the nature of science as a complement to the practices involved with activities such as investigations, field studies, and experiments.

This discussion leads to several questions. First, what should students understand about the nature of science? Second, what elements of the *Framework* present opportunities for teaching and learning about the nature of science? Third, are there any additions to the fundamental components—practices, crosscutting concepts, core disciplinary ideas—that would contribute to students' developing a deeper and broader understanding of the nature of science? The NGSS are being developed based on the *Framework,* therefore, it will be important to have an understanding of how the nature of science can be represented through the dimensions described in the *Framework.*

Science Practices and Crosscutting Concepts

Let us begin by examining the science practices and crosscutting concepts for connections between the fundamentals of doing scientific investigations and a basis for understanding the scientific enterprise.

Although one could propose all of the practices as essential for understanding the nature of science, four practices seem fundamental to understanding the nature of science. Those practices are:

- Developing and using models,
- Analyzing and interpreting data,

- Constructing explanations, and
- Engaging in argument from evidence.

From the crosscutting concepts one can use the following as complementary components to the proposed practices the combination establishes a procedural and conceptual a bridge to the nature of science.

- Patterns
- Cause and Effect: Mechanisms and Explanation
- Systems and System Models

Nature of Science: A Perspective
It seems clear that instruction that centers on the integration of practices, core disciplinary ideas, and crosscutting concepts could set the stage for teaching and learning about the nature of science. This said, learning about the nature of science requires more than engaging in activities and conducting investigations.

When the three dimensions of the science standards are combined, one can ask: What is central to the intersection of the practices, core ideas, and crosscutting concepts? Or, what is the relationship among the three basic elements of *The Framework for K–12 Science Education?* Humans have a need to explain the world around them. In some cases, the need originates in potential dangers, sometimes it is a curiosity, and in other cases the promise of a better life. Science is the pursuit of explanations of the natural world. As a foundation for K–12 science education, the issue is explaining the natural world and especially the formation of adequate, evidence-based scientific explanations. To be clear, this sort of explanation should not be confused with how students engage in the practice of constructing explanations. Obviously, students in K–12 are not likely to construct new explanations of the natural world; they can understand and engage in the process scientists use to acquire scientific knowledge.

Now, the science teachers' question—How do I put the elements of practices and crosscutting concepts together to help students understand the nature of science? Suppose students observe the moon's movements in the sky, changes in seasons, phase changes in water, or life cycles of organisms. One can have them observe patterns and have them propose explanations of cause-effect. Then, have the students develop a model of the system based on their proposed explanation. Next, they design an investigation to test the model. In designing the investigation they have to gather data and analyze data. Next they participate in the practice of constructing an explanation using an evidence-based argument. A science teacher may also probe students' understanding of possible mechanisms for the phenomena they observe.

Using Examples from the History of Science
It is one thing to develop the practices and crosscutting concepts in the context of core disciplinary ideas. It is another aim to develop an understanding of the nature of science within those contexts. The use of case studies from the history of science provides contexts to develop students' understanding of the nature of science. For example, in the upper grades case studies on the following topics might be used to broaden and deepen understanding about nature of science.

- Copernican Resolution
- Newtonian Mechanics
- Lyell's Study of Patterns of Rocks and Fossils
- Progression from Continental Drift to Plate Tectonics
- Lavoisier/Dalton and Atomic Structure
- Darwin Theory of Biological Evolution and the Modern Synthesis
- Pasteur and the Germ Theory of Disease
- James Watson and Frances Crick and The Molecular Model of Genetics

These explanations could be supplemented with other cases from history. The point is providing an instructional context that bridges the practices and nature of science through understanding the role of systems models, patterns, cause and effect, the analysis and interpretations of data, the importance of evidence with scientific arguments, and the construction of scientific explanations of the natural world. In the case studies these understandings of the nature of explanations are placed in the larger context of scientific models, laws, and theories.

A Rationale and Research

Addressing the need for students to understand both the concepts and practices of science and the nature of science is not new in American education. The writings of James B. Conant, in the 1940s and 1950s, for example, argue for a greater understanding of science by citizens (Conant, 1947). In *Science and Common Senses* (Conant, 1951), discusses the "bewilderment of laymen" when it comes to understanding what science can and cannot accomplish both in the detailed context of investigations and larger perspective of understanding science. Here is a statement by Conant " …the remedy does not lie in a greater dissemination of scientific information among nonscientists. 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, page 4). In the context of this discussion, tactics are analogue to practices and the strategies are analogue to the nature of scientific explanations.

The present discussion recommends the aforementioned "tactics of science practices and crosscutting concepts" to develop students' understanding of the larger strategies of the scientific enterprise—the nature of scientific explanation. One should note that Conant and colleagues went on to develop the *Harvard Cases in History of Science*, a historical approach to understanding science. An extension of the nature of science as a learning goal for recording education soon followed the original work at Harvard. In the late 1950s, Leo Klopfer adapted the *Harvard Cases* for use in high schools (Klopfer & Cooley, 1963). Work on the nature of science has continued with lines of research by Lederman (1992), Lederman and colleagues (Lederman at al, 2002d; 2002b), and Duschl (1990; 2000; 2008). One should note that one aspect of this research base addresses the teaching of nature of science (see, e.g. Lederman and Lederman, 2004; Flick and Lederman, 2004; Duschl, 1990; McComus, 1998; Osborne et al, 2003; Duschl & Grandy, 2008).

Further support for teaching about the nature of science can be seen in 40 years of Position Statements from the National Science Teachers Association (NSTA). In the late 1980s, *Science*

For All Americans (Rutherford & Ahlgren, 1989) and in the 1990s policy statement *Benchmark for Science Literacy* (AAAS, 1993) and *National Science Education Standards* (NRC, 1996) clearly set understanding the nature of science as learning outcomes for science education.

Recently, discussions of the (NRC, 2012) and implications for science teaching have provided background or instructional strategies that connect specific practices and the nature of scientific explanations (Duschl, 2012; Krajcik & Merritt, 2012; Reise, Berland, & Kenyon, 2012).

Conclusion

This discussion addressed the challenge of including the nature of science in classrooms based on the NGSS. The approach centered on the intersection of science practices, core disciplinary ideas, and crosscutting concepts. The nature of the scientific explanations was proposed as the idea central to standards-based classrooms. Beginning with the practices, core ideas, and crosscutting concepts, science teachers can progress to the regularities of laws in importance of evidence, and the formulation of theories in science. With the addition of historical examples, the nature of scientific explanations assumes both a human face and is recognized as an ever-changing enterprise.

Based on the public and state feedback, as well as feedback from key partners like the National Science Teachers Association (NSTA), steps were taken to make the Nature of Science more prominent in the performance expectations. It is important to note that while the Nature of Science was reflected in the Framework through the practices, understanding the Nature of Science is more than just practice. As such, the direction of the lead states was to indicate Nature of Science appropriately in both Science and Engineering Practices and Crosscutting Concepts. A matrix of Nature of Science across K-12 is also included in this appendix.

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Overview

One goal of science education is to help students understand the nature of scientific knowledge. This matrix presents eight major themes and grade level understandings about the nature of science. Four themes extend the scientific and engineering practices and four themes extend the crosscutting concepts. These eight themes are presented in the left column. The matrix describes learning outcomes for the themes at grade bands for K-2, 3-5, middle school, and high school. Appropriate learning outcomes are expressed in selected performance expectations and presented in the foundation boxes throughout the standards.

Understandings about the Nature of Science

Categories	K-2	3-5	Middle School	High School
Scientific Investigations Use a Variety of Methods	▪ Science investigations begin with a question. ▪ Science uses different ways to study the world.	▪ Science methods are determined by questions. ▪ Science investigations use a variety of tools and techniques. ▪ There is not one scientific method.	▪ 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.	▪ 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	▪ Scientists look for patterns and order when making observations about the world.	▪ Science findings are based on recognizing patterns. ▪ Science uses tools and technologies to make accurate measurements and observations.	▪ Science knowledge is based upon logical and conceptual connections between evidence and explanations. ▪ Science disciplines share common rules of obtaining and evaluating empirical evidence.	▪ 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	▪ Science knowledge can change when new information is found.	▪ Science explanations can change based on new evidence.	▪ 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.	▪ 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	▪ Science uses drawings, sketches, and models as a way to communicate ideas. ▪ Science searches for cause and effect relationships to explain natural events.	▪ Science theories are based on a body of evidence and many tests. ▪ Science explanations describe the mechanisms for natural events.	▪ 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.	▪ 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 have 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.

Understandings about the Nature of Science				
Categories	**K-2**	**3-5**	**Middle School**	**High School**
Science is a Way of Knowing	▪ Science knowledge helps us know about the world.	▪ 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.	▪ 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.	▪ Science is both a body of knowledge that represents 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	▪ Science assumes natural events happen today as they happened in the past. ▪ Many events are repeated.	▪ Science assumes consistent patterns in natural systems. ▪ Basic laws of nature are the same everywhere in the universe.	▪ 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.	▪ 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	▪ People have practiced science for a long time. ▪ Men and women are scientists and engineers.	▪ Men and women choose careers as scientists and engineers. ▪ Most scientists and engineers work in teams. ▪ Science affects everyday life. ▪ Creativity and imagination are important to science.	▪ 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.	▪ Scientific knowledge is a result of human endeavors, imagination, and creativity. ▪ Individuals and teams from many nations and cultures have contributed to science and engineering advances. ▪ 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.	▪ Scientists study the natural and material world.	▪ Science findings are limited to questions that can be answered with empirical evidence.	▪ 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 does not make the decisions that society takes.	▪ 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.

☐ Nature of Science understandings most closely associated with Practices

☐ Nature of Science understandings most closely associated with Crosscutting Concepts