NORTH DAKOTA SCIENCE CONTENT STANDARDS: APPENDIX H

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Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards

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APPENDIX H – Understanding the Scientific Enterprise: 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 the historical accumulation of knowledge. An essential part of science education is learning science and engineering practices and developing knowledge of the concepts that are foundational to science disciplines. Further, students should develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting and analyzing. This final statement establishes a connection between the *Next Generation Science Standards* (NGSS) and the nature of science. Public comments on previous drafts of the NGSS called for more explicit discussion of how students can learn about the nature of science.

This chapter presents perspectives, a rationale and research supporting an emphasis on the nature of science in the context of the NGSS. Additionally, eight understandings with appropriate grade-level outcomes are included as extensions of the science and engineering practices and crosscutting concepts, not as a fourth dimension of standards. Finally, we discuss how to emphasize the nature of science in school programs.

The Framework for K-12 Science Education

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) acknowledged 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* reflected on the practices of science and returned to 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" (NRC, 2012, page 79). This quotation presents a series of

concepts and activities important to understanding the nature of science as a complement to the practices imbedded in investigations, field studies, and experiments.

Nature of Science: A Perspective for the NGSS

The integration of scientific and engineering practices, disciplinary core ideas, and crosscutting concepts sets 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 scientific and engineering practices, disciplinary core ideas, and crosscutting concepts? Or, what is the relationship among the three basic elements of *A Framework for K-12 Science Education*? Humans have a need to know and understand the world around them. And they have the need to change their environment using technology in order to accommodate what they understand or desire. In some cases, the need to know originates in satisfying basic needs in the face of potential dangers. Sometimes it is a natural curiosity and, in other cases, the promise of a better, more comfortable life. Science is the pursuit of explanations of the natural world, and technology and engineering are means of accommodating human needs, intellectual curiosity and aspirations.

One fundamental goal for K-12 science education is a scientifically literate person who can understand the nature of scientific knowledge. Indeed, the only consistent characteristic of scientific knowledge across the disciplines is that scientific knowledge itself is open to revision in light of new evidence.

In K-12 classrooms, the issue is how to explain both the natural world and what constitutes the formation of adequate, evidence-based scientific explanations. To be clear, this perspective complements but is distinct from students engaging in scientific and engineering practices in order to enhance their knowledge and understanding of the natural world.

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 50s, for example, argue for a greater understanding of science by citizens (Conant, 1947). In *Science and Common Senses* (1951), Conant 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. Conant says: "…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 the discussion here, tactics are analogous to science and engineering practices, as well as to the nature of scientific explanations.

The present discussion recommends the aforementioned "tactics of science and engineering practices and crosscutting concepts" to develop students' understanding of the larger strategies of the scientific enterprise—the nature of scientific explanations. One should note that Conant and colleagues went on to develop *Harvard Cases in History of Science*, a historical approach to understanding science. An extension of the nature of science as a learning goal for 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 et al., 2002), and Duschl (1990; 2000; 2008). One should note that one aspect of this research base addresses the teaching of the nature of science (see, e.g., Lederman & Lederman, 2004; Flick & Lederman, 2004; Duschl, 1990; McComas, 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), the 1990s policy statement *Benchmarks for Science Literacy* (AAAS, 1993), and *National Science*

Education Standards (NRC, 1996) clearly set the understanding of the nature of science as a learning outcome in science education.

Recently, discussions of *A Framework for K-12 Science Education* (NRC, 2012) and implications for teaching science have provided background for instructional strategies that connect specific practices and the nature of scientific explanations (Duschl, 2012; Krajcik & Merritt, 2012; Reiser, Berland, & Kenyon, 2012).

The Nature of Science and NGSS

The nature of science is included in the *Next Generation Science Standards*. Here we present the NOS Matrix. The basic understandings about the nature of science are:

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

The first four of these understandings are closely associated with practices and the second four with crosscutting concepts. The NOS Matrix presents specific content for K-2, 3-5, middle school and high school. Appropriate learning outcomes for the nature of science are expressed in the performance expectations, and presented in either the foundations column for practices or crosscutting concepts of the DCI standard pages.

Again, one should note that the inclusion of nature of science in NGSS does not constitute a fourth dimension of standards. Rather, the grade level representations of the eight understandings have been incorporated in the practices and crosscutting concepts, as seen in the performance expectations and represented in the foundation boxes.

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. ▪ Scientist use different ways to study the world.	▪ Science methods are determined by questions. ▪ Science investigations use a variety of methods, tools, and techniques.	▪ 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. ▪ Scientists use 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	▪ Scientists use drawings, sketches, and models as a way to communicate ideas. ▪ Scientists search 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 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.

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 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	▪ 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 of diverse backgrounds are scientists and engineers.	▪ 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.	▪ 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 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.	▪ Scientists study the natural and material world.	▪ Science findings are limited to what 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 is not responsible for society's decisions.	▪ 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

Implementing Instruction to Facilitate Understanding of the Nature of Science

Now, the science teacher's 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 propose explanations of cause-effect. Then, the students can 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 construct an explanation using an evidence-based argument. These experiences allow students to use their knowledge of the practices and crosscutting concepts to understand the nature of science. This is possible when students have instruction that emphasizes why explanations are based on evidence, that the phenomena they observe are consistent with the way the entire universe continues to operate, and that we can use multiple ways to investigate these phenomena.

The Framework emphasizes that students must have the opportunity to stand back and reflect on how the practices contribute to the accumulation of scientific knowledge. This means, for example, that when students carry out an investigation, develop models, articulate questions, or engage in arguments, they should have opportunities to think about what they have done and why. They should be given opportunities to compare their own approaches to those of other students or professional scientists. Through this kind of reflection they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science.

Using examples from the history of science is another method for presenting the nature 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 in which to develop students' understanding of the nature of science. In the middle and high school grades, for example, case studies on the following topics might be used to broaden and deepen understanding about the 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 Francis Crick and the Molecular Model of Genetics

These explanations could be supplemented with other cases from history. The point is to provide an instructional context that bridges tactics and strategies with practices and the 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. Through the use of historical and contemporary case studies, students can understand the nature of explanations in the larger context of scientific models, laws, mechanisms, and theories.

In designing instruction, deliberate choices will need to be made about when it is sufficient to build students' understanding of the scientific enterprise through reflection on their own investigations, and when it is necessary and productive to have students analyze historical case studies.

Conclusion

This discussion addressed how to support the development of an understanding of the nature of science in the context of the *Next Generation Science Standards*. The approach centered on eight understandings for the nature of science and the intersection of those understandings with science and engineering practices, disciplinary core ideas, and crosscutting concepts. The nature of the scientific explanations is an idea central to standards-based science programs. Beginning with the practices, core ideas, and crosscutting concepts, science teachers can progress to the regularities of laws, the importance of evidence, and the formulation of theories in science. With the addition of historical examples, the nature of scientific explanations assumes a human face and is recognized as an ever-changing enterprise.

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