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WHAT EVER HAPPENED TO SCIENTIFIC INQUIRY?

A Look at Evolving Notions of Inquiry Within the Science Education Community and National Standards

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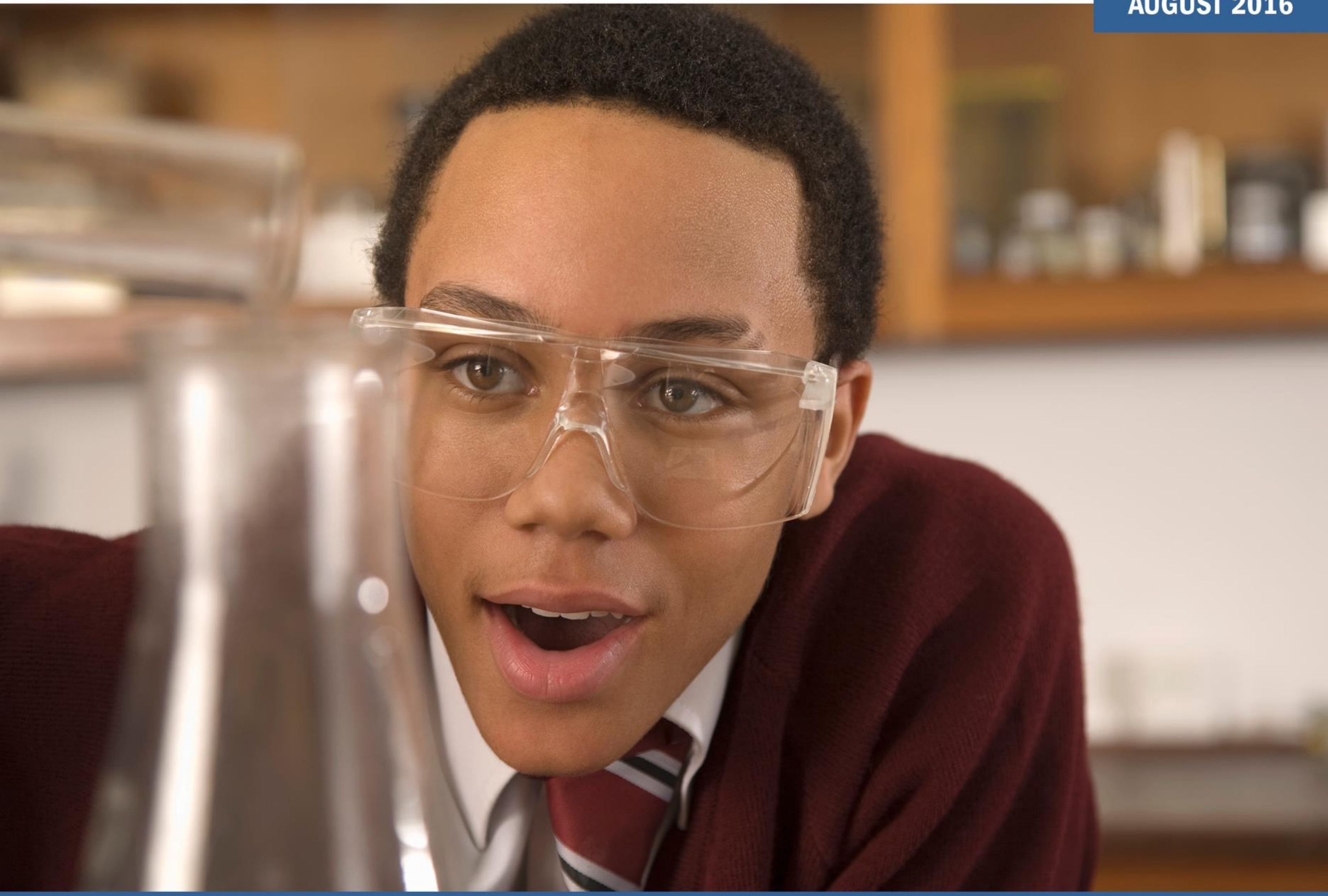

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Introduction

Once prominently featured as its own content area within the National Science Standards (National Research Council [NRC], 1996), the term "scientific inquiry" is rarely mentioned within the newly released *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (subsequently referred to as NRC framework) (NRC, 2012) and Next Generation Science Standards (referred to subsequently as NGSS; NGSS Lead State Partners, 2013). Instead of a focus on scientific inquiry as a separate content area, in the new standards documents notions of inquiry[1] have been refined, redefined, and interwoven within a new three-dimensional learning framework for science. The three dimensions of science learning, as described in these new standards documents, include core ideas, crosscutting concepts, and scientific and engineering practices. These dimensions are understood as interrelated and, together, foster the learning and application of inquiry characterized as the systematic and iterative process "that scientists employ as they investigate and build models and theories about the world" (NRC, 2012, p. 30). Although the authors refer to the scientific and engineering practices as the primary means by which students draw on core ideas and crosscutting concepts to engage in inquiry, the authors are quick to emphasize that inquiry entails the fluid, integrated, and iterative interplay among these three dimensions of learning.

This report explores the evolving notions of scientific inquiry over time, including how scientific inquiry is currently reflected within the new NRC framework and NGSS. This report also explores the extent to which current trends related to notions of inquiry are reflected in the state science standards adopted by Wisconsin and neighboring states. This report centers on the following guiding question:

> How is the term "scientific inquiry" currently understood and being used by members of the science education community, particularly in light of the NRC's *A Framework for K–12 Science Education* and the release of the Next Generation Science Standards?

The report is divided into two parts. Part I explores key trends in the use and understanding of the term "scientific inquiry" over time as reflected in prior and current national standards and other related sources. Part II examines the extent to which current notions of inquiry outlined in the NRC framework and NGSS are reflected in the science standards adopted by Wisconsin and neighboring states within the Great Lakes and Midwest regions.

[1] The terms "inquiry" and "scientific inquiry" are used interchangeably within this report and are assumed to have the same meaning.

Part I

Part I explores the history of, and current trends in the use and understanding of the term "scientific inquiry," and how these notions have changed over time. Part I is organized by two guiding subquestions.

Key Guiding Subquestions

- How was the term "scientific inquiry" understood and defined prior to the Next Generation Science Standards?
- How does the current NRC framework and the NGSS define and/or refer to notions of scientific inquiry?

Methods

To answer this first subquestion, several key sources were reviewed, including two documents from the NRC: the *National Science Education Standards* (NRC, 1996) and *Inquiry and the National Science Education Standards* (NRC, 2000). In addition, a limited number of additional sources, such as research reviews and selected primary sources, were reviewed to help describe the history and evolution of the term "inquiry" across time. The team also conducted interviews with five science education experts identified as having a role in the development or translation of the NRC framework and NGSS to the field (see Appendix E for a list of key informants and interview protocols). Responses to interviews were used to augment findings from these other written sources. Findings based on this evidence are summarized in the following section.

Findings

Inquiry as a Set of Steps and Procedures

Evidence has suggested that after the turn of the century and before the release of the National Science Education Standards (NRC, 1996), scientific inquiry was viewed within the science community primarily as a set of steps or procedures. Prior to the late 19th century, U.S. science educators treated science as a body of objective knowledge and facts to be learned (NRC, 2000; Rudolph, 2005). In 1909, John Dewey, in a speech given to the American Association for the Advancement of Science, introduced to American educators the notion of science as a method of thinking that is equally important to science content (NRC, 2000). In *How We Think* (Dewey, 1910a), Dewey outlined the methods used in the work of scientists, which included a set of five discrete steps he referred to as "a complete act of thought" (Dewey, 1910a, pp. 68–78). According to one scholar (Rudolph, 2005), although Dewey's intent had been to promote the reflective process associated with how scientists' work, instead what became popularized was Dewey's set of five discrete steps (Rudolph, 2005).

By the early 20th century, a greater emphasis on "thinking like a scientist" and science as a laboratory process that follows a set of prescribed steps and procedures (i.e., the scientific method) grew in popularity and became associated with science education in American schools (Barrow, 2006; NRC, 2000; Rudolph, 2005; Wissehr, Concannon, & Barrow, 2011). While there are many variations in labels and interpretation of the steps associated with the scientific method, the sequential steps and procedures associated with this method often include observation, posing a question, stating a hypothesis, conducting an experiment, and evaluating the results of that experiment (McLelland, 2006).

Inquiry as a Hands-On and Minds-On Approach

In 1989, the American Association for the Advancement of Science (AAAS) introduced a more refined and expanded notion of scientific inquiry, positing that it involved more than simply following a set of sequential, rigid steps and procedures. This emerging understanding of inquiry reflected new thinking about scientific literacy and inquiry as a strategy for teaching science that was beginning to emerge around this time (AAAS, 1989; Barrow, 2006, NRC, 2000; Young, 2013). For example, Barrows (2006), in his examination of evolving perspectives on inquiry notes that the American Association for the Advancement of Science created a document entitled "Benchmarks for Scientific Literacy" (AAAS, 1993). In this document, the AAAS included a chapter dedicated to inquiry that referred to inquiry as a "habit of the mind" (Barrow, 2006, p. 267). The AAAS document reflected the emerging shift in the science community away from inquiry as a set of rigid, prescribed steps and toward inquiry as encompassing both thought and process.

This shift in understanding was reaffirmed and further promoted in the mid-1990s when the National Academy of Sciences released the National Science Education Standards (NRC, 1996). In the introduction to the new Science Standards (NRC, 1996) the authors explained:

> The Standards call for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. (p. 2)

More specifically, the NRC standards defined scientific inquiry as follows:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

The publication of these standards solidified emerging notions of scientific inquiry, like those put forth by AAAS, and represented a critical turning point in contemporary views of scientific inquiry. Rather than inquiry being defined as an exclusively hands-on process, or set of rigid and prescribed steps to be followed, the NRC had redefined inquiry as an approach that encompasses both knowledge and skills ("hands-on" and "minds-on" [NRC, 2012, p. 2]). Scientific inquiry was now recognized as central to how scientific understanding and progress are built and was prominently represented in the standards as its own content area.

The National Science Education Standards (NRC, 1996) authors further explained how new perspectives on inquiry necessitate shifts in emphasis. The authors noted that the standards put less emphasis on "activities that demonstrate and verify science content" and more emphasis on "activities that investigate and analyze science questions." Likewise, the standards place less emphasis on "getting an answer" and more emphasis on "using evidence and strategies for developing or revising an explanation" (NRC, 1996, p. 113).

The prior National Science Education Standards (NRC, 1996) included eight core science content areas. The standards prominently featured "science as inquiry" as one of these eight core content areas. Inquiry was defined as having two complementary elements or pillars: fundamental abilities and fundamental understandings. A set of fundamental abilities and understandings was defined for each of three grade bands: K–4, 5–8, and 9–12. For example, the fundamental abilities and understanding for Grades 5–8 are included in Table 1.

Table 1. Science Inquiry: Grades 5–8 Fundamental Abilities and Understandings

Fundamental Abilities	Fundamental Understandings
▪ Identify questions that can be answered through scientific investigations. ▪ Design and conduct a scientific investigation. ▪ Use appropriate tools and techniques to gather, analyze and interpret data. ▪ Develop descriptions, explanations, predictions and models using evidence. ▪ Think critically and logically to make the relationships between evidence and explanations. ▪ Recognize and analyze alternative explanations and predictions. ▪ Communicate scientific procedures and explanations. ▪ Use mathematics in all aspects of scientific inquiry.	▪ Different kinds of questions suggest different investigations. ▪ Current scientific knowledge and understanding guide scientific investigations. ▪ Mathematics is important in all aspects of inquiry. ▪ Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations. ▪ Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories. ▪ Science advances through legitimate skepticism. ▪ Investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data.

Source: NRC, 1996, pp. 145–148.

Inquiry: The Five Essentials

Four years after the publication of the standards, NRC released a companion document titled *Inquiry and the National Science Education Standards* (NRC, 2000). This document provided further explanation and guidance for educators to better understand new views of inquiry and its role in science education. Specifically, this document introduced and explained five essentials of inquiry. These five essentials were intended to better convey that inquiry entails the integration of knowledge and skills and that the varying science abilities and understandings outlined in the standards could be conceived as a unified set of essentials.[2]

[2] The five essentials are distinctly different from Dewey's five steps.

These five essentials are as follows:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternate explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

This document provided an in-depth explanation of how new definitions of inquiry were distinct from prior uses of the term. For example, the authors explained:

> Students do not come to understand inquiry simply by learning words such as "hypothesis" and "inference" or by memorizing procedures such as "the steps of the scientific method." They must experience inquiry directly to gain a deep understanding of its characteristics. Yet experience in itself is not sufficient. Experience and understanding must go together. Teachers need to introduce students to the fundamental elements of inquiry. They must also assist students to reflect on the characteristics of the processes in which they are engaged. (NRC, 2000, p. 23)

Inquiry-based teaching focuses on developing students' abilities to ask and evaluate questions to be investigated, consider the difference between facts and opinions, and formulate explanations from evidence (NRC, 2000). An inquiry-based approach to teaching science was strongly emphasized in the *Inquiry and the National Science Education Standards* report. The authors of two sources that explore notions of inquiry as reflected in the 1996 National Science Standards suggest that the term "inquiry" encompasses inquiry-based teaching (Asay & Orgill, 2010; Barrow, 2006).

Translation of New Notions of Inquiry to the Field

Following the release of the National Science Standards (NRC, 1996) and its companion document *Inquiry and the National Science Education Standards* (NRC, 2000), the term "scientific inquiry" was fraught with confusion for many educators. Multiple sources suggest that the term "inquiry" was referred to by varying labels and was interpreted differently by educators (Asay & Orgill, 2010; Barrow, 2006; Capps & Crawford, 2012; NRC, 1996, 2012; Settlage, 2003; Young, 2013). For example, in his analysis of how notions of inquiry have changed during the 20th century, Barrows (2006) concluded:

> Over the past century, science educators have provided multiple interpretations of inquiry. Consequently, K–12 teachers of science, students, and parents are confused…there is no uniform agreement among the science education community about what is the meaning of inquiry as recommended by the NRC (1996). (Barrows, 2006, p. 274)

Evidence has suggested that the meaning of the term "inquiry" as a set of steps and procedures may have persisted, despite explicit efforts by national organizations to clarify the meaning of the term "inquiry" and its role in science teaching (Asay & Orgill, 2010; Barrow, 2006;

Capps & Crawford, 2012; NRC, 2000, 2012; Settlage, 2003; Young, 2013). For example, Assay and Orgill (2010) examined the extent to which the five essentials of scientific inquiry, as outlined in the companion document *Inquiry and the National Science Education Standards* (NRC, 2000), were being practiced in actual classrooms. The authors analyzed nearly 300 feature articles that appeared in *The Science Teacher* from 1998 to 2007 and discovered that the inquiry practice of gathering evidence appeared in 82% of the articles. However, other essentials of inquiry, such as learners formulate explanations from evidence, connect explanations to scientific knowledge, and communicate and justify explanations, were present in fewer than 25% of the articles reviewed. The authors concluded from their review that most educators appeared to view "inquiry more as a process than as a vehicle for learning science content…" (Assay & Orgill, 2010, p. 57).

During key informant interviews, science education experts shared similar views of how the term "inquiry" has suffered from both multiple meanings and misinterpretations by educators in the field. For example, Matt Krehbiel, Associate Director of Science for Achieve, noted:

> …prior to the emphasis on inquiry, scientific process was often taught as the scientific method, a rigid linear idea.

Dr. Helen Quinn, Professor Emeritus at Stanford and former Chair of the NRC council board, remarked:

> In schools, science inquiry had become synonymous with hands on science, the doing without always including the analyzing and thinking part.

Dr. Quinn further shared that some educators even misunderstood the "hypothesis" part, encouraging students to make a guess, not even construct a true hypothesis—such as a prediction based on a theory or model. At that time, the way inquiry was interpreted in schools was very "thin."

Dr. Melissa Braaten, Assistant Professor of Science and Teacher Education at the University of Wisconsin-Madison, explained:

> In schools, inquiry had come to mean one narrow image of doing formulaic, defined experiments. Teachers would refer to it as 'the scientific method' like it was a titled thing. But, what they were trying to do in the name of inquiry didn't resemble the intellectual work of scientists at all.

Reflecting on how these misconceptions may have been perpetuated with the field, Joseph Krajcik, Professor of Science Education at Michigan State University and Lead writer for the Next Generation Science Standards, noted:

> …while well intentioned, when the National Science Standards assigned inquiry to its own separate content area, it meant that inquiry remained separate from other science learning.

These key informants also noted that over the years the term "inquiry" has been confused with "inquiry-based teaching." In addition, some educators believed that when students engage in unstructured, open-ended explorations, they are doing "inquiry."

For example, Mr. Krehbiel shared:

> In the field, it (inquiry) has been interpreted in a lot of different ways. Sometimes it meant open discovery, no parameters, just let kids explore and figure out something on their own. In other iterations, it meant, you were letting students figure things out on their own, but really you (the teacher) had an answer you wanted them to get to.

A state K–5 science education assessment coordinator and pioneering state member of NGSS recalled:

> [Prior to NGSS], teachers were having students do inquiry for the sake of inquiry with no content. It was all process, no understanding.

Summary

Prior to the release of the NRC framework and the NGSS, evidence has suggested that notions of inquiry, as outlined in the National Science Education Standards, may never have fully taken hold within the science education community. Instead, views of scientific inquiry suffered from misinterpretations and multiple interpretations, most of which were not consistent with notions of inquiry as reflected within the 1996 national science standards and companion documents (NRC, 2000).

How Does *A Framework for K–12 Science Education* and the Next Generation Science Standards Define and Refer to Scientific Inquiry?

To answer the second subquestion, a comprehensive review was conducted of two key documents: *A Framework for K–12 Science Education* (NRC, 2012) and the NGSS that are based on the NRC framework (NGSS Lead State Partners, 2013). The focus of document reviews was to identify references to scientific inquiry and examine how notions of inquiry within the current standards have shifted since the release of the first science standards by NRC in 1996 and the companion document *Inquiry and the National Science Education Standards* (NRC, 2000). The NRC framework and NGSS are "based on a rich and growing body of research on teaching and learning in science, as well as on nearly two decades of efforts to define foundational knowledge and skills for K–12 science and engineering" (NRC, 2012, p. 2). The NRC framework and NGSS documents, therefore, were selected as sources that likely reflect the most current thinking about scientific inquiry held within the science education community.

Responses gathered through key informant interviews with science education experts, several of which played an integral part in the development of the NRC framework and NGSS, offered additional perspectives and evidence to augment these document reviews (see Appendix D for a list of key informants and interview protocols).

Scientific Inquiry as Reflected in the NRC Framework and NGSS

Once prominently featured as its own content area within the National Science Standards (NRC, 1996), the term "scientific inquiry" is rarely mentioned within the newly released *Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) and NGSS (NGSS Lead State Partners, 2013). Instead of a focus on scientific inquiry as a separate content area, in the new standards documents notions of inquiry have been refined, redefined, and interwoven within a new three-dimensional learning framework for science. The three dimensions of science learning, as described in these new standards documents, include disciplinary core ideas, crosscutting concepts, and scientific and engineering practices. These dimensions are understood as interrelated and, together, foster the learning and application of inquiry characterized as the systematic and iterative process "that scientists employ as they investigate and build models and theories about the world" (NRC, 2012, p. 30). While the authors refer to the scientific and engineering practices as the primary means by which students draw on core ideas and crosscutting concepts to engage in inquiry, the authors are quick to emphasize that inquiry entails the fluid, integrated, and iterative interplay among these three dimensions of learning.

Current Use of the Term "Inquiry"

Evidence from both document reviews and key informant interviews suggests that many prominent science educators are increasingly shying away from use of the term "scientific inquiry." Document scans of the NRC framework and NGSS yielded very few incidences where the term "inquiry" was referenced. In most of these cases, "inquiry" was used in the context of redefining its meaning.

There appears to be two main reasons for this trend. First, some argue that inquiry is not a term used by real working scientists, and so its use in science education is not appropriate. Dr. Quinn remarked:

> While it is what we do—we inquire—scientists do not use the term inquiry.

Other science education experts, as well as authors of the NRC framework and NGSS, have pointed out that another reason to avoid using the term "scientific inquiry" is that it continues to be fraught with misunderstanding and multiple interpretations by educators in the field, none of which accurately capture its intent. For example, in the introduction to the NRC framework the authors explained:

> …because the term inquiry extensively referred to in previous standards documents has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the practices…is to better specify what is meant by inquiry in science and the range of cognitive, social and physical practices it requires. (NRC, 2012, p. 30)

National science experts interviewed also conveyed a reluctance or avoidance of the term "scientific inquiry." For example, Dr. Krajcik exclaimed:

> I have avoided using the term inquiry for 30 years. Why don't I use that term? Because it has come to mean everything from students conducting cookbook investigations, to teachers doing inquiry based teaching, to a student engaged in a full-fledged investigation. We have lost the meaning of what inquiry is when it retains so many differing interpretations. What do I use instead? I talk about having kids figure things out. If they have a problem or question, we encourage them to explore, be curious about how the world works—try to figure it out.

Dr. Braaten shared*:*

> I am glad that NGSS dropped the word inquiry, because of the way it got taken up in schools, as being the scientific method. In fact, some of the educators I talk to tell me "inquiry" is over. What I hope they mean is that the sequential, step-by-step experiment approach to teaching science is over.

By virtually abandoning use of the term, perhaps the authors of the NRC framework and NGSS intended to create a "blank slate" from which a more authentic, accurate, and nuanced notion of inquiry could emerge.

Notions of Inquiry Within the NRC Framework and NGSS

How are notions of inquiry reflected within the NRC framework and NGSS? The following section highlights four recent shifts in notions of inquiry observed in the NRC framework and NGSS, and gleaned from key informant interviews:

1. Inquiry as a means for constructing scientific understanding—not a content area
2. Inquiry as a fluid, integrated, and iterative set of practices that scientists use
3. Inquiry as three dimensional learning
4. Inquiry as independent from science pedagogy

1. Inquiry as a means for constructing scientific understanding—not a content area

In the prior National Science Standards (NRC, 1996), scientific inquiry was treated as its own distinct and isolated content area. One of the most concrete changes with the new NRC framework and NGSS is that inquiry is no longer explicitly identified as a content area. Instead, inquiry is primarily reflected through a set of eight scientific and engineering practices that represent one of three integrated, essential means by which students construct scientific understanding (i.e., through the integration of core ideas, crosscutting concepts, and scientific and engineering practices).

The eight scientific and engineering practices are as follows (NRC, 2012, p. 42):

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

The NRC framework explains that one purpose for recharacterizing inquiry as scientific and engineering practices was to help clarify what is "meant by inquiry in science and the range of cognitive, social and physical practices it requires" (NRC, 2012, p. 30). Moving scientific inquiry out of the content standards conveys the notion that inquiry should not stand alone, but rather it should be interwoven throughout all science learning.

As explained by Mr. Krehbiel:

> The (scientific and engineering) practices are the next iteration of science inquiry. Inquiry has not gone away—it lives on through the scientific and engineering practices-- not as a separate unit of study as it was before, but rather woven into science learning throughout the year, where practices are exercised and integrated with learning of the crosscutting concepts and disciplinary core ideas.

The authors of *A Framework for K–12 Science Education* (NRC, 2012) explicitly referenced earlier standards and notions of inquiry, acknowledging that the term "inquiry" has suffered from varying interpretations across time. The authors clarified that inquiry, as reflected in the new NRC framework, is not a "process-only" endeavor, nor is it a set of prescribed steps. The NRC framework referred to inquiry instead as the systematic and iterative process "that scientists employ as they investigate and build models and theories about the world" (NRC, 2012, p. 30). The authors explain that inquiry, as enacted through the practices, includes the coordination of "knowledge and skill simultaneously" (p. 41).

Although there seems to be consensus within the science education community that the scientific and engineering practices are essential to inquiry, some experts view these eight practices slightly differently. For example, some key respondents describe the eight practices primarily as the means by which students construct new explanations, models and understanding, while others view the practices as both a "means" as well as an "end" for science learning—i.e., that mastering the habits and skills associated with the practices themselves is also an important learning goal for students, not just a process by which they can learn content. For example, Dr. Braaten noted:

> Inquiry is not an end in itself—it is not a separate goal or content area. Not a unit to cover.

In contrast, one state K–5 science education assessment coordinator noted that while the practices are primarily a "means" for building scientific understanding:

> At the same time, inquiry is also about understanding how scientists go about their work. This is the "what" of inquiry.

Mr. Krehbiel shared:

> In its best iteration, inquiry is a mechanism for learning—a process, but also an opportunity to learn about the process of science. Practices are therefore both a process, and also information about that process. Students need to get better with carrying out investigations, for instance, in order to understand and apply science. We need to be sure they are building proficiency in these practices across a year, and across their K–12 education experience.

2. Inquiry as a fluid, integrated, and iterative set of practices that scientists use

As explained previously, the NRC framework and NGSS identify eight scientific and engineering practices to be used in inquiry, implemented in conjunction with the other two dimensions of the NRC framework and NGSS: core ideas and crosscutting concepts. The current conception of inquiry intends to illustrate how science is actually carried out in the field—through an inquiry process that is not rigid and dictated by a specific set of steps, but as fluid and iterative in nature. Responses from science education experts emphasized this point. For example, Dr. Krajcik remarked:

> I have taken off the numbers associated with the 8 practices and I use arrows instead. I do this to show how they all work together. Having the 8 practices doesn't mean that you start with a question, then move on to the next practice. It might mean that when you are analyzing data, you come up with a new question, or construct an argument. There is no linearity implied. The practices are tied together and any one of them could lead to another.

Dr. Braaten shared:

> The practices are not sequential—it really bugs me that they numbered them. The way it is intended is that one practice sends you to another practice. They cascade into one another—there is natural flow between them.

The NRC framework offers greater clarity about how it is that these eight practices should work together through participation in three spheres of activity:

1. Empirical investigation
2. Developing explanations and solutions
3. Evaluation

The first sphere is empirical investigation. The authors noted that, "In this sphere of activity, scientists determine what needs to be measured; observe phenomena; plan experiments, programs of observation, and methods of data collection; build instruments; engage in disciplined fieldwork; and identify sources" (NRC, 2012, p. 45). In many ways, this first sphere of inquiry activity aligns well with prior notions of inquiry as the tasks involved in conducting scientific investigations.

The second sphere is developing explanations and solutions. The authors noted that in this sphere, scientists "draw from established theories and models and to propose extensions to theory or create new models. Often, they develop a model or hypothesis that leads to new questions to investigate or alternative explanations to consider" (NRC, 2012, p. 45). This sphere of inquiry activity emphasizes inquiry as a means for building scientific understanding through constructing, testing, and revising theories and models.

The third sphere is evaluation. This sphere refers to the

> [I]terative process that repeats every step of the work. Critical thinking is required, whether in developing and refining an idea (an explanation or a design) or in conducting an investigation. The dominant activities in this sphere are argumentation and critique,

> which often lead to further experiments and observations or to changes in proposed models, explanations, or designs. Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design. (NRC, 2012, p. 46)

This third sphere of inquiry emphasizes its cyclical and fluid nature. This sphere represents a subtle shift from early notions of inquiry that imply a more sequential approach.

Dr. Quinn explained:

> For me, the practices are a description of scientific inquiry, the iterative nature of doing….the idea is that you are always looking at and analyzing a system, some kind of description of how the system works. These are often diagrammatic when describing the systems, showing what is flowing in and out of that system. In this sphere, students are describing their thinking through explicit modeling. Then, students have to put their own mental models on paper…this helps them better see the contradictions between the observations and their current way of thinking. Seeing these contradictions can help students revise their thinking and understanding based on evidence.

Dr. Braaten explained:

> Inquiry is more explanatory, model building work. It is iterative in nature and, follows many cycles and paths. The scientific and engineering practices enable students to pursue a question that has intellectual depth for that discipline.

3. Inquiry as three-dimensional learning

As explained earlier, while the NRC framework and NGSS identify eight distinct practices, they also emphasize that these practices are not to be implemented in isolation. Rather, these practices are to be interwoven with science learning across all core science subjects and for all crosscutting concepts. The NRC framework and NGSS describe this approach to science education as three-dimensional learning. In other words, the eight scientific and engineering practices do not simply represent another set of steps and procedures—but rather serve as one of three essential means by which scientific understanding is constructed.

Dr. Krajcik offered an analogy to help convey this idea.

> The practices, crosscutting concepts, and disciplinary core ideas, are interwoven, tightly together like a rope. Each individual strand is weak, and doesn't allow the rope to properly function. The strength and functionality of the rope comes when you put the three strands together.
>
> How do these work together? When you have a question or problem you might pursue, you can't address or pursue it without drawing on your background knowledge, without engaging in practices and without using cross cutting concepts. The three have to work in concert to support a learning in making sense of phenomena and constructing greater understanding.

Dr. Quinn explained:

> It is perfectly fine to use scientific inquiry if it is encapsulated in practices. I believe students should have opportunities to engage in all of those practices.
>
> But, it is also equally important to clarify, that you cannot inquire about nothing—you have to be investigating and trying to understand a phenomenon, based on theories and models of something specific. This is where the disciplinary core ideas and crosscutting concepts come in.

4. Inquiry as independent from science pedagogy

Inquiry, in the 1996 National Science Education Standards (NRC, 1996) and its companion document (NRC, 2000), was defined as consisting of abilities, and understandings, which were intended to be taught using inquiry-based teaching methods. In fact, *Inquiry and the National Science Education Standards* (NRC, 2000), dedicated 200 pages to making the case for the inquiry-based teaching approach, including numerous examples of inquiry-based teaching in the classroom.

In the current NRC framework and NGSS, inquiry-based teaching is still recognized as important, but there is a shift away from an exclusive emphasis on inquiry-based teaching as the preferred instructional approach. For example, the NRC framework and NGSS explicitly noted that educators should feel free to use varying instructional approaches to promote students' capacity to engage in inquiry and develop scientific understanding and skill (NGSS Lead State Partners, 2013; NRC, 2012). The NRC framework also refers the reader to other resources, including the NRC reports *Taking Science to School: Learning and Teaching in Grades K–8* (NRC, 2007) and *America's Lab Report: Investigations in High School Science* (NRC, 2006), when considering methods for teaching science.

This view was reinforced in interviews with science education experts. For example, Dr. Quinn explained:

> In the process of inquiry and learning science there are going to be some short intervals of direct instruction. You cannot understand all of science just through engaging in the practices. Teachers might have to first introduce students to a new concept, such as air pressure. Teachers may need to engage the class in discussing new science ideas new to the students, needed in order to better understand the phenomenon they are looking at.

Summary

Part I of this report explored how notions of scientific inquiry have changed over time. A comparison of the current NRC framework (NRC, 2012) and the NGSS (NGSS Lead State Partners, 2013) with earlier National Science Education Standards (NRC, 1996) and other documents (NRC, 2000), was combined with information gleaned from interviews with science education experts in the field.

These findings suggest four key changes related to perspectives on scientific inquiry, including:

- **Inquiry as a means for constructing scientific understanding—not a content area.** Rather than being treated as its own distinct and isolated content area, inquiry is now reflected primarily through the eight scientific and engineering practices that represent one of three interconnected means by which students construct scientific understanding. Moving scientific inquiry out of the content standards conveys the notion that inquiry is not about learning a set of steps and procedures isolated from content, but that inquiry is interwoven throughout all science learning. At the same time, some educators still recognize the need for students to build their proficiency in the practices of scientists (i.e., strengthen their capacity to use the practices and reflect on that use when engaged in the process of doing science).
- **Inquiry as a fluid, integrated, and iterative set of practices that scientists use.** Earlier notions of inquiry were described as two elements: understandings and abilities. These separate pillars were soon replaced by a set of "five essentials." Presently, inquiry is viewed as a set of fluid and unified practices that occur through three spheres of activity. These practices are intended to flow naturally from one to the other in an iterative fashion, not in any specific sequence, or according to any prescribed steps.
- **Inquiry as three-dimensional learning.** Within the new standards, there is a greater emphasis on students' constructing theories and models, engaging in argumentation and critique, and pursuing science learning through fluid, iterative cycles. This shift in emphasis towards inquiry as a reflective approach that is integrated and interwoven with all science learning conveys notions of inquiry as an endeavor that depends on the integration of knowledge and skill—not simply as a process independent of content.
- **Inquiry as independent from science pedagogy.** Current views state that inquiry-based teaching is important for engaging students in inquiry and helping to build students' understanding and skill in science. At the same time, the NRC framework and NGSS explicitly note that educators should feel free to use varying instructional approaches to promote students' capacity to engage in inquiry and develop scientific understanding and skill. This represents a change from the NRC's earlier emphasis on inquiry-based teaching as the strongly preferred instructional approach.

As a final note, evidence suggests that while current views of inquiry represent some important shifts, overall they do not differ dramatically from views of inquiry as outlined in the prior National Science Education Standards (NRC, 1996) and as elucidated in the companion resource titled *Inquiry and the National Science Education Standards* (NRC, 2000). At the same time, current views of inquiry are distinctly different from notions of inquiry that have prevailed in the field (i.e., inquiry as a set of prescribed steps and procedures).

Part II

Part II examines the extent to which current notions of inquiry, as outlined in NGSS, are reflected in state science standards adopted by Wisconsin and neighboring states within the Great Lakes and Midwest region. Part II of this report is organized by two guiding subquestions.

1. How are states in the Midwest region addressing the topic of scientific inquiry in light of the development of *A Framework for K–12 Science Education* and the Next Generation Science Standards?
2. How does the definition of scientific inquiry within the Next Generation Science Standards align with or differ from the definitions of inquiry as reflected in Wisconsin's Model Academic Standards for Science?

Methods

To answer these second two key guiding questions, staff from the Midwest Comprehensive Center conducted reviews of the following sources to identify evidence for trends related to past and current definitions of scientific inquiry:

- Website scans and standards of state department of education agencies in Wisconsin and six neighboring states in the Great Lakes and Midwest region.
- Comparative reviews of Wisconsin's Model Academic Standards for Science and related documents with current and prior science standards.

Findings

Highlights of the key findings from these reviews are outlined in this section, organized by the two guiding subquestions.

> How are states in the Midwest and Great Lakes regions addressing the topic of scientific inquiry in light of the development of *A Framework for K–12 Science Education* and the Next Generation Science Standards?

To address this subquestion, a scan of state department of education websites within the seven-state region of the Great Lakes Comprehensive Center and Midwest Comprehensive Centers (Indiana, Ohio, Michigan, Minnesota, Illinois, Iowa, and Wisconsin) was conducted. (See Table A1 for information related to state website scans.)

As of June 2016, 17 states[3] and the District of Columbia have officially adopted the NGSS. Three states in the Great Lakes and Midwest region (Iowa, Illinois, and Michigan) are among these 17 states. Given the updated notions of inquiry reflected within the NRC framework and NGSS, we presume that states that have adopted these standards are adopting, or plan to adopt, new definitions of inquiry and its role in science education.

[3] The 17 states that have adopted the NGSS are Arkansas, California, Connecticut, Delaware, Hawaii, Iowa, Illinois, Kansas, Kentucky, Maryland, Michigan, New Jersey, Nevada, Oregon, Rhode Island, Vermont, and Washington; the District of Columbia has also adopted the standards.

Scans of state department of education websites for three other states in the region (Ohio, Indiana, and Minnesota) indicate that these states have not adopted the Next Generation Science Standards. Indiana has recently adopted new standards that reflect portions of NGSS, and will be implemented in the 2016–17 academic year. Minnesota plans to update their science standards in 2017. The third state, Ohio, released new Science Standards in 2011 prior to the release of the NGSS.

An examination of the specific inquiry-related grade-based standards being used in Minnesota, Indiana, and Ohio (the three states that have not adopted the NGSS) has suggested that notions of inquiry as reflected in these state standards align most closely with one of the three spheres of inquiry outlined in the NGSS: empirical investigation.[4] For example, state standards related to inquiry in these three states primarily focus on tasks associated with conducting investigations such as “Maintain a record of observations, procedures and explanations being careful to distinguish between actual observations and ideas about what was observed” (Minnesota STEM Teacher Center, 2016, para. 3.1.1.2.3). At the same time, it is notable that some states also include references to inquiry that reflect current notions of inquiry as iterative and fluid. For example, the Ohio science standards outline several guiding principles, including an explanation of inquiry as a learning cycle that includes “engage, explore, explain, extend and evaluate” (Ohio Department of Education, 2011, p. 6).

Wisconsin is the only state in the seven-state region that has not recently revised its science standards; the standards were last revised in 1998.

How does the definition of scientific inquiry within the Next Generation Science Standards align with or differ from definitions of inquiry reflected in the current Wisconsin’s Model Academic Standards for Science?

This section examines the extent to which definitions of inquiry included in the current Wisconsin’s Model Academic Standards for Science align with notions of inquiry as reflected in the NRC framework (NRC, 2012) and the NGSS (NGSS Lead States, 2013).

In 1998, DPI adopted the Wisconsin Model Academic Standards for Science (WMASS; Wisconsin Department of Public Instruction, 1998). These standards, which were developed based on the National Science Standards released in 1996, include eight areas of focus: science connections, nature of science, science inquiry, physical science, earth and space science, life and environmental science, science applications, and science in personal and social perspectives. As outlined in Appendix B, science inquiry is identified as its own content area within WMASS. The “inquiry” standards within the WMASS differ slightly for each of the three grade bands: K–4, 5–8, and 9–12.

[4] The two other spheres include developing explanations and solutions whereby students draw from, extend, and construct new models and theories; and the third sphere of evaluation, whereby students engage in iterative cycles that “often lead to further experiments and observations or to changes in proposed models, explanations, or designs” (NRC, 2012, p. 46).

Comparison of WMASS With National Science Standards

In 2014, a team of Wisconsin educators directed by Eric Brunsell of the University of Wisconsin–Oshkosh comparatively analyzed all science content areas within WMASS with the Next Generation Science Standards (Brunsell, 2014.). Given DPI's interest in exploring the extent to which scientific inquiry as outlined in the current WMASS aligns with inquiry as reflected in the NRC framework and NGSS, we built upon the review completed by the University of Wisconsin–Oshkosh.

First, we conducted a qualitative review of the WMASS "science inquiry" standards (Wisconsin Department of Public Instruction, 1998, para. C) with the earlier National Science Standards (NRC, 1996), and the five essentials of inquiry identified in a companion document to the 1996 standards (NRC, 2000). This review was done to assess the extent of alignment with national science standards available at the time that WMASS were developed.

We conducted a comparative review of WMASS with the current NGSS (NGSS Lead State Partners, 2013). We focused this review on comparing the WMASS standards for "scientific inquiry" (Wisconsin Department of Public Instruction, 1998, para. C) with the eight scientific and engineering practices outlined in the NRC framework and Next Generation Science Standards (NGSS Lead State Partners, 2013; NRC, 2012) to determine the extent of alignment.

For each grade band and set of standards, the extent of alignment was assessed by making a comparison between language that appears in the current WMASS standards for science inquiry and the wording of the NRC framework and NGSS eight scientific and engineering practices (NGSS Lead State Partners, 2013; NRC, 2012).

Findings: WMASS and Prior National Science Standards (NRC, 1996)

An examination of the extent of alignment between WMASS and the 1996 standards from the NRC suggested strong alignment. For example, for Grade 4, four of the five abilities and five of the six understandings were well addressed by WMASS, and for Grade 12, five of the six abilities and three of the six understandings were well addressed by WMASS. As one exception, for Grade 8, only two of the five abilities and four of the seven understandings were well addressed by WMASS. Notably, the WMASS identification of separate "scientific inquiry" standards aligns with the organization of the 1996 National Science Standards that also separate inquiry into its own content area with associated standards.

WMASS and the Five Essentials of Inquiry (NRC, 2000)

As discussed, NRC released a companion document to the 1996 science education standards, titled *Inquiry and the National Science Education Standards*, in 2000. This document featured a set of five essentials to scientific inquiry, as follows:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority of evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.

4. Learners evaluate their explanations in light of alternate explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

Each WMASS was compared with these five inquiry essentials. The results of this analysis showed strong alignment between WMASS and the essentials of inquiry. For example, in Grades 4, 8 and 12, four of the five essentials were well addressed in WMASS. However, it is also important to note that some of the WMASS did not have an associated "essential" from the NRC 2000 document. For example, in Grade 8, the WMASS C.8.2., "Identify data and locate sources of information including their own records to answer the questions being investigated" could not be aligned with one of the five essentials.

WMASS and the NRC Framework/NGSS (NGSS Lead State Partners, 2013; NRC, 2012)

Finally, we compared the current WMASS with the current eight scientific and engineering practices outlined in the following. As noted previously, the current review sought to expand and confirm the results of an earlier comparative review led by Eric Brunsell (2014) of the University of Wisconsin–Oshkosh. As part of our procedures, we highlighted and documented instances where our analysis yielded differing or conflicting results.

Eight Scientific and Engineering Practices (NRC, 2012; NGSS Lead State Partners, 2013)

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics, information and computer technology, and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Similar to the University of Wisconsin–Oshkosh review, the results of our analysis indicate fair alignment between WMASS and the eight scientific and engineering practices included in the current NGSS. For example, for Grade 4, six of the eight scientific practices were well addressed. However, two practices (developing and using models and using mathematics, information and computer technology, and computational thinking) were not addressed. For Grade 8, six of the eight practices were well addressed by WMASS, and two practices were partially addressed: (1) developing and using models and (2) using mathematics, information and computer technology, and computational thinking. For Grade 12, all eight practices were addressed fairly well. Two practices were less well aligned with WMASS: (1) using mathematics, information and computer technology, and computational thinking and (2) engaging in argument from evidence. Notably, practices specific to engineering, defining problems, and designing solutions are not significantly addressed at any grade level in WMASS.

The second phase of this review focused on the extent to which the WMASS standards for scientific inquiry reflected the three spheres of inquiry activity outlined in the NRC framework:

Three Spheres of Inquiry Activity (NRC, 2012)

- Empirical investigation
- Developing explanations and solutions
- Evaluation

The comparative analysis of the WMASS suggests that the WMASS science inquiry standards align most closely with the sphere of "empirical investigation" and align far less well with the two other spheres of inquiry activity: (1) developing explanations and solutions and (2) evaluation. Among the Grade 4 WMASS, only three of the eight WMASS science inquiry standards refer to NGSS inquiry spheres two and three: developing explanations and solutions, and evaluation. For Grade 8, four of the 11 WMASS science inquiry standards relate to NGSS inquiry spheres two and three. For Grade 12, alignment is slightly stronger with four of the seven WMASS standards relating to the NGSS inquiry spheres of developing explanations and solutions, and evaluation.

Despite the relatively strong alignment between the specific WMASS standards and the eight scientific and engineering practices, the current WMASS identification of science inquiry as a topical area within the standards and the focus of WMASS primarily on specific inquiry tasks associated with only one of the three spheres of inquiry activity (conducting empirical investigations) suggest that the notions of inquiry as reflected in WMASS are not fully consistent with the most current thinking among science education leaders. Specifically, WMASS emphasizes inquiry as primarily about procedures rather than as a means for constructing scientific understanding.

Summary

This report reflects findings based on a review of documents and state education websites, interviews conducted with science education experts, and a comparative review of standards in an effort to answer four guiding questions about evolving notions of scientific inquiry.

These findings suggest the following:

- Prior notions of inquiry have been refined, redefined, and interwoven within a new three-dimensional framework for learning in science.
- Notions of scientific inquiry within national standards have undergone significant shifts over the years, evolving away from views of inquiry as a set of rigid steps and procedures.
- Current notions of inquiry suggest that it is a fluid, integrated, and iterative means by which students construct scientific understanding, and that inquiry depends on the integration of knowledge and skill.
- Three of the seven states in the Great Lakes and Midwest region have adopted the NGSS, and one state has adopted standards based in part on NGSS. These four states are likely to

embrace notions of inquiry that are consistent with current thinking within the science education community.

- Two other states within the Great Lakes and Midwest region have updated their science standards in the past five years—one of these states plans to update standards further within the next year. These two states currently have standards that reflect both emerging as well as more traditional perspectives on inquiry.
- Wisconsin is the only state in the seven-state region that has not recently revised its standards. WMASS standards related to science inquiry reflect notions of scientific inquiry that align more fully with earlier notions of inquiry as being primarily focused on empirical investigation. Current notions of inquiry, as characterized within the current NRC framework and NGSS, emphasize inquiry as a means for constructing scientific understanding. The WMASS do not include this emphasis.

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Appendix A. Website Scans

Table A1 shows the results of a scan of state department of education websites within the seven-state region of the Great Lakes Comprehensive Center and Midwest Comprehensive Centers (Indiana, Ohio, Michigan, Minnesota, Illinois, Iowa, and Wisconsin). Scans included an examination of (a) state science standards, (b) references to these standards, and (c) definitions of scientific inquiry reflected within these standards.

Table A1. Scientific Inquiry

State Agency	Webpages	Definition of Scientific Inquiry Adoption of Next Generation Science Standards
Ohio Department of Education (ODE)	▪ http://education.ohio.gov/getattachment/Topics/Ohios-Learning-Standards/Science/ScienceStandards.pdf.aspx ▪ http://education.ohio.gov/Topics/Ohios-Learning-Standards/Science/Transition-Tools-Ohio-Learning-Standards-K-1/Scientific-Inquiry-%E2%80%93-Primer	Included in the Ohio Revised Science Education Standards are a set of guiding principles, including a definition of scientific inquiry: Scientific Inquiry: There is no science without inquiry. Scientific inquiry is a way of knowing and a process of doing science. It is the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world.... Teachers need to model scientific inquiry by teaching with inquiry. ODE has a primer about scientific inquiry, which lists the following key aspects of the term: ▪ Make observations and describe objects and events. ▪ Identify and ask valid and testable questions to guide scientific investigations. ▪ Examine resources to gather information to see what is already known. ▪ Reflect on appropriate scientific practices and procedures to plan, design, and conduct investigations. ▪ Use tools, technology, and mathematics. ▪ Organize, evaluate, and interpret observations, measurements, and other data. ▪ Review what is already known in light of experimental evidence. ▪ Develop hypotheses and alternative explanations, propose answers, suggest models, and make predictions. ▪ Evaluate a variety of assumptions and conclusions.

State Agency	Webpages	Definition of Scientific Inquiry Adoption of Next Generation Science Standards
		▪ Revise explanatory models using logic and evidence. ▪ Communicate ideas and the results of investigations and scientific arguments to others for discussion and evaluation. Ohio adopted its current science standards in July 2011.
Illinois State Board of Education	▪ http://www.isbe.net/nILS/science/default.htm ▪ http://www.isbe.net/ils/science/standards.htm	The former Illinois Learning Standards provided the following information about scientific inquiry: Asking questions and seeking answers are at the heart of scientific inquiry. Following the steps of scientific inquiry, students learn how to gather evidence, review and understand their findings, and compare their solutions with those of others. They learn that there can be differing solutions to the same problem, some more useful than others. In the process, they learn and apply scientific principles. They also learn to be objective in deciding whether their solutions meet specifications and perform as desired. Illinois adopted the Next Generation Science Standards in February 2014, as outlined in 23 Illinois Administrative Code 1, Appendix D.
Indiana Department of Education	▪ http://www.doe.in.gov/standards/science ▪ http://in.gov/sboe/files/2016_Science_Standards_Review.pdf	In April 2016, Indiana adopted a new set of science standards. The standards were informed by the Next Generation Science Standards and require computer science for all elementary and middle school students.
Iowa Department of Education	▪ https://www.educateiowa.gov/sites/files/ed/documents/2016-03-31%20Assessment%20Task%20Force%20Recommendation%20on%20Science%20Assessment%20Tab%20G.pdf	Iowa adopted the Next Generation Science Standards in August 2015 through an Iowa State Board of Education vote (256.11(12) 2012).
Michigan Department of Education	▪ http://www.michigan.gov/mde/0,4615,7-140-28753_64839_65510-339833--,00.html ▪ http://www.michigan.gov/documents/mde/K-12_Science_Performance_Expectations_v5_496901_7.pdf ▪ Michigan State Board of Education vote 1278b(1)(b), 2011: http://law.justia.com/codes/michigan/2011/chapter380/act451of1976/451-1976-2/451-1976-2-16/section380-1278a/	▪ According to the state's grade-level content expectations, scientific inquiry "involves observing, questioning, investigating, recording, and developing solutions to problems." ▪ Michigan adopted the Next Generation Science Standards in November 2015 through a Michigan State Board of Education vote (1278b(1)(b), 2011).

State Agency	Webpages	Definition of Scientific Inquiry Adoption of Next Generation Science Standards
Minnesota Department of Education	▪ http://www.education.state.mn.us/MDE/EdExc/StanCurri/K-12AcademicStandards/Science/index.htm ▪ Minnesota vote 3501.0945, 2009: https://www.revisor.mn.gov/rules/?id=3501.0945	▪ Minnesota adopted its current science standards in 2009 (3501.0945, 2009). These standards are scheduled to be revised in 2017–18. ▪ Strand 1 is titled "Nature of Science and Engineering." Included in this strand is Substrand 1: "The Practice of Science," which includes understandings about science and scientific inquiry and investigations. ▪ "Scientific inquiry is a set of interrelated processes used to pose questions about the natural world and investigate phenomena." For most grade levels, standards related to scientific practices refer to steps and procedures used in investigations.
Wisconsin Department of Public Instruction	▪ http://dpi.wi.gov/science/standards	In Wisconsin, science inquiry is part of the science standards: ▪ Content Standard "Science Inquiry": Students in Wisconsin will investigate questions using scientific methods and tools, revise their personal understanding to accommodate knowledge, and communicate these understandings to others. ▪ Rationale: "Students should experience science in a form that engages them in actively constructing ideas and explanations and enhances their opportunities to develop the skills of doing science. Such inquiry (problem solving) should include questioning, forming hypotheses, collecting and analyzing data, reaching conclusions and evaluating results, and communicating procedures and findings to others." Wisconsin adopted its current science standards in 1998.

Appendix B. Wisconsin's Model Academic Standards for Science Crosswalk

Table B1 lists the specific standards related to science as inquiry included within the WMASS (Wisconsin Department of Public Instruction, 1998, para. C).

Table B1. Wisconsin's Model Academic Standards for Science: Inquiry

Science Inquiry: Grade 4	Science Inquiry: Grade 8	Science Inquiry: Grade 12
C.4.1 Use the vocabulary of the unifying themes to ask questions about objects, organisms, and events being studied.	C.8.1 Identify questions they can investigate using resources and equipment they have available.	C.12.1 When studying science content, ask questions suggested by current social issues, scientific literature, and observations of phenomena, build hypotheses that might answer some of these questions, design possible investigations, and describe results that might emerge from such investigations.
C.4.2 Use the science content being learned to ask questions, plan investigations, make observations, make predictions, and offer explanations.	C.8.2 Identify data and locate sources of information including their own records to answer the questions being investigated.	C.12.2 Identify issues from an area of science study, write questions that could be investigated, review previous research on these questions, and design and conduct responsible and safe investigations to help answer the questions.
C.4.3 Select multiple sources of information to help answer questions selected for classroom investigations.	C.8.3 Design and safely conduct investigations that provide reliable quantitative or qualitative data, as appropriate, to answer their questions.	C.12.3 Evaluate the data collected during an investigation, critique the data-collection procedures and results, and suggest ways to make any needed improvements.
C.4.4 Use simple science equipment safely and effectively, including rulers, balances, graduated cylinders, hand lenses, thermometers, and computers, to collect data relevant to questions and investigations.	C.8.4 Use inferences to help decide possible results of their investigations, use observations to check their inferences.	C.12.4 During investigations, choose the best data-collection procedures and materials available, use them competently, and calculate the degree of precision of the resulting data.
C.4.5 Use data they have collected to develop explanations and answer questions generated by investigations.	C.8.5 Use accepted scientific knowledge, models, and theories to explain their results and to raise further questions about their investigations.	C.12.5 Use the explanations and models found in the earth and space, life and environmental, and physical sciences to develop likely explanations for the results of their investigations.

Science Inquiry: Grade 4	Science Inquiry: Grade 8	Science Inquiry: Grade 12
C.4.6 Communicate the results of their investigations in ways their audiences will understand by using charts, graphs, drawings, written descriptions, and various other means, to display their answers.	C.8.6 State what they have learned from investigations, relating their inferences to scientific knowledge and to data they have collected.	C.12.6 Present the results of investigations to groups concerned with the issues, explaining the meaning and implications of the results, and answering questions in terms the audience can understand.
C.4.7 Support their conclusions with logical arguments.	C.8.7 Explain their data and conclusions in ways that allow an audience to understand the questions they selected for investigation and the answers they have developed.	C.12.7 Evaluate articles and reports in the popular press, in scientific journals, on television, and on the Internet, using criteria related to accuracy, degree of error, sampling, treatment of data, and other standards of experimental design.
C.4.8 Ask additional questions that might help focus or further an investigation.	C.8.8 Use computer software and other technologies to organize, process, and present their data.	
	C.8.9 Evaluate, explain, and defend the validity of questions, hypotheses, and conclusions to their investigations.	
	C.8.10 Discuss the importance of their results and implications of their work with peers, teachers, and other adults.	
	C.8.11 Raise further questions which still need to be answered.	

Appendix C. List of Sources

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Appendix D. Scientific Inquiry Report—Interviewee Information

The Midwest Comprehensive Center team conducted interviews with five science education experts identified as having a role in the development or translation of the NRC framework and NGSS to the field. The list of key informants with their title, and affiliation, is provided in Table D1.

Table D1. List of Science Education Experts

Name	Title	Affiliation
Dr. Joseph Krajcik	Lappan-Phillips Professor of Science Education and Director of CREATE for STEM	Michigan State University
Dr. Melissa Braaten	Assistant Professor of Curriculum and Instruction	University of Wisconsin–Madison
Dr. Helen Quinn	Professor Emerita	SLAC National Accelerator Laboratory, Stanford University
Matthew Krehbiel	Associate Director for Science	Achieve
Respondent prefers to remain anonymous	Coordinator of K–5 Elementary Science and Science Assessment	State education agency

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The **Midwest Comprehensive Center** (MWCC), funded through a grant from the U.S. Department of Education, provides technical assistance to the state education agencies (SEAs) of Illinois, Iowa, Minnesota, and Wisconsin. MWCC services are focused on building SEA capacity to support districts and schools to ensure that all students graduate from high school ready for college or a career. MWCC provides support across a number of reform areas, including school improvement, educator development and effectiveness, early childhood education, and standards and assessments. MWCC brings experience and expertise in the areas of engaging stakeholders in policy design and implementation, providing research and content expertise to inform initiatives, and planning for high-quality implementation and sustainability.