Why the Critics of the Next Generation Science Standards are Wrong: **A Position Paper.**

Dear Chairman Micheli and members of the Wyoming Board of Education:

Introduction. We the undersigned are active or retired science or mathematics educators and others interested in science education at the University of Wyoming, but we wish to make it clear that we are writing as private citizens, not as representatives of UW. We understand that you are working under difficult constraints and that you are fully aware of the effect that your decision will have on the quality of science instruction for Wyoming students for the next several years. We are concerned, however, that you are moving forward on this project without fully understanding the research upon which the NGSS are based. Because two of your members have asked for this information, and because we want to be sure that everyone has had an opportunity to review this information, we are taking the liberty of sending it to all of you.

Research has given us a much better understanding of the nature of science and the question of how students learn about science than we have ever had before. The NGSS are based upon this research. We believe that any standards that you approve must also be based upon this research if they are to provide the best possible education for our students. We do not apologize for the fact that this is a lot to read. The subject is large and complex and does not lend itself to "sound bites". We have tried to be concise without compromising the integrity or meaning of this information. We all understand what is at stake here, so please read carefully. There will be a test.

The following are examples of why this information is needed, and will be discussed later in the paper:
When someone argues that:

- "Evolution is just a theory" or the "The NGSS presents human's role in climate change as fact rather than theory", that person does not understand the nature or the language of science. (For more information, see pp 5 and 10)
- The NGSS does not include the "scientific method", that person does not understand the nature of science. (see p.4)
- The science standards must reflect the role of energy and agriculture in our state's economy, that person does not understand the nature of science. (See pp.10-11).
- The NGSS emphasizes scientific practices at the expense of content, that person does not understand how students learn science. (See p.11).

Sources. The literature about the nature of science and the nature of science learning is huge, and each of us has our own areas of special interest and favorite scholars and researchers. However, for the purposes of this paper we are primarily relying on two documents published by the National Research Council. These documents summarize what is known about science and science learning and give recommendations for teachers, administrators, school boards, policy makers, legislators, and state boards of education. Free downloads of these books are

available from the National Academies Press and the links for these downloads are included in the bibliography for readers who wish to further investigate these issues. These two documents provide the research used to construct the NGSS.

Taking Science to School (2007) is a consensus report published by the NRC's Committee on Science Learning, Grades K-8. It summarizes research literatures from cognitive science, developmental psychology, science education and the history and philosophy of science and uses this information to synthesize what is known about how children in grades K-8 learn the practices of science and to make recommendations for educators, policy makers and parents.

Ready, Set, Science (2008), written by Sarah Michaels, Andrew W. Shouse and Heidi A. Schweingruber was also published by the NRC. It is designed for teachers, instructional facilitators, and curriculum coordinators. This document specifically addresses the practical classroom-based application of the research described in Taking Science to School.

We did not use the *Final Evaluation of the Next Generation Science Standards* from the Fordham Institute for reasons that will be discussed later in this paper. (See pp 11-13)

Executive summary:
This paper explores the following questions:

What is science? Science is much more than just a body of knowledge. It is" fundamentally about establishing lines of evidence and using the evidence to develop and refine explanations using theories, models, hypotheses, measurements and observations" (NRC, 2008, p. 18).

What is the nature of science literacy? In order to be literate in science, students must be able to:

- Understand scientific explanations
- Generate scientific evidence
- Reflect on scientific knowledge and
- Participate productively in science (NRC, 2007, pp. 36-41)

How do students learn science? Students learn science best when they are engaged in the practices of science. (NRC, 2007 p.3)

For the balance of this paper, we will discuss what research tells us about these topics and explain why many criticisms of the NGSS do not take into account what we know about the nature of science, the nature of scientific literacy, and how students learn science.

I. The Nature of Science. Traditionally, we have considered science to be a body of knowledge representing the current understanding of natural systems. Over the last half-century, we have come to understand that science is much more. It is also a process by which knowledge is continually developed, extended, refined, and revised. It involves applying principles of critical thinking, for example, to evaluate the validity of claims (NRC, 2007). "At the core, science is fundamentally about establishing lines of evidence and using the evidence to develop and refine explanations using theories, models, hypotheses, measurements and observations" (NRC, 2007, p. 18). "When learning science, one must come to understand both the body of knowledge and the process by which it is established, extended, refined and revised" (NRC, 2007, p. 26).

II. What do scientists actually do? The following quote from *Ready Set Science* (NRC, 2008) discusses this question.

> Over the past few decades, historians, philosophers of science, and sociologists have taken a much closer look at what scientists actually do—with often surprising results. In the conventional view, the lone scientist, usually male and usually white, struggles heroically with nature in order to understand the natural world. Sometimes scientists are seen as applying a "scientific method" to get their results. They are perceived as removed from the real world, operating in an airy realm of abstraction. Studies of what scientists actually do belie these stereotypes. They approach problems in many different ways and with many different preconceptions. **There is no single "scientific method" universally employed by all (emphasis ours)**. Scientists use a wide array of methods to develop hypotheses, models, and formal and informal theories. They also use different methods to assess the fruitfulness of their theories and to refine their models, explanations, and theories. They use a range of techniques to collect data systematically and a variety of tools to enhance their observations, measurements, and data analyses and representations. Studies also show that science is fundamentally a social enterprise. Scientists talk frequently with their colleagues, both formally and informally. Science is mainly conducted by large groups or widespread networks of scientists. An increasing number of women and minorities are scientists. They exchange e-mails, engage in discussions at conferences, and present and respond to ideas via publication in journals and books. Scientists also make use of a wide variety of cultural tools, including technological devices, mathematical representations, and methods of communication. These tools not only determine what scientists see but also shape the kinds of observations they make. **Although different domains of science rely on different processes to develop scientific theories, all domains of science share a certain feature. Data and evidence hold a primary position in deciding any issue.** When well-established data, from experiments or observations, conflict with a hypothesis or theory, that idea must be modified or abandoned and other explanations must be sought that can incorporate or take account of the new evidence. Theories, models, and hypotheses are rooted in empirical evidence based on observation and experience and therefore can be

tested and revised or expanded if necessary. Scientists develop and modify models, hypotheses, and theories to account for the broadest range of observations possible. (pp. 3-4)

III. The Language of Science. Again, from *Ready, Set, Science* (NRC, 2008):

In science, words are often given specific meanings that may be different from or more precise than their everyday meanings. It is important for educators to be clear about specific scientific usage to avoid confusion.

A **scientific theory**—particularly one that is referred to as "the theory of… ," as in the theory of electromagnetism or the theory of thermodynamics or the theory of Newtonian mechanics—is an explanation that has undergone significant testing. Through those tests and the resulting refinement, it takes a form that is a well-established description of and predictor for, phenomena in a particular domain. **A theory is so well established that it is unlikely that new data within that domain will totally discredit it; instead, the theory may be modified and revised to take new evidence into account**. There may be domains in which the theory can be applied but has yet to be tested; in those domains the theory is called a **working hypothesis**. Indeed, the term "hypothesis" is used by scientists for an idea that may contribute important explanations to the development of a scientific theory. Scientists use and test hypotheses in the development and refinement of models and scenarios that collectively serve as tools in the development of a theory. Outside science, the term "theory" has additional meanings, and these other meanings differ in important ways from the above use of the term. One alternative use comes from everyday language, in which "theory" is often indistinguishable in its use from "guess," "conjecture," "speculation," "prediction," or even "belief**"** (e.g., "My theory is that indoor polo will become very popular" or "My theory is that it will rain tomorrow"). Such "theories" are typically very particular and unlike scientific theories have no broader conceptual scope.

A datum—or "data" in plural form—is an observation or measurement recorded for subsequent analysis. The observation or measurement may be of a natural system or of a designed and constructed experimental situation. Observation, even in the elementary and middle school classroom, may be direct or may involve inference or technological assistance. For example, students may begin by conducting unaided observations of natural phenomena and then progress to using simple measurement tools or instruments such as microscopes.

Evidence is the cumulative body of data or observations of a phenomenon. When the evidence base provides very persistent patterns for a well-established property, correlation, or occurrence, this becomes the basis for a scientific claim. Scientific claims, always based on evidence, may or may not stand the test of time. Some will eventually be shown to be false. Some are demonstrated to occur forever and always in any context, and scientists refer to these claims as

> factual…Facts are best seen as evidence and claims of phenomena that come together to develop and refine or to challenge explanations. For example, the fact that earthquakes occur has been long known, but the explanation for the fact that earthquakes occur takes on a different meaning if one adopts plate tectonics as a theoretical framework. The fact that there are different types of earthquakes (shallow and deep focus) helps deepen and expand the explanatory power of the theory of plate tectonics. (pp. 4-6)

To summarize: Science is more than a body of content knowledge. It is also a constellation of practices that are used in order to develop and refine theories. It is a social activity with its own vocabulary in which many terms have different meanings than those used by the general public.

IV. What does it mean to be "Scientifically Literate?"

Current thinking defines scientific literacy as being comprised of four strands. As described in *Ready, Set, Science* (NRC, 2008):

> (These strands) offer a new perspective on what is learned during the study of science, and they embody the idea of knowledge in use—the idea that students' knowledge is not static. Instead, students bring certain capabilities to school and then build on those capabilities throughout their K-12 science education experiences, both inside and outside the classroom. Proficiency involves using all four strands to engage successfully in scientific practices.
>
> Another important aspect of the strands is that they are intertwined, much like the strands of a rope. Research suggests that each strand supports the others, so that progress along one strand promotes progress in the others. For example, there is evidence that students can make substantial gains in their conceptual knowledge of science when given opportunities to "do" science, and scientific reasoning tends to be strongest in domains in which a person is more knowledgeable. Students are more likely to make progress in science when classrooms provide opportunities to advance across all four strands.
>
> Many science educators may want to interpret the strands in light of the current language and concepts of science education—for example, mapping the strands to the content, process, and nature of science, and participation, respectively. But it is important to note that the strands were developed because the Committee on Science Learning thought current assumptions about what constitutes the "content, process, and nature of science" are inadequate. In a sense, the first three strands revise and expand common ideas about the content, process, and nature of science to better reflect research and to include greater emphasis on the application of ideas.
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> **Strand 1: Understanding Scientific Explanations**

To be proficient in science, students need to know, use, and interpret scientific explanations of the natural world. They must understand interrelations among central scientific concepts and use them to build and critique scientific arguments. This strand includes the things that are usually categorized as content, but it focuses on concepts and the links between them rather than on discrete facts. It also includes the ability to use this knowledge.

For example, rather than memorizing a definition of natural selection, a child who demonstrates proficiency with scientific explanations would be able to apply the concept in novel scenarios. Upon first encountering a species, the child could hypothesize about how naturally occurring variation led to the organism's suitability to its environment.

Part of this strand involves learning the facts, concepts, principles, laws, theories, and models of science. As the National Science Education Standards state: "Understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationship between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events."

Strand 2: Generating Scientific Evidence

Evidence is at the heart of scientific practice. Proficiency in science entails generating and evaluating evidence as part of building and refining models and explanations of the natural world. This strand includes things that might typically be thought of as "process," but it shifts the notion to emphasize the theory and model-building aspects of science.

Strand 2 encompasses the knowledge and skills needed to build and refine models and explanations, design and analyze investigations, and construct and defend arguments with evidence. For example, this strand includes recognizing when there is insufficient evidence to draw a conclusion and determining what kind of additional data are needed.

This strand also involves mastering the conceptual, mathematical, physical, and computational tools that need to be applied in constructing and evaluating knowledge claims. Thus, it includes a wide range of practices involved in designing and carrying out a scientific investigation. These include asking questions, deciding what to measure, developing measures, collecting data from the measures, structuring the data, interpreting and evaluating the data, and using results to develop and refine arguments, models, and theories.

Strand 3: Reflecting on Scientific Knowledge

Scientific knowledge builds on itself over time. Proficient science learners understand that scientific knowledge can be revised as new evidence emerges.

They can also track and reflect on their own ideas as those ideas change over time. This strand includes ideas usually considered part of understanding the "nature of science," such as the history of scientific ideas. However, it focuses more on how scientific knowledge is constructed. That is, how evidence and arguments based on that evidence are generated. It also includes students' ability to reflect on the status of their own knowledge. Strand 3 brings the nature of science into practice, encouraging students to learn what it feels like to do science as well as to understand what the game of science is all about. Strand 3 focuses on students' understanding of science as a way of knowing. Scientific knowledge is a particular kind of knowledge with its own sources, justifications, and uncertainties. Students recognize that predictions or explanations can be revised on the basis of seeing new evidence, learning new facts, or developing a new model. In this way, students learn that they can subject their own knowledge to analysis.

When students understand the nature and development of scientific knowledge, they know that science entails searching for core explanations and the connections between them. Students recognize that there may be multiple interpretations of the same phenomenon. They understand that explanations are increasingly valuable as they account for the available evidence more completely. They also recognize the value of explanations in generating new and productive questions for research.

Strand 4: Participating Productively in Science

Science is a social enterprise governed by a core set of values and norms for participation. Proficiency in science entails skillful participation in a scientific community in the classroom and mastery of productive ways of representing ideas, using scientific tools, and interacting with peers about science. This strand calls for students to understand the appropriate norms for presenting scientific arguments and evidence and to practice productive social interactions with peers in the context of classroom science investigations. It also includes the motivation and attitudes that provide a foundation for students to be actively and productively involved in science classrooms. Strand 4 puts science in motion and in social context, emphasizing the importance of doing science and doing it together in groups. Like scientists, science students benefit from sharing ideas with peers, building interpretive accounts of data, and working together to discern which accounts are most persuasive.

Strand 4 is often completely overlooked by educators, yet research indicates that it is a critical component of science learning, particularly for students from populations that are underrepresented in science. Students who see science as valuable and interesting tend to be good learners and participants in science. They believe that steady effort in understanding science pays off—not that some people understand science and other people never will. (pp. 18-21)

V. How do students learn science? Research on student learning has yielded two important findings:

1. Students learn science by actively engaging in the practices of science.
2. A range of instructional approaches is necessary as part of a full development of science proficiency. (NRC, 2007, p3)

Students learn science by actively engaging in the practices of science. This is the reason that the science and engineering practices are included in the NGSS. Those practices are:

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. (Achieve, 2013, Appendix F p.3)

A range of instructional approaches is necessary as part of the full development of science proficiency. This document is not the place for a lengthy discussion of instructional methods but, at the risk of over-simplifying, there are two relatively short guidelines for recognizing classroom activities that are and are not likely to be productive.

Teaching activities that allow students to behave like scientists are likely to be effective. The authors of *Ready, Set, Science* (NRC, 2008) explain that:

> The way that scientists operate in the real world is remarkably similar to how students operate in effective science classrooms. [The NGSS] present a structure in which science classrooms are places where educators strive to structure students' scientific practice so that it resembles that of scientists. In these classrooms students engage in a process of logical reasoning about evidence. They work cooperatively to explore ideas. They use mathematical or mechanical models develop representations of phenomena and work with various technological and intellectual tools. Students participate in active and rigorous discussion - of predictions, of evidence, of explanations and the relationships between hypotheses and data. They examine, review and evaluate their own knowledge. This ability to evaluate knowledge in relation to new information or alternative frameworks and to alter ideas accordingly is a key scientific practice. Of course, students can't behave exactly like scientists. They don't yet know enough and haven't had enough experience with the practices of science. But students who understand science as a process of building theories from evidence develop many of the skills and practices that scientists demonstrate. They can be taught to apply their existing knowledge to new problems or in new or different contexts. They can make connections between different representations of a

concept. They can ask themselves why they believe something and how certain they are in their beliefs. They can become aware that their ideas change over time as they confront new evidence or use new tools or models to examine data. They can learn how to ask fruitful and researchable questions, how to challenge a claim, and where to go to learn more. (pp. 3-6)

Conversely, activities that engage students in things that scientists do not do are likely to be unproductive. These activities include lectures, defining vocabulary lists, "cookbook labs", and reading textbooks for the decontextualized memorization of facts and formulas. These practices may have a place in the curriculum, but should be deemphasized.

Criticism of the NGSS. We will now review some of the criticisms of the NGSS that were raised at the May 11, 2014 Board of Education meeting in Casper, WY, and which have been heard in other meetings regarding the NGSS.

- When someone argues, "Evolution is just a theory" or the "The NGSS presents human's role in climate change as fact rather than theory" the person does not understand the nature or the language of science. The use of the term *theory* over the years has been troublesome, for it means something entirely different in science than it does in everyday life. In science a *theory* is a concept that has been thoroughly tested and moved from an hypothesis to a trusted truth, verified in studies (often over generations of use) tested, passed judgment by scientists for years and years, passed many tests through use. An example would be Bernoulli's principles about air pressure and wings, which helps us figure out how to make planes that fly. These scientific theories should be accepted as a working truth. The *theory of plate tectonics* is another example. It has been tested worldwide for over 100 years, and while it has been modified, and may be further modified in the future, the basic theory remains unchanged.
- When someone argues, "The NGSS does not include the scientific method" that person does not understand the nature of science. There is no single method that scientists use, and in particular they seldom use the linear step-by-step process described in many science textbooks (memorized by generations of students). This method represents an obsolete view of the nature of science.
- When someone argues, "The science standards must reflect the role of energy and agriculture in our state's economy" that person does not understand the nature of science. These specific issues fall into the domain of the social studies, especially history, geography, and economics. They may be included in the state's social studies standards, but have no place in the science standards. We do believe that it is important for students to understand the role of energy and agriculture, but that this should be a part of each district's curriculum rather than in state standards. Curricula developed under the rubric of "Science, Technology and Society" and "Socio-scientific Reasoning" among others provide a rich body of curriculum that could be used in this way. These issues can be presented in an interdisciplinary way that honors the limits of the various disciplines involved. In addition to not understanding the difference between science

and social studies, people who use this argument also do not understand the difference between standards and curriculum.

- When someone argues, "The NGSS emphasizes scientific practices at the expense of content" that person does not understand how students learn science. Students learn science best when they participate in the practices of science which emphasize content, period.
- The arguments that, "The NGSS promote an atheist worldview" or "are unconstitutional because they are sectarian" or that "creation science" should be given equal time in the curriculum, are made when people do not understand the differences between science and religion, or the proper relationship between the two. These two arguments exemplify the difference between science and religion (and "creation science"). Science promotes neither atheism nor any form of religion. It has nothing to do with religion one way or the other. It recognizes that science can only address questions that can be investigated empirically. Religion in general and "creation science" in particular, add God and miracles to the discussion. When this happens, it becomes impossible to use empirical methods to evaluate evidence or arguments. Unlike science, which continually revises theories in the light of new evidence, "creation science" selectively seeks evidence to validate the theory and rejects evidence that raises questions about the theory. Most of the world understands that religion and science can co-exist as long as they do not try to trespass on each other's domains. We do not have the space to debate this here, but for those interested in a sensible approach to the issue we recommend the work of the distinguished American paleontologist, evolutionary biologist, and historian of science Stephan Jay Gould. In his book "*Rock of Ages*", Gould, (1999) states,

> I write this little book to present a blessedly simple and entirely conventional resolution to an issue so laden with emotion and the burden of history that a clear path usually becomes overgrown by a tangle of contention and confusion. I speak of the supposed conflict between science and religion, a debate that exists only in people's minds and social practices not in the logic or proper utility of these entirely different and equally vital subjects. I present nothing original in stating the basic thesis for my argument follows a strong consensus accepted for decades by leading scientific and religious thinkers alike. (preamble)

Finally, a word (well…several words) about The Fordham Institute. One of the skills that scientists and students must develop is to consult multiple sources for their work and to develop the ability to evaluate the validity of sources. Many of the objections to the NGSS are based upon the work of the Fordham Institute, especially their report "***A Final Evaluation of the Next Generation Science Standards".*** **(Gross, Paul R. 2013)** The Fordham Institute is not a credible source for several reasons:

Their philosophy and the criteria they use to evaluate standards are out of date. The Fordham Institute is well-known in science education circles as an unapologetic and persistent advocate of the view that in science education "content is everything" and that students must learn the

basic facts of science before they can participate in higher level thinking activities. Consider the following, from that report:

- "Recommended 'practices' dominated the NGSS, relegating essential knowledge---which should be the ultimate goal of science education---to secondary status" (Gross, 2013, p. 7).
- "The purpose of K–12 science standards, therefore, is not primarily to encourage mastery of "practices" or to encourage "inquiry-based learning." Rather, the purpose is to build knowledge first so that students will have the storehouse of information and understanding that they need to engage in the scientific reasoning and higher level thinking that we want for all students"(p. 12).
- "Unfortunately, the NGSS suffer from the belief—widespread among educators—that practices are more important than content… Throughout the NGSS, content takes a backseat to practices, even though students need knowledge before they'll ever demonstrate fluency or mastery of scientific practices" (p. 12).

The idea that "essential knowledge" is the ultimate goal of science education is wrong. The ultimate goal of science education is to develop all four of the strands of scientific literacy. By limiting their scope to "essential knowledge", the Fordham Institute report only addresses the first of the four strands.

The argument that students must learn the basics first has long since been discredited. For example: Schmoker (1996) states that:

> We also labor under the incorrect notion that students must master basic skills before they can learn higher-order skills or engage in complex activities. Studies…clearly demonstrate that the opposite is true: Students learn best when basic skills are taught in a vital, challenging context that makes the skills meaningful. The very thing that keeps students from achieving in these areas is the dry, irrelevant teaching strategies we often employ, especially with students who most need real challenges (Means, Chelemer, & Knapp, 1991). Low-performing students stand to gain the most from approaches that incorporate basic skills into complex, higher-order tasks and problems. Schools and effective programs have demonstrated that standardized test scores can improve significantly when challenging tasks and activities are used (Resnick, Bill, Lesgold &Leer 1991; Schmoker & Wilson 1993; Livingston, Castle, & Nations 1989; Pogrow 1988, 1990). (p. 66)

The Fordham Institute has evaluated the NGSS and standards from all 50 states using the four criteria of organization, content and rigor, clarity and specificity to evaluate standards. These are necessary but not sufficient to insure quality. At a minimum, standards must also reflect current understanding of the nature of scientific literacy and how students learn science and these issues receives no consideration from the Fordham Institute. In fact their recommendations contradict current research on learning. In order to receive an "A" from Fordham, standards must focus only on content. Standards, such as NGSS, that are based on an

understanding of the nature of science and research on how students learn receive lower grades from Fordham.

The Fordham report is also guilty of misrepresenting the role of the practices in NGSS. "Recommended 'practices' dominated the NGSS, relegating essential knowledge---which should be the ultimate goal of science education---to secondary status" (Gross, 2013, p. 7). "[The NGSS authors] conferred primacy on practices and paid too little attention to the knowledge-base that makes those practices both feasible and worthwhile". (Gross, 2013, p. 11) **In fact, the NGSS assigns equal value to content, practices and cross-cutting concepts and argues that they should blend together seamlessly in instructional activities.**

Finally, the NGSS are research-based and the Fordham Institute report is not. *Taking Science to School* (NRC, 2007) cites hundreds of studies to support the conclusions it has reached about the nature of science and how students learn science. The Fordham Institute report has only a handful of citations and provides no bibliography. Without any documented research base researchers and others can only conclude that it is based upon the opinions of the authors and nothing else.

Conclusion. In summary, we accept the research-based view that the major goal of science education is to change our classrooms from being places where the prime focus is on content and convert them to communities of scientists, where students use scientific practices in concert with the cross-cutting concepts and core knowledge to develop their understanding of the four strands of scientific literacy. This will require major changes in the way science is taught and will require extensive professional development for our teachers. Those of us who are involved in training teachers or providing professional development have already revised our programs to align with the NGSS and we have no intention of going back to standards that we know to be out of date and inferior. The NGSS provide the most research-based road map that exists for teachers, administrators and those of us in higher education to make these changes. The actions of the legislature and Governor Mead have denied teachers and students access to the most powerful tool available to make this happen. As a result, our students will not be as well prepared for college or the world of work as students from states who have implemented NGSS.

Signed, (alphabetical order)

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