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Misconceptions Scientists Often Have About the K-12 National Science Education Standards

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Abstract

This paper exposes and addresses seven misconceptions scientists often have about the National Research Council's (NRC) National Science Education Standards (NSES). These misconceptions were encountered during the course of three different types of educational activities that have brought scientists into contact with the standards.

The NRC standards represent a key element of science education reform that challenges educators to develop and facilitate an inquiry-based learning process with "students as scientists." Scientists' deep experience of science and how science is practiced is potentially of enormous value in support of this process. Misconceptions scientists have about the NRC Science Education Standards inhibit the degree to which scientists may be of service. The misconceptions described here can be addressed effectively through self-study, experience in inquiry-based classrooms, participation in workshops, and partnerships with expert educators.

Introduction and Background

This paper exposes and addresses seven misconceptions scientists often have about the National Science Education Standards (NSES) (The National Research Council 1996; see Note 1). These misconceptions were encountered in the course of three different types of activities that have brought scientists into contact with the standards:

1. Conducting presentations and discussions at the Space Science Institute's (http://www.spacescience.org) annual workshops for scientists on K-12 education (see Note 2)
2. Working with scientists in partnership with educators to develop an educator guide (for grades 5-8) related to a NASA planetary science mission

3. Interacting with scientists who are consulting with the Space Science Institute (SSI) to help prepare education and public outreach segments to research proposals for NASA Office of Space Science (http://spacescience.nasa.gov) programs

The National Academy of Science's National Research Council published the standards in 1996. The document is based on a nationwide collaboration of educators and scientists and is widely regarded as an important guide to modern systemic reform efforts in science education. It offers a vision of what it means to be scientifically literate and how best to achieve such literacy. The NRC standards (the focus of this paper) represent one of a broader collection of educational standards in science, technology, mathematics, and geography that have been developed by a variety of scientific and educational organizations over the past few years (see Note 3).

Some of the misconceptions listed below are common to all who are unfamiliar with the NRC standards, and these are readily addressed simply by raising awareness. However, a few of the misconceptions are quite tenacious, based as they are in deeply rooted beliefs and experiences in traditional methods of science education. Exposing and finding effective ways to address the sources of misunderstanding can serve to empower the scientist-educator partnerships that are deemed so critical to the success of modern science education reform. Bruce Alberts (1993), president of the National Academy of Sciences, has written:

> I now view effective science education partnerships between scientists and pre-college education science teachers in a completely different light--as the only hope for lasting systemic change in pre-college science education and, therefore, as an important national priority for the United States.

Misconception 1: The NRC Science Education Standards are required for all schools. When a person hears the word "standard," he or she tends to infer the nuance of "requirement." Moreover, "national standard" tends to imply a requirement for the nation. Nevertheless, the NRC standards are optional, and state education systems interpret them and relate to them in many different ways, some more embracing than others (Blank 1997). For example, many states have developed a set of state science content standards that derive directly from the guidelines provided by national documents such as the NRC standards and the AAAS Benchmarks (American Association for the Advancement of Science 1993). On the other hand, California is a notable example of a state whose science education standards have deviated significantly from the NRC standards (Woolf 1999). In addition, states have varying requirements on local school districts to conform to their state standards. As a result, one must investigate on a case-by-case basis the relationship between national standards and a given school or school district.

The educational system in the United States is in stark contrast to that in most other countries that do not have standards per se, but instead have required national curricula. It is important to remember that standards do not provide a curriculum, and so in America it is up to curriculum developers, in partnership with scientists and teachers nationwide, to voluntarily design courses of instruction and student experiences that lead to learning the fundamentals articulated in the standards.

Misconception 2: The National Science Education Standards are a list of scientific facts students should know. To many people, the term "education standard" naturally translates to "fact a student should know." The NRC standards are much more than a collection of facts. The content standards alone describe what all students--regardless of background or circumstance--should understand and be able to do at different grade levels, from kindergarten through high school. The NRC content standards are differentiated by grade level (K-4, 5-8, and 9-12; see Note 4).

The NRC content standards are organized under the following headings: Unifying Concepts and Processes in Science, Science as Inquiry, Physical Science, Life Science, Earth and Space Science, Science and Technology, Science in Personal and Social Perspective, and History and Nature of Science. Note that perspectives and experiences with the way science works and evolves are at least as heavily emphasized as the fundamental ideas and concepts in science.

A very common misconception is that the standards involve content areas only, but the NRC document provides guidelines for systemic change that go well beyond this. The document also includes standards for teaching, student assessment, professional development of teachers, science programs in schools and school districts, and for science education policies in school systems. For example, the NRC teaching standards advocate an "inquiry-based" approach to classroom instruction that has many similarities with the way modern scientists *practice* science (described below).

Misconception 3: Standards-based methods of science teaching are consistent with the way most of today's scientists learned science in school (grades K-14). Most of today's scientists, including those in our workshops and those who engaged in our project to create an educator guide, have been taught science (and thus continue to teach science) using traditional methods that consist mainly of lectures, memorization, and textbooks. Scientists often fail to recognize that "the basics that worked so well" for them in school may not work so well for the majority of students who will not become scientists. An extremely effective way of illustrating potential problems with traditional teaching and assessment methods was provided by one of our 1995 workshop presenters, Jay Hackett of the University of Northern Colorado, who showed the following viewgraph:

> **The Monotillation of Traxoline**
> (attributed to Judy Lanier)
>
> It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is monotilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then bracter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.
>
> Directions: Answer the following questions in complete sentences. Be sure to use your best handwriting.
>
> 1. What is traxoline?
> 2. Where is traxoline monotilled?
> 3. How is traxoline quaselled?
> 4. Why is it important to know about traxoline?

The presentation of the "Traxoline" story illustrates how it is possible to "pass the test" without really knowing or understanding much of anything. Students can memorize and use sophisticated vocabulary, but be devoid of any deeper conceptual understanding rooted in their own experience. It remains for many scientists to discover and internalize that modern science education reform is about teaching students in a so-called "inquiry-based" fashion--a way that bears enormous similarity to how scientists practice science, as opposed to how they learned it in school. Table 1 offers an analogy between the approach to scientific research and an approach to teaching science aligned with standards. It has shown some early promise in assisting scientists with conceptual change about science teaching.

Table 1. Practicing Science vs. Teaching Science

Scientific Research Approach	Standards-Based Teaching Approach
Raise fundamental question of interest that is addressable via scientific investigation.	Engage student interest; guide the development of questions [i.e., establish basis for **inquiry**] in a specific area of content.
Research what is already known.	Discuss with students what they already "know" or think they know [**prior knowledge assessment**] to help address the question(s).
Make a prediction or hypothesis in answer to the question of interest.	Ask students to make a prediction or hypothesis in answer to a question of interest.
Plan and implement an experiment to test the prediction.	Plan and implement an experiment to test the prediction [**hands-on activity**].
Reflect on the results of the experiment and how they affect what was known before. Be alert for how the new data do or do not readily fit into the existing structure of scientific understanding.	Reflect with students on the results of their hands-on activity/investigation and use their predictions to assist them with gaining new/deeper understanding of content. Be alert for any shifts from "prior knowledge" as students integrate their new experiences.
Communicate new knowledge via talks and papers. Science community judges the validity and value of the results. New questions are raised.	Communicate new knowledge via presentations, papers, demonstrations, and exams [**assessment methods**]. Teachers judge students' learning and guide them to apply it to new circumstances.

It is ironic that several scientists in previous workshops have expressed strong skepticism of the value of an "inquiry-based" approach to learning. In some cases, this resistance was primarily because such an approach does not advocate teachers telling students immediately when they are wrong. Some scientists felt that failing to tell students they were wrong about their preconceptions was a grave disservice and an unnecessary attempt to protect their self-esteem at the expense of science learning. But in inquiry-based learning, it is the teacher's task to lead students to conduct discussions, investigations, and activities that challenge their false ideas and allow them to think and construct their own understanding.

When scientists eventually penetrate the education jargon (terms in bold in right column of Table 1), they can see that the inquiry-based approach to learning has many similarities to the way they themselves learn new things in scientific research. At this point, it is often somewhat easier to consider that modern standards-based teaching may not be so much of a fad. This is not to say that all lectures, memorization, and textbook learning should be abandoned. The standards simply say that there should be less emphasis on these modes of learning and more emphasis on inquiry-based learning. Educational research has shown this to be an effective approach for deepening student understanding and retention.

Misconception 4: "Standards-based activities" are equivalent to "hands-on activities." A standards-based lesson offers the educator a sound approach to instruction based on the best available research about how students learn and what teaching practices facilitate that learning. This often involves the use of what are commonly called "hands-on" activities, but as may be discerned from Table 1 above, such activities by themselves are insufficient to make the lesson "standards-based." In addition, Table 2 summarizes the difference between a conventional approach to teaching, a hands-on approach, and an inquiry-based approach aligned with standards. The differences are illustrated in the context of teaching a biology lesson about trees. The examples clearly show that "hands-on" is a necessary but not sufficient quality for being "inquiry-based," and so it is possible for a lesson to be "hands-on" without being aligned with standards. (This illustration was developed in collaboration with Dr. Tim Slater of Montana State University.)

Table 2. Comparing Approaches to Teaching and Assessment

Conventional Approach	Hands-On Approach	Inquiry-Based Approach
The teacher tells students that trees can be classified by examining their bark and their leaves. She shows pictures of trees in a textbook and asks students to memorize the names of the different types of trees according to the sort of bark and leaves they have.	The teacher tells students that trees can be classified by examining their bark and their leaves. She shows pictures of trees in a textbook and takes students to the park and asks them to match the pictures with the real trees. She asks students to memorize the tree names for the test. The class moves on to another hands-on activity about plants and flowers.	The teacher tells students that scientists classify trees by the different features they have. She asks them to come up with ideas for what features would distinguish one tree from another. She takes them to the park to explore their ideas and to make observations and gather data that would help them create their own classification scheme for trees. She asks them to compare their schemes with established classification schemes and to present reports on their results. She follows up with a lesson about the nature and classification of trees in other climates.

Note that standards-based lessons also provide a basis for new inquiry so that one lesson can build on another. Standards-based teaching does not consist of a string of isolated, "one-shot" activities any more than science consists of series of one-shot experiments. After significant trials and reviews, our team of scientists, teachers, and educational specialists learned to build a more inquiry-based approach into the lessons of our educator guide related to planetary science. This was a significant change from the more common practice of generating a book of hands-on activities.

In the Space Science Institute’s April 1999 workshop for scientists on K-12 education, presenters enacted a role play of two teachers discussing the differences among Table 2’s three approaches in their lesson planning. This proved to be a useful and entertaining way of making the needed distinctions. The workshops also provide first-hand experience to scientists in using exemplary standards-based curricular materials and in observing local schoolteachers making use of such materials. These activities allow scientists to experience and observe how a "hands-on activity" fits into the more complete learning cycle of a standards-based lesson that includes assessing prior knowledge, reflecting on how the activity has changed or extended prior understanding, and applying what is learned to new circumstances. The activities also permit scientists to see how teachers can act effectively as "guides on the side," who facilitate student learning, rather than "sages on the stage," who transmit information unilaterally.

Misconception 5: The NRC standards apply only to curricular materials. No, the NRC standards address many other educational activities besides the development of curricular materials. For example, there are standards that articulate best practices in how to professionally develop teachers. An example of a conventional approach to a teacher "workshop" would be an all-day series of lectures by scientists. By contrast, teacher workshops that are aligned with standards are themselves models for inquiry-based instruction (see Tables 1 and 2). Such professional development opportunities provide participants with appropriately tailored background and experience, both with the pertinent science and with the best instructional practices. They provide direct hands-on experience with standards-based lessons that teachers can readily use in the classroom. (Such curricular materials are best disseminated in conjunction with teacher training.) Standards-based professional development also follows up with workshop participants to support them in their efforts to improve their teaching practice.

Misconception 6: Scientific research topics are easily linked to standards, and thus a K-12 educational product or activity that is "standards-based" or "aligned with standards" is easy to create. It is often easy to make general intellectual links between a scientific research topic and many of the content standards, but this is not the same as aligning with standards. Aligning an educational product or activity with the NRC standards is a challenging, multi-dimensional task that is often underestimated. For example, to align a lesson with the standards requires awareness of the research about how students learn, what misconceptions they commonly have, how their capabilities change with age, and what instructional and assessment methods work best--all of this in addition to a deep understanding of the fundamental science being taught by the lesson. Successful standards-based curricular materials are also subject to review, field testing, and revision before being broadly disseminated. The development process takes significant time, money, and expertise in science, classroom teaching, and standards-based curriculum design.

At the start of the educator guide project, the development team interpreted "standards-based" to mean an intellectual linkage between the planetary mission science and science content standards. This is a very common misinterpretation (see Note 5). As a result, some of the preliminary lessons of our educator guide were misguided and inappropriately claimed to address several content standards at once. With the help of reviewers who were more seasoned experts in curriculum design, we eventually recognized that an effective lesson stays focused on student learning of one (or possibly two) science content standard. A standards-based science lesson or educational experience must be focused on a fundamental concept rather than on myriad details associated with a research project. Such details are usually too specific and/or too complex to be valuable for general use in K-12 education. Nevertheless, research projects may be used as real-world, inspirational *contexts* for teaching fundamental concepts--say, about gravity, energy, or how scientific inquiry is done.

For example, NASA's Cassini mission will study the Saturn system. There are no science education standards that say students should learn all about the research conducted by the Cassini mission. However, there *are* Earth and Space science education standards that call for the study of the Solar System and the planets. Standards also say that students should learn about systems, order, and organization; about science as a human endeavor; and about the relationship between technology and scientific discovery. Cassini's exploration of the Saturn system (as well as other research projects) can provide a motivational context for such standards-based learning. Table 3 illustrates the difference between a learning goal aligned with standards and one consistent with a more rote learning approach tied to a specific research interest.

Table 3. Comparison of Lesson Learning Goals

More Traditional Learning Goal	Learning Goal Aligned with Standards
The Saturn system has 18 moons and 5 major rings. The interactions between the moons and rings help to define the ring structure.	Students use the Saturn system as a context to learn that a system consists of different parts. These parts interact with one another in ways that define the characteristics of the system as a whole.

Note that the students will learn many of the details of the Saturn system on the way to using it as a context for learning the more fundamental concept of what it means to be a system. Alignment with standards means that the learning goal is focused on the fundamental concept rather than on the details. Thus, at the end of a successful standards-based lesson about the Saturn system, the student should have learned enough about systems to apply his or her knowledge to other systems. Merely memorizing information about the rings and moons does not have the same power to transfer to other learning contexts.

Another key aspect of alignment with standards is age-appropriateness. Scientists, many of whom teach undergraduate and graduate courses, have a tendency to lump K-12 together without discriminating between the grade levels. It is not realistic to produce a standards-based lesson or educator guide that serves *all* grade levels unless special consideration is given to how the needs and expected cognitive capabilities of students at different grade levels would be addressed. In the development of the educator guide, our initial charge from the NASA lab was to generate a K-12 teacher guide. We eventually recognized that we had neither the funds nor the expertise to develop curricular materials that covered all K-12 grades, and chose to focus our efforts on grades 5-8, where the planetary science content had the best chance of integrating with the existing curriculum.

Misconception 7: Practicing teachers generally know all about the standards and how to apply them. Not necessarily so. Generally, good K-12 teachers are experts in managing a classroom of active young people. This is another multi-dimensional challenge, often underestimated by scientists and others who have not done it on a day-to-day basis. Teachers also know what types of activities really engage their students' curiosity, and they recognize the attributes of lesson plans and educator guides that are the most accessible, easy-to-use, and effective in the classroom setting.

Although teachers are generally expert at adapting all sorts of ideas for use in their classrooms, they may not necessarily be trained or experienced in *consciously* applying the standards. In our educator guide project, three of the four exceptional classroom teachers with whom we worked had never perused a copy of the NRC standards, let alone prepared standards-based curricular materials for use by other teachers. Of course, the scientists in our partnership started out even less familiar with the standards, and they too learned a great deal throughout our development process. The scientists' gift was a touchstone to real-world exploration and a deep understanding of the process and content of science.

The challenging task of designing curriculum aligned with standards required us to add team members and reviewers who were experienced in applying and evaluating principles of standards-based curriculum design. We augmented our development team of teachers and scientists with a curriculum design consultant and an evaluator, both from the local university's college of education. We were fortunate to have a curriculum specialist who had also spent considerable time in the classroom. Such a hybrid professional proved to be very valuable in helping to bridge the gaps of understanding and experience between scientists, teachers, and educational specialists. She worked with us to include direct quotes from the standards in our educator guide to help elucidate the intended learning goals for teachers. Our workshops for scientists include presentations and discussions led by such education specialists and practicing teachers.

Concluding Remarks

The NRC standards represent a key element of science education reform that challenges educators to develop and facilitate an inquiry-based learning process with "students as scientists." Scientists' deep experience of science and how science is practiced is potentially of enormous value in support of this process. Misconceptions scientists have about the NRC science education standards inhibit the degree to which scientists may be of service in partnership with educators.

Good science educators well recognize the tenacity of misconceptions (Mestre 1991; see Note 6). Standards-based lessons alert teachers to common misconceptions (i.e., the force of gravity requires an atmosphere [Bar, Sneider, & Martimbeau 1997]) and provide students with experiences and information that directly challenge and help resolve these misconceptions. Facilitating such deep conceptual change takes time, using teaching and assessment methods that go well beyond the traditional ones and that have significant parallels with the way scientists learn new things. Scientists know well the challenges and excitement of conceptual change in their research as they operate on the boundary between the known and unknown on behalf of humanity. Students are operating on the boundary between their personal known and unknown, and their deeply held misconceptions might best be likened to a well-worn scientific paradigm such as Ptolemy's epicycles. Eventually the paradigm shifts, but generally not without a lot of time, energy, and evidence.

For scientists to be the most effective in helping students and educators overcome misconceptions in science, they must first confront and resolve any misconceptions they may harbor about effective science education. Experiences in workshops and scientist-educator partnerships suggest that misconceptions 3, 4, 6, and 7 are the most challenging for scientists to overcome. These misconceptions (and perhaps others that are yet lurking) can be exposed and addressed effectively via some of the approaches described here, as well as through self-study, experience in inquiry-based classrooms, participation in workshops, and partnerships with expert educators.

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Notes

Note 1: Throughout the paper, the term "scientist" is broadly construed to include research scientists, engineers, and others with significant science and technical background or training.

Note 2: Over 300 space and earth scientists have benefited from NASA- and NSF-funded workshops for scientists on K-12 education conducted by the Space Science Institute in Boulder, Colorado. Follow the "Workshops" link from http://www.spacescience.org.

Note 3: The Mid-continent Regional Educational Laboratory (McREL) has created a Web site (http://www.mcrel.org) that provides several standards-related documents and resources, including an integration of the NRC National Science Education Standards with other relevant education standards.

Note 4: The AAAS Benchmarks are differentiated even more finely in the early grades (K-2, 3- 4) in concert with the best research on what is developmentally appropriate for students at various ages.

Note 5: This same misinterpretation comes up often in conversations with scientists preparing education and public outreach segments for their scientific research proposals.

Note 6: The 21-minute video "A Private Universe," created by Matthew Schneps and Phil Sadler of Harvard University, has proved very striking to scientists who report gaining valuable perspective and insight into common barriers to learning. The video begins by showing footage that substantiates how 21 out of 23 graduates and faculty of Harvard University could not correctly explain Earth's seasons. The video goes on to explore the ideas and perceptions of a bright ninth-grade girl named Heather who clings tenaciously to her misconceptions about the seasons in spite of substantial science instruction. This video is available through the Astronomical Society of the Pacific (http://www.aspsky.org).

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