FEATURE ARTICLE

Why Engaging in the Practices of Science Is Not Enough to Achieve Scientific Literacy

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Abstract

The National Research Council's Framework for K–12 Science Education *and the resulting* Next Generation Science Standards *call for engaging students in the practices of science to develop scientific literacy. While these documents make the connections between scientific knowledge and practices explicit, very little attention is given to the shared values and commitments of the scientific community that underlie these practices and give them meaning. I argue that effective science education should engage students in the practices of science while also reflecting on the values, commitments, and habits of mind that have led to the practices of modern science and that give them meaning. The concept of methodological naturalism demonstrates the connection between the values and commitments of the culture of science and its practices and provides a useful lens for understanding the benefits and limitations of scientific knowledge.*

Key Words: *Nature of science; science practices; methodological naturalism; scientific literacy; NGSS.*

○ Introduction

With the introduction of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), the discussion of the goals for science education has largely shifted from the concept of scientific literacy toward engaging students in the practices of science. Yet I think it is important to keep in mind our ultimate goals for science education, and, in that sense, I find the concept of scientific literacy useful. Here, I will articulate a vision of scientific literacy that emphasizes critical evaluation of how scientific knowledge is produced and used. This definition of scientific literacy is built upon the foundation of students' familiarity and proficiency in the practices of science, but it also includes a conscious appreciation of the values, commitments, and habits of mind that undergird those practices. In other words, students should not only understand scientific knowledge and practice, but also be able to articulate how this knowledge and practice reflects the values and norms of the culture of science. This type of knowledge is best developed through engagement in science practices and explicit reflection and discussion of those experiences. Thus, engaging students in productive talk about scientific knowledge and practice is an important aspect of developing scientific literacy.

A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas presents a new vision for science education (National Research Council [NRC], 2011). The *Framework* was designed to address the weaknesses in current science education, which include an emphasis on breadth over depth, lack of coherence among grade levels, and curriculum that highlights facts rather than the process of science. The *Framework* recommends that

> Science and engineering education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design. (NRC, 2011, p. 2)

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In order to address these goals, the *Framework* was organized around three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. The *Next Generation Science Standards* (NGSS) integrated these three dimensions to develop performance expectations for K–12 education.

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The *Framework* emphasizes that students must engage in the practices of science in order to develop scientific literacy because "Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge" (NRC, 2011, p. 26). The NGSS make the connections between content knowledge and scientific practices explicit and will, hopefully, help teachers begin to make this important shift in their instruction. However, while engaging in the practices of science will help students develop a better appreciation for how scientific knowledge is produced, it will not necessarily help them understand the values, commitments, and goals that shape the practices and give them meaning in the scientific community. It is this appreciation that allows citizens to disentangle scientific information from the political, economic, and ideological aspects of sociocientific issues such as climate change, biomedical ethics, and conservation biology. Here, I argue that scientific literacy also requires an understanding of the culture and discourse of science, which is a component of, but not synonymous with, broader notions of the "nature of science" (NOS; e.g., Abd-El-Khalick et al., 1998; McComas, 1998; National Science Teachers Association, 2000).

○ The Culture & Discourse of Science

Culture includes a "set of shared attitudes, values, goals, and practices that characterizes an institution or organization" (Merriam-Webster). Building on the work of Lev Vygotsky, many researchers have studied the influence of culture on learning and development. One such researcher, Barbara Rogoff, asserts that "human development is a process in which people transform through their ongoing participation in cultural activities, which in turn contribute to changes in their cultural communities across generations" (Rogoff, 2003, p. 37). This perspective affords critical insights into the nature of science. Through this lens, we can see that science itself is a culture that is continually being defined by its members. In addition, the culture of science shapes the values, goals, and practices of individual scientists. The NRC *Framework* and the NGSS explicitly emphasize the importance of the practices of science in developing students' scientific literacy, but they give little attention to the embedded attitudes, values, and goals of science. While the *Framework* recognizes that "scientific inquiry embodies a set of values," the committee decided that "considerations of the historical, social, cultural, and ethical aspects of science and its applications" would be "better treated at the level of curriculum design than at the level of framework and standards" (NRC, 2011, p. 248). Like many others, I am concerned that the short shrift given to these topics within the *Framework* will inhibit the effectiveness of the NGSS and ultimately hinder the development of scientific literacy. Appendix A of the *Framework* notes that "Many of those who provided comments thought that the 'nature of science' needed to be made an explicit topic or idea. They noted that it would not emerge simply through engaging with practices" (NRC, 2011, p. 334).

Descriptions of NOS often include the notion that science is socially and culturally embedded and that scientists share particular values and perspectives, but generally focus on a list of consistent themes about knowledge construction across scientific disciplines rather than the epistemological foundations of scientific culture. This approach results in lists of consensus statements that have been highly criticized for being overly simplistic and positivistic (see Duschl & Grandy, 2013). However, science education that includes the culture of science does not have to be reduced to these lists, but instead can be accomplished by reflecting on the values, commitments, and discourse that underlie the practices of science as students engage in them.

Each culture is expressed through a particular discourse, which is "a socially accepted association among ways of using language, of thinking, and of acting" (Gee, 1991, p. 3). Scientific literacy includes the ability to participate in scientific discourse to some degree, even if only as a critical consumer of scientific information. While not all students will become scientists, all citizens of our society need the skills to continue to learn about science outside of school and the ability to apply their understanding to make personal decisions and engage in public discussions of socioscientific issues. If we hope to develop scientifically literate citizens, science education must extend beyond content knowledge and scientific practices to uncover the values and habits of mind that are specific to science.

We all participate in multiple discourses within different social groups and institutions (family, ethnic, socioeconomic, school, workplace, church, peer group, etc.), and a major goal of education is to help students develop literacy in multiple discourses. When learning a new discourse, it is important to not only to engage in the practices of the discourse, but also to have explicit instruction in the values and habits of mind of the culture that gives meaning to those practices. The *Framework* suggests that

> Through discussion and reflection, students can come to realize that scientific inquiry embodies a set of values. These values include respect for the importance of logical thinking, precision, open-mindedness, objectivity, skepticism, and a requirement for transparent research procedures and honest reporting of findings. (NRC, 2011, p. 248)

It is crucial that science teachers help students appreciate the differences between the natural sciences and other ways of knowing about the world. The shared values of the culture of science lead to particular practices and habits of mind. This in turn defines the types of questions that science addresses and limits the types of explanations that are developed.

The culture of modern science is usually traced to the scientific revolution in Europe around the 17th century, but the values and methods of science have changed substantially over the past two centuries. Philosophers and sociologists of science still debate the nature of scientific knowledge and its demarcation from other ways of knowing about the world. However, scientists generally are not concerned with these issues because the matter has been sufficiently settled by their cultural values and practices. The National Academy of Sciences and the American Association for the Advancement of Science (AAAS) assert that the goal of science is to develop natural explanations for natural phenomena based on empirical evidence (National Academy of Sciences, 1998; AAAS, 2006). In addition, they agree that explanations that are not amenable to empirical testing are not a part of science. "This self-imposed convention of science, which limits inquiry to testable, natural explanations about the natural world, is referred to by philosophers as 'methodological naturalism' " (Kitzmiller et al. v. Dover Area School District 2005).

The concept of methodological naturalism is useful in helping to distinguish between scientific and nonscientific questions and claims.

It is important for students to realize that not every question can be addressed by science. For example, questions concerning morality, beauty, religion, and social justice cannot be answered by the purely empirical methods of natural sciences. Evolution is an excellent context that biology teachers can use to help students develop an understanding of the limits of scientific explanations. For example, it is adherence to methodological naturalism that distinguishes evolutionary theory from intelligent design (Pennock, 2011). Both evolutionary theory and intelligent design offer explanations for the adaptations of organisms to their environment, but intelligent design relies on claims about an intelligent creator that cannot be investigated empirically. An activity I have found especially helpful for teaching these ideas is comparing and contrasting excerpts from the writings of William Paley and Charles Darwin. The materials were developed by the Modeling for Understanding in Science Education (MUSE) Project and are available online at http://ncisla.wceruw.org/muse/naturalselection/.

○ Methodological Naturalism Unites Values & Practices

Science is a "complex social activity" that is "built upon a distinctive set of values" that both shapes and is itself shaped by the values and viewpoints of the larger society in which it takes place (AAAS, 1989). The NRC *Framework* and the NGSS describe eight practices of working scientists that are essential elements of K–12 science education. The *Framework* stresses that "engaging in scientific inquiry requires coordination both of knowledge and skill simultaneously" (NRC, 2011, p. 41) and argues that engaging students in the practices of science helps them understand how scientific knowledge develops, increases interest, and deepens content knowledge. However, much less emphasis is given to the values, goals, and habits of mind of the culture of science that give meaning to these practices.

At the heart of the culture of science are the shared beliefs that the natural world operates in consistent ways and that humans can understand the universe, along with a commitment to methodological naturalism. In addition, the scientific community generally adheres to a shared set of ethical norms, which are especially concerned with intellectual honesty, the reliability of data, and avoiding subjective bias. Certain dispositions such as curiosity, skepticism, creativity, and perseverance are also generally esteemed within the culture of science because these dispositions help advance scientific knowledge. The AAAS, in their 1989 report *Science for All Americans*, emphasized the importance of understanding these commitments, ethical norms, and dispositions for scientific literacy; chapters 1 ("Nature of Science") and 12 ("Habits of Mind") are still some of the best resources for teachers on these topics.

The concept of methodological naturalism demonstrates the connection between the values and commitments of the culture of science and its practices. Table 1 highlights how the practices of science flow from the shared values of the scientific community. As students engage in these practices, it is important that they reflect on the values that give meaning to them within the culture of science. Historical case studies can also be used to demonstrate how the practices of modern science have taken shape over time. For example, the growing commitment to methodological naturalism is evident in the historical development of evolutionary theory. Throughout the 19th century, explanations of adaptation due to design (e.g., Paley's watchmaker analogy) were supplanted by empirically testable explanations (e.g., Lamarck's hypothesis of the inheritance of acquired characteristics) and eventually reconciled with multiple lines of evidence in Darwin's theory of natural selection. A historical perspective can help students develop a deeper understanding of key scientific ideas as well as an appreciation for the sociocultural processes that shape these explanations and the practices of science more generally. In addition, a historical perspective helps explain the similarities and differences between the values and practices of science and other ways of understanding the world such as philosophy, economics, religion, literary criticism, and history, which are each characterized by their own distinct discourses. The ability to analyze and critique scientific discourse, the capacity to differentiate it from other discourses, and the ability to apply scientific information to socioscientific issues are important, but generally overlooked, features of scientific literacy.

○ Supporting Students in Engaging in the Discourse of Science

There are many challenges to helping students develop the type of scientific literacy I have described here. Unfortunately, the NRC *Framework* gives little attention to the values and commitments that underlie the practices of science, and the NGSS does not include any performance expectations specifically emphasizing the culture or discourse of science. Engaging students in the practices is an important step, but work by R. S. Schwartz and colleagues (Schwartz & Crawford, 2004; Schwartz et al., 2004) suggests that reflection is critical for helping learners develop an understanding of NOS as they engage in scientific inquiry. Appendix H of the NGSS acknowledges that "learning about the nature of science requires more than engaging in activities and conducting investigations" (NGSS Lead States, 2013). Thus, Appendix H includes a list of eight basic NOS understandings and a matrix for learning outcomes of these themes at each grade band. In addition, the foundation boxes included with the performance expectations highlight connections to NOS. However, NGSS implementation efforts so far have focused nearly exclusively on "three-dimensional learning," which integrates practices, disciplinary knowledge, and crosscutting concepts by designing curriculum and instructional strategies to meet the performance expectations. While these are excellent goals, without explicit attention to the values and commitments of scientists that underlie the practices, students will not understand how scientific knowledge differs from other domains such as politics, law, or religion. Without this understanding, citizens are limited in their ability to apply scientific information, especially in regard to complex socioscientific issues such as climate change.

Development of scientific literacy as described here requires both engaging students in scientific discourse and reflecting on those norms. Many researchers have focused on the role of classroom talk in engaging students in scientific discourse. I have found Michaels and O'Connor's (2012) "Talk Science Primer" to be an invaluable resource as I have worked to develop my own teaching practice in this area. In addition, chapter 7 of NRC's (2007) *Taking Science to School* summarizes the literature on productive participation in scientific practices and discourses that supports the view of scientific literacy described here. The book asserts that "The norms of scientific

Table 1. Making the culture of science explicit through the NGSS science practices.

NGSS Scientific Practices	Some of the Associated Values, Goals & Habits of Mind of the Culture of Science	Principles of Methodological Naturalism	Examples of Activities That Support This Understanding
Asking questions	Curiosity; observant; falsifiability; creativity	Science is limited to questions about how the natural world works that are amenable to empirical investigation	Distinguishing between scientific and nonscientific questions; consideration of how questions reflect our values
Developing and using models	The natural world operates in consistent ways; inference; models explain phenomena and suggest testable predictions	Models represent physical mechanisms for natural phenomena	Historical case studies of how scientific models have changed over time or why different models can coexist
Planning and carrying out investigations	Reliance on empirical evidence; precision; reproducibility; creativity; perseverance	There is not a single "scientific method," but all of the natural sciences share a commitment to methodological naturalism	Discussion of experimental science vs. observational (e.g., much of astronomy and evolutionary biology); ethical considerations such as animal research or human subjects
Analyzing and interpreting data	Logical reasoning; objectivity; inference; skepticism; intellectual honesty; reliance on empirical evidence	Physical phenomena are observable and explainable through naturalistic means	Analyzing the assumptions and uncertainty in data; current examples of scientists interpreting the same data differently or historical examples in which the meaning of data was initially unclear
Using mathematics and computational thinking	Logical reasoning; characterizing uncertainty; objectivity; precision	Physical phenomena are observable and explainable through naturalistic means	Discussion of why scientists value mathematical representation and statistical analysis; correlation vs. causation
Constructing explanations	The universe is understandable; curiosity (explanations are answers to questions); creativity; reliance on empirical evidence	Physical phenomena can be explained by natural explanations; explanations are subject to change with new evidence	Reflecting on how biases influence our explanations and applications of science (e.g., Nazi eugenics)
Engaging in argument from evidence	Informed skepticism; valuing empirical evidence over authority; objectivity; consistency with evidence and other explanations	Evidence must be grounded in observation (empirical), and experiments must be reproducible	Consideration of how scientific evidence differs from evidence in other disciplines; examples of scientific articles as arguments from evidence
Obtaining, evaluating, and communicating information	Intellectual honesty; collaboration; informed skepticism; open-mindedness; clear communication	Science informs other discourses but is silent on questions and explanations that are not addressed through methodological naturalism (morality, law, politics, religion, etc.)	What aspects of addressing climate change require scientific information? What aspects are economic, political, or social? Ethical considerations of applications of science (e.g., stem cell research, genome modification)

argument, explanation, and the evaluation of evidence differ from those in everyday life. Students need support to learn appropriate norms and language for productive participation in the discourses of science" (NRC, 2007, p. 186). *Taking Science to School* emphasizes that while productive engagement in scientific discourse is challenging for all students, "it may be particularly difficult for students who have had less experience with the forms of reasoning and talk that are privileged in American middle-class schools" (p. 190).

Culturally or linguistically diverse students may encounter more barriers in developing scientific literacy than mainstream students because their home discourses are less similar to scientific discourse (Brown et al., 2005). In addition, the structure and culture of school itself often presents challenges for these students (Barton & Yang, 2000; Varelas et al., 2011). For these reasons, I would argue that instruction that specifically emphasizes the culture of science is vital to ensure equity in science education. Similarly, Meyer and Crawford (2011) draw on literature from multicultural education to propose teaching science as a cultural way of knowing in order to support students from populations underrepresented in the sciences. At the same time, it is important that educators are sensitive to students' personal beliefs and cultural differences. I agree with Barbara Rogoff's perspective that as educators, we "can assist people in learning new ways of doing things while maintaining other ways, and can help people learn when to use each approach" (Glaǎveanu, 2011).

○ Conclusion

Developing scientifically literate citizens is a worthy but challenging goal for science educators. Individuals and our society face many personal and collective decisions around issues such as health care, biomedical ethics, climate change, energy use, and the health of our environment, which require scientific literacy. Current reform efforts that emphasize the integration of scientific practices with disciplinary knowledge offer a step in the right direction for science education, but they leave out important aspects of the culture of science that promote the development of scientific literacy. Unfortunately, many science educators perceive instructional decisions concerning the role of NOS as a dichotomy between explicit instruction around simplified heuristics and engaging students in the practices of science (Duschl & Grandy, 2013). Here, I present a different view: Effective science education should engage students in the practices of science while reflecting on the values, commitments, and habits of mind that have led to the practices of modern science and that give them meaning. The concept of methodological naturalism demonstrates the connection between the values and commitments of the culture of science and its practices and provides a useful lens for understanding the benefits and limitations of scientific knowledge. Explicitly addressing the sociocultural aspects of NOS is especially vital for ensuring that students from diverse cultural and linguistic backgrounds have access to the discourse of science and opportunities to develop scientific literacy.

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