Seeking NOS Standards: What Content Consensus Exists in Popular Books on the Nature of Science?

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Abstract: Nature of science (NOS) has clearly won a place in science teaching given its increasing inclusion in standards documents, but the exact NOS elements that should be the focus of instruction have not yet been well determined. This study reviewed eight nature of science books designed for the general reader with the rationale that much might be learned about the most appropriate NOS content by examining works written for non-scientists by experts in the history and philosophy of science.

A qualitative analysis of each text resulted in a set of twenty-three unique NOS content domain topics each found in at least one book in the set of those reviewed. Each book was reviewed again with respect to this master list of topics and compared against a rubric of 0-3 (no to high) to gauge the degree of inclusion of each topic. This information permitted the ranking of books and of topics related to the level of inclusion of each NOS content element. The topics most frequently included definitions of science, characteristics and goals of science, general discussions of the history of science, the roles of induction and deduction, the contributions of Kuhn and Popper, the roles of induction and deduction, and the interplay of science and society. The lowest ranked topics focused on the role of models in science, definitions of pseudoscience, NOS in specific science disciplines, the distinction between science and technology and the role of creativity in science.

Assuming that the books reviewed contain all of the most useful suggestions for what members of the general public should know about NOS, the next step is to determine what not to codify as K-12 standards. This process can not take place with a simple frequency count of the elements but rather must occur as an active dialogue within the NOS community of science educators; not all of the elements found in this set of books are likely to be equally useful and even those that appeared infrequently may still be useful standards. A proposal for the list of NOS elements most pertinent to inform K-12 education is provided here as Table 1. Some suggestions for elements that might be included in a compete set of NOS standards include contributions of Kuhn, explicit contrasts between science and religion, definitions of pseudoscience (demarcation issues), the nature of NOS in specific science disciplines (physics vs. biology, for example) and postmodernist threats.

Finally, the books that contained the greatest number of NOS elements and hence might be recommended as worthy ancillary references were Dunbar (1995), Wolpert (1994) and Okasha (2002).

Keywords: nature of science, science teaching, science content standards

Purpose

There is little doubt among science educators and those interested in science curriculum reform that a robust and authentic science curriculum must contain elements of the nature of science (NOS) if students are to understand and appreciate the scientific enterprise beyond the simple recitation of the facts of science.

The nature of science is more than the fusion of elements from the history and philosophy of science (HPS) and might best be defined most broadly as a “. . . hybrid arena which blends aspects of various social studies of science including the history, sociology and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors." (McComas, Clough and Almazroa, 1998, p. 4). Therefore, NOS studies can paint a full and accurate picture of how science functions. From this picture, science educators can design science curricula that portray science accurately and appropriately.

Organizations at the forefront of the U.S. science education standards such as the American Association for the Advancement of Science (1989), the National Research Council (1994) agree that knowledge of the history and philosophy of science (HPS) is a significant element of science literacy and hence of the science curriculum. This view has influenced many of the forty-nine U.S. state science content standards documents which now are beginning to contain NOS standards. An increasing number of non-U.S. education authorities are including aspects of the nature of science as essential elements of science instruction (McComas and Olson, 1998).

There is reason to be pleased that NOS is now a topic included in science standards but more work must be done to define the discipline of NOS to guide K-12 instruction. One of the problems with the existing NOS standards is lack of standardization in focus and language. Consider, for example, the following statement from the current California science content framework stating that "within the scientific community, individuals or groups may sometimes see only what they desire to see or have been conditioned to see" (California Department of Education, 2003, p.17). An individual who is knowledgeable about the nature of science would see that the underlying issue here addresses "theory dependent observation." Others might feel that this statement is just some Orwellian newspeak suggesting a lack of objective reality or at least the impossibility of perceiving it. For teachers, who may lack the most informed views of the nature of science, one might predict that such statements make little sense and would be ignored. Even for the NOS-knowledgeable, it is unclear what teachers would be expected to do with such a statement in terms of classroom instruction.

Even as we converge on a definition of the nature of science appropriate for K-12 instruction, we must also consider that this content must also be appropriate for teacher education as well as for their students. A variety of studies have made clear that teachers' knowledge of NOS plays a major role in the way in which science is portrayed verbally and with respect to the experiences and written materials provided to students. As Carey and Stauss (1970) stated, "if the teacher's understanding and philosophy of science are not congruent with the current interpretations of the nature of science, . . . then the instructional outcomes will not be representative of science" (p. 368). Therefore, the nature of science is not simply an element of K-12 curriculum but must also inform the curricular, content and pedagogical content knowledge (Shulman, 1986) that teachers must possess if they are to be effective in the science classroom.

Recently, one of the interesting and fruitful quests with respect to NOS studies in the science education community has been to define what key nature of science ideas are most appropriate for the inclusion in the K-12 science curriculum. Fortunately, consensus has begun to emerge from the extensive literature in the history and philosophy of science. Principally, Osborn, Collins, Ratcliffe, Millar and Duschl (2003), McComas (1998), Lederman (2002), and McComas, Clough and Almazroa (1998) have suggested surprisingly parallel sets of NOS content recommendations.

TABLE 1
A suggested list of core NOS ideas appropriate to inform K-12 curriculum development, instruction and teacher education

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1) Science demands and relies on empirical evidence.
2) Knowledge production in science shares many common factors and shared habits of mind, norms, logical thinking and methods (such as careful data recording, truthfulness in reporting, care in observation, etc.)
    - However, there is no one step-wise scientific method by which all science is done
    - Experiments are not the only route to knowledge
    - Science uses both inductive reasoning and hypothetico-deductive testing
    - Scientific conclusions are peer reviewed but observations and experiments are not generally repeated
3) Scientific knowledge is tentative but durable. (This means that science cannot prove anything but scientific conclusions are still valuable and long lasting because of the way in which they are developed)
4) Laws and theories are related but distinct kinds of scientific knowledge. Hypotheses are special, but general, kinds of scientific knowledge).
5) Science has a creative component.
6) Science has a subjective element. (Ideas and observations in science are "theory"-laden; this bias plays both potentially positive and negative roles in scientific investigation).
7) There are historical, cultural and social influences on science.
8) Science and technology impact each other, but they are not the same.
9) Science and its methods cannot answer all questions. (In other words, there are limits on the kinds of questions that can be asked of science).

Even as this list is established it is important that no important elements of the nature of science are overlooked. Therefore, the study reported here provides an additional data source of potential core NOS content elements by looking outside both the formal NOS and science education communities. This study adds new data to the conversation by providing the results of a detailed review of current nature of science books designed for the general reader. The rationale for the selection of these books and this research agenda is that much might be learned about the most appropriate NOS content by examining works written by experts in the history and philosophy of science for non-scientists ostensibly to enhance science literacy and encourage interest in this domain. At best, one might logically assume that these authors have chosen to include basic and important NOS topics supported by interesting and illustrative examples and we could learn from these choices. The goal is not to have K-12 learners use these as classroom texts, although that recommendation might be appropriate in some cases, but rather to use these books as another source of information regarding what content standards might be in the area of the nature of science.

Method

The books which were the focus of this study were found by searching key terms in data bases of books in print and through a listserv solicitation of suggestions of such works from members of the science education community who are interested in and knowledgeable about the nature of science. Approximately forty works were suggested (see Appendix A) and while many of these would certainly make interesting points about the history and philosophy of science, those that would serve most immediately had to be somewhat comprehensive. Books from the past decade were deemed most appropriate since they are likely to feature current and accurate descriptions of science. As we well know, interpretations of how science functions may change (Duschl, 1985) and one of the challenges with respect to any content in science is to ensure that it is current.

Slightly more difficult was the determination of which books were designed for the general reader and which were written primarily as texts in the philosophy or history of science. In most cases the distinction was made clear by the level of language included, the length of the book, and the stated purpose of the book as described on web sites and/or on the book jacket. These elements were considered jointly resulting in a set of eight books selected for intense analysis.

Forming NOS Content Categories

Following the selection of the books, an extensive qualitative analysis of each text ensued using a grounded theory approach in which the categories reported are suggested by and authenticated by a cycle of reading and review. This was accomplished by carefully examining the content of each book and noting the major NOS topics. This initial reading resulted in the proposal of a list of topics established for each individual book. These individual topic lists were examined as a group in a process that resulted in a reduction in the total number of topics when similar areas were grouped together into mutually exclusive categories (see Appendix A). The resulting "master" list of NOS topics from the review of all texts numbered twenty-three unique NOS content domains. While it is not reasonable to assume that this "master" list includes all possible NOS content appropriate for a general audience, when considering the variety of books reviewed omissions are unlikely. The individual books were again reviewed with reference to the master list to ensure that no significant NOS content was overlooked.

Measuring and Reporting the Level of NOS Inclusion

Next a separate analysis was initiated to make a subjective determination of the degree to which each individual book addressed each topic. To accomplish this, a scale from 0 to 3 was established to evaluate and report the level of inclusion of that topic in each book. (See Table 2 for the rubric applied in the performance of this task). A "0" represents no inclusion, while a "3" designates inclusion at a very high level in comparison to the set of books. This rating scale was developed by cross case comparison rather than by using an external standard. Among the books reviewed, those with a 3 for a particular NOS topic had the largest coverage of this content compared with the other books. However, this level does not indicate that this is the most robust, complete, or appropriate treatment that could be provided for this content element.

TABLE 2
Rubric for the evaluation of the degree of inclusion of particular NOS content elements in the books reviewed

0	No perceptible inclusion of the content category
1	Content is included at a basic level (perhaps only with a simple definition) or discussed the content by implication rather than direct statements. In such cases, one would have to possess some advance knowledge about the issue to recognize what the author was discussing. For instance, Dunbar (1995) talks about "cause and effect" vs. "explanatory" science which is clearly related to the distinction between law and theory. However, by using these other terms the distinction will be so easily seen.
2	This level is used when the content inclusion is intermediate between levels 1 and 3.
3	Within the set of books, this is the level of maximal inclusion. Cromer (1993) devotes approximately a third of the book to a recounting of the history of science as do Derry (1999) and Thompson (2001). Sardar and VanLoon (2002) frame their book on issues related to the social practice of science and criticisms of science and earn the highest score accordingly.

The final task was to rank both the inclusion of particular NOS elements across all books and to rank the books themselves based on their inclusion of the greatest number of elements.

Data

The results of this study are reported in Appendix A. Each of the twenty-three ideas-about-science found in the set of books reviewed is listed in the left-most column. In the "total and rank" column to the right the total score for the subjective measure of the degree of inclusion of each NOS element is provided along with the rank of that element from highest to lowest. Since there were some ties, this scale extends from 1 to 12 (highest level of inclusion to lowest). The column at the extreme right contains a total value for the inclusion for a particular NOS element without regard for the extent of that inclusion. This number is reported with the percentage of books containing that content element. Therefore, if the level of inclusion is reported at 100%, we know that this content element appears in all of the books reviewed. Finally, the row that the bottom of Appendix A provides the total of the values for the inclusion of content elements for each specific book along with the rank from 1 to 7 (highest inclusion to lowest). This may be interpreted to suggest that the book ranked "1" contains the most unique content elements and the book with the highest rank (in this case 7) contains the lowest number of such elements. The numbers in this row do not reflect the extent of coverage in any given book.

Results and Implications

The most fundamental conclusion that we might reach from this analysis is that different authors emphasize different but somewhat shared perspectives of the nature of science while communicating this topic to an audience of general readers. Topics most frequently seen in this set of books include the *definition of what science is*, *the characteristics and goals of science*, *historical development of science*, *the role played by induction and deduction in science*, *contributions of Kuhn and Popper* and the *impact of science on society*. Lowest ranked topics are the *distinction between science and technology*, the *role and nature of models in science*, *creativity* as a vital ingredient in science, *nature of science in specific disciplines* and *critiques of pseudoscience*. Interesting, several of these topics would seem appropriate for inclusion in science instruction even though they are not widely included in this sample of NOS books.

As an example, consider that 63% (5 of 8) of the books contained some material regarding the distinction between realism and instrumentalism (also know as anti-realism) ranking it seventh in terms of the total amount of material on this subject included in the set of books. From a philosophy of science perspective this is a topic of interest and importance, but it is not likely that school science instruction would be enhanced by the inclusion of this somewhat arcane element in the science curriculum for students. On the other hand, science teachers might benefit from consideration of realism and instrumentalism because such discussion would enhance their vision of how learners think about scientific information. Likewise, the roles of Kuhn and Popper, while somewhat equal in inclusion in the books reviewed, should not inform science education equally. Kuhn is generally considered to have described how science actually functions and in doing so paints a portrait of the scientific enterprise that students should access. Popper, on the other hand, is best known for his idea of falsification, prescribing how science might function if it were to be more effective. This worthy and interesting idea belongs in a book about the philosophy of science, but K-12 learners might not profit much from it in its purest sense since it is prescriptive rather than descriptive. However, in terms of discussing demarcation criteria that separate science from non-science there may be some utility in evoking the potential for falsification as one element of "test" to make the separation.

To discuss some specific curious aspects of the books analyzed, consider the fact that induction as a knowledge generation tool is almost always discussed but deduction much less frequently found. One would think that the so-called "arch of knowledge" (Oldroyd, 1986) which includes both induction and deduction would be an important element of any conversation about the structure of scientific epistemology. The problem of induction was included in many of the books and, fortunately, hypothetico-deductive thinking featured in several of the books making the discussion of knowledge generation more complete that it would be otherwise. In a similar fashion, we find that laws are only rarely discussed in these books (although the term itself is used frequently), but discussions of theories and aspects of theory building and testing are widely included but not at a very robust level. This same trend may be seen in many secondary school biology texts where the terms "law" and "theory" are commonly provided but only rarely are these concepts defined (McComas, 2003).

It may be tempting to take the list of twenty-three concepts principles in the nature of science and turn them into NOS standards, but the science education community must engage in an informed discussion about what to include and for whom. For instance, one could imagine a set of NOS standards to inform the development of the K-12 curriculum and perhaps a slightly different and expanded set of standards to direct science teacher education. The goal of the analysis presented here is to ensure that our proposals for NOS standards (see Table 1, for example) do not omit any important elements of the description of how science functions. In that case, the project has succeeded well. Comparing the results of this analysis with the NOS content proposals demonstrates the high degree of completeness.

The areas included in many of the books that are not generally reflected in current NOS standards relate to the *contributions of Kuhn and Popper*, *the role of models in science*, *postmodernist issues and scientism* and the *ethical implications of science.* More than half of the books contained specific references both to the threat to the acceptance and understanding of science of postmodernism and scientism. Defining these terms and discussing the associated challenges with students are vital to a full appreciation of science and the interplay of science and society. Another implication of this review is that perhaps our NOS standards should be crafted to be specific rather than embracing. This suggestion comes from the understanding that the issue of the ethical implications of science could easily be subsumed and implied within a standard targeting the interplay of science and society. However, if teachers fail to understand what might be discussed within a science-society standard, this important issue may be neglected. Of course, more specificity would results in a greater number of more highly focused NOS standards.

Likewise, several of these authors remind us that pseudoscience is a continuing threat to an understanding of science itself and should be addressed head on. The important but mutually exclusive roles of science and religion must also be an element of classroom instruction. Finally, it was interesting to see how these authors used incidents and personalities from the history of science to provide examples of how science functions and how scientists behave. Not surprisingly, physicists Galileo, Newton and Einstein were featured heavily while Dunbar (1995) provides some interesting examples from the science of anthropology. One recommendation that occurs after examining these books is that the examples should come from a variety of sciences but it was no surprise that the examples came primarily from physics then chemistry and finally biology. The notion of the shared characteristics across science disciplines is an important aspect of the nature of science.

This study has shown that even a set of books targeting the nature of science may neglect important issues. For instance, only three of the books (38%), remind us that creativity is an important ingredient in the scientific enterprise. Failure to communicate this fact to students would both misrepresent the true nature of knowledge creation and testing in science and would very likely cause some students to discount science as a viable career choice. The same is true of the distinction between science and technology, a widespread misconception among students and some teachers. Only one book (13%) makes this important point.

There was no initial goal to rate individual books such that one might be recommended as a useful source for either teachers or students, but given the rigor of the study, such a recommendation is unavoidable. In terms of completeness, robustness and even style, Okasha (2002), Dunbar (1995) and Wolpert (1994) each would serve teachers well as either in-class references or sources for professional growth.

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Wolpert, L. (1994). *The Unnatural Nature of Science.* Cambridge: Harvard University Press.

Appendix A

Books in English Addressing Aspects of the Nature of Science for General Readers

Arber, A. (1954). *The Mind and the Eye: A Study of the Biologist's Standpoint.* Cambridge, UK: Cambridge University Press.

Atkins, P.W. (1995). *Periodic Kingdom: A Journey into the Land of the Chemical Elements.* New York: BasicBooks.

Bechtel, W. (1988). *Philosophy of Science: An Overview for Cognitive Science.* Hillsdale, NJ: Lawrence Earlbaum.

Beveridge, W.I. B. (1950). *The Art of Scientific Inquiry*. New York: Norton.

Bodanis, D. (2000). *$E=mc^2$ A Biography of the World's Most Famous Equation.* New York: Anchor.

Bronowski, J. (1951). *The Common Sense of Science.* New York: Knopf.

Bronowski, J. (1990). *Science and Human Values.* New York: Harper Collins Publishers.

Brownowski, J. (1973). *The Ascent of Man.* Boston: Little Brown

Calder, R. (1970). *Man and the Cosmos. The Nature of Science Today*. New York: Penguin Books.

Capra, F. (1999). *The Tao of Physics: An Exploration of the Parallels between Modern Physics and Eastern Mysticism.* Shambhala Publications, Inc.

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Koestler, A. (1990). *The Sleepwalkers.* New York: Viking Penguin

Kosso, P. (1992). *Reading the Book of Nature.* Cambridge, U.K. Cambridge University Publishing

Kuhn, T. (1962). *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Ladyman, J. (2002). *Understanding Philosophy of Science.* New York: Routledge.

LeShan, L. and Margenau, H. (1982). *Einstein's Space and Van Gogh's Sky: Physical Reality and Beyond.* New York: Macmillan

Levinson, T. (1994). *Measure for Measure: A Musical History of Science.* New York: Simon & Schuster.

Logan, C. (2003). *Absolute Zero.* New York: Harper Collins.

Losee, J. (1993). *A Historical Introduction to the Philosophy of Science.* New York: Oxford University Press.

Medawar, P. (1984). *The Limits of Science.* New York: Harper Collins.

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***These books were reviewed as part of the study reported here.**

Appendix A

(W.F. McComas / NARST 2005)

Results of a Qualitative Analysis of Five Books on the Nature of Science Designed for the General Public.

The subjective scale runs from 0-3 in terms of coverage. 0 represents no discernable inclusion and 3 is a major focus in the book.

Nature of Science Content Elements Featured in the Books Reviewed	Chalmers (1999)	Cromer (1993)	Derry (1999)	Dunbar (1995)	Okasha (2002)	Sardar (2002)	Thompson (2001)	Wolpert (1994)	Total and Rank (High to Low)	Included in books regard-less of extent
1) Science defined to some extent	1	1	1	1	2	2	1	1	10 / 7	8 (100%)
2) Characteristics and Goals of Science (General-izability, Experiment, Prediction, Cause and Effect)	2	1	1	1	2	1	2	2	12 / 5	8 (100%)
3) Explanations in Science (e.g. Hempel)	1	0	1	1	3	0	1	0	7 / 7	6 (75%)
4) Theory vs. Law (definitions and roles as tools and products of science)	1	0	0	1	1	0	2	1	6 / 8	5 (63%)
5) General Portrayal of the Historical Development of Science and/or Use of Specific Historical Examples	2	3	3	2	1	1	3	1	16 / 2	8 (100%)
6) Induction and Deduction as Modes of Knowledge Generation in Science (Problems of Induction) (e.g. Bacon) H/D testing	3	0	2	2	3	1	3	1	15 / 3	7 (88%)
7) Realism vs. Instrumentalism (anti-realism)	1	0	0	2	3	1	3	0	10 / 7	5 (63%)
8) Theory Ladenness of Data / Fallibility of Observations	2	2	2	0	2	0	2	0	10 / 7	5 (63%)
9) Distinction between Science and Technology	0	0	0	0	0	0	0	3	3 /11	1 (13%)
10) Creativity is an Important Element of Science	0	0	0	1	1	0	0	3	5 / 10	3 (38%)
11) Kuhn=s Contributions (Paradigm et al)	3	1	1	1	3	2	3	2	16 / 2	8 (100%)
12) Popper=s Contributions and/or Falisifiability)	3	1	1	2	3	2	3	2	17 / 1	8 (100%)

Nature of Science Content Elements Featured in the Books Reviewed	Chalmers (1999)	Cromer (1999)	Denny (1999)	Dunbar (1995)	Okasha (2002)	Sardar (2002)	Thompson (2001)	Wolpert (1994)	Total and Rank (High to Low)	Included in books regard-less of extent
13) Theory Testing Issues (Quine-Duhem)	3	0	2	1	1	0	3	1	11 / 6	6 (75%)
14) Contributions from other philosophers of science (e.g. Feyerabend, Lakatos)	3	0	0	1	0	2	2	1	9 / 8	5 (63%)
15) The Roles of Models in Science	0	0	2	0	0	0	0	0	2 / 12	1 (13%)
16) No Single Scientific Method but Shared Approaches Exist (may be implied by example)	1	0	0	0	0	1	1	2	5 / 9	4 (50%)
17) Science as a Social Enterprise (Scientists compete & cooperate) (Sometimes implied)	0	2	1	1	1	3	0	3	11 / 6	5 (63%)
18) Science Criticized (relativity of science knowledge, knowledge is not privileged, the SSK agenda, scientism, postmodernist issues)	0	0	0	2	3	3	1	2	11 / 6	5 (63%)
19) Contrast between Science and other ways of Knowing (Usually religion but sometimes myth or witchcraft)	0	1	3	1	2	1	0	2	10 / 7	6 (75%)
20) Analysis and Critique of Pseudoscience (usually astrology) and/or Non-Science and/or Non-natural science such as psychoanalysis)	0	0	3	0	1	0	0	3	7 / 7	3 (38%)
21) Impact of Science on Society and Vice Versa	0	1	3	1	1	3	2	3	14 / 4	7 (88%)
22) Ethical Implications of Science and/or Ethical Responsibility of Scientists	0	0	3	1	1	2	1	3	11 / 6	6 (75%)
23) NOS Issues and Specific Science Disciplines such as Biology, Physics	0	0	0	1	3	0	2	0	6 / 8	3 (38%)
Number of Elements (regardless of degree of inclusion) in each book w/ Rank (1-8) (High to Low)	13 / 6	9 / 7	15 / 4	18 / 2	19 / 1	14 / 5	17 / 3	18 / 2		