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Representations of Nature of Science in High School Chemistry Textbooks over the Past Four Decades

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Abstract: This study assessed the representations of nature of science (NOS) in high school chemistry textbooks and the extent to which these representations have changed during the past four decades. Analyses focused on the empirical, tentative, inferential, creative, theory-driven, and social NOS, in addition to the myth of ‘‘The Scientific Method,’’ the nature of scientific theories and laws, and the social and cultural embeddedness of science. A total of 14 textbooks, including five ‘‘series’’ spanning one to four decades, were analyzed. The textbooks commanded significant market shares in the United States and were widely used in some of the most populace states. Relevant textbook sections were scored on each of the target NOS aspects on a scale ranging from −3 to +3, which reflected the accuracy, completeness, and manner (explicit versus implicit) in which these aspects were addressed. The textbooks fared poorly in their representations of NOS. Additionally, with a few exceptions, textbook scores either did not change or decreased over the past four decades. These trends are incommensurate with the discourse in national and international science education reform documents, which has witnessed an increasing emphasis on the centrality of NOS to scientific literacy and pre-college science education during the same time period. Assessment and evaluation strategies, and policies need to be targeted if substantial and desired changes in the ways NOS is addressed in science textbooks are to be effected. © 2008 Wiley Periodicals, Inc. J Res Sci Teach 45: 835–855, 2008
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Over the past four decades, the goal of helping students and teachers develop informed views of nature of science (NOS) has increasingly become central to the vision and discourse of national science education reform documents both in the United States and across the globe (e.g., American Association for the Advancement of Science [AAAS], 1971, 1990; Council of Ministers of Education—Canada, 1997; Curriculum Council, 1998; Millar & Osborne, 1998; National Center for Educational Research and Development [NCERD, 1997]; National Research Council [NRC, 1996]; National Science Teachers Association, 1982, 2000). Understandings of NOS are currently regarded a significant outcome of pre-college science education and a central component of scientific literacy (AAAS, 1990; NRC, 1996). The focus on NOS has generated extensive research and development efforts over the past four decades, which were directed toward assessing pre-college students' and science teachers' NOS views; designing, enacting, and testing units, courses, and curricula aimed at helping students and teachers develop informed views of NOS; and investigating the transfer of teachers' NOS understandings into instructional practices (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992). While some progress has been made, much remains to be desired: recent research consistently shows that the greater majority of students and teachers continue to ascribe to naïve views of major aspects of NOS (Abd-El-Khalick, 2005; Abd-El-Khalick & Akerson, 2004; Bianchini & Colburn, 2000; Bora & Cakiroglu, 2006; Khishfe & Abd-El-Khalick, 2002). This state of affairs could be attributed to the complexity associated with effecting systemic reforms in the way science is taught at the pre-college and college levels, as well as the curricula and practices associated with pre-service and

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inservice science teacher education. Nonetheless, we believe that a major factor contributing to the present situation is related to the ways NOS is represented in commercial science textbooks.

Science educators and researchers think of textbooks as instructional *resources* that support teachers in planning and delivering science instruction to meet local and national curricular standards (Chiappetta & Koballa, 2002). However, it is an undeniable reality that in the larger majority of classrooms, textbooks become *the* curriculum and determine, to a much larger extent than desired by science educators, what is taught and learned about science in these classrooms (Chiappetta, Sethna, & Fillman, 1991; Chiappetta, Ganesh, Lee, & Phillips, 2006; Rieff, Harwood, & Phillipson, 2002; Shiland, 1997). Chiappetta et al. (2006) and Weiss, Banilower, McMahon, and Smith (2001) noted that more than 90% of secondary school science teachers rely on textbooks to organize and deliver instruction and assign homework. In a significant sense, textbooks "define academic subjects as students experience them. . . [and]. . . represent school disciplines to students" (Valverde, Bianchi, Schmidt, McKnight, & Wolfe, 2002, p. 2).

In the case of NOS, the impact of textbooks gains significance because very few, if any, commercially viable science textbooks have been recently designed specifically to help pre-college students develop informed NOS conceptions as emphasized in current science education reform documents. Earlier attempts to develop such textbooks and curricula (e.g., Holton, 1981; Klopfer & Cooley, 1963; Rutherford, Holton, & Watson, 1975) did not achieve commercial success or widespread use in science classrooms. The impact of textbooks has been deemed so important for the success of science education reform efforts that the AAAS led extensive efforts through Project 2061 to produce case studies, which meticulously analyzed commercial science textbooks for their alignment with the *Benchmarks for Science Literacy* (AAAS, 1993) (see for e.g., Kesidou & Roseman, 2002; Stern & Roseman, 2004). These analyses, which were widely publicized among teachers and school districts, aimed to pressure commercial publishers to pay closer attention to national standards when producing or revising science textbooks.

Nonetheless, very little empirical research has been dedicated to assessing how NOS is actually represented in commercial science textbooks, and in what ways and the extent to which publishers have responded to the reforms discourse related to NOS. Science textbook analyses have mainly focused on representations of scientific literacy themes (e.g., Chiappetta et al., 1991) and the historical accuracy of the treatment of specific science concepts (e.g., Brito, Rodriguez, & Niaz, 1995). Thus, the purpose of this study was to assess ways in which NOS is represented in high school chemistry textbooks and the extent to which these representations have changed during the past four decades. The focus on chemistry textbooks stemmed from the researchers' disciplinary expertise and teaching experiences. The study was guided by the following questions: (1) How is NOS represented in high school chemistry textbooks that span the past four decades? (2) Have these representations of NOS changed during the past four decades? (3) To what extent do these changes, if any, reflect changes in scholarship about NOS?

Review of the Literature

There is a dearth of research that specifically examined the representation of NOS themes or aspects in secondary science textbooks in general and chemistry textbooks in particular. A number of studies have focused on different aspects of the content, structure, curriculum design features, and disciplinary emphases of high school science textbooks, but none, to the best of our knowledge, have specifically targeted the representation of NOS aspects such as those targeted in this study. For example, some studies focused on questioning styles (e.g., Lowery & Leonard, 1978), readability levels (e.g., Chiang-Soong & Yager, 1992), attention to controversial and social issues (e.g., Levin & Lindbeck, 1979; Rosenthal, 1984), inclusion of evolutionary theory (e.g., Skoog, 1984, 1979), and the treatment of specific subject matter content (e.g., Anderson, 1990; Lloyd, 1990; Staver & Lumpe, 1993) of secondary biology and/or chemistry textbooks. Other studies examined textbook representations of specific science concepts or theories from pedagogical perspectives or by reference to the historical development of such constructs. For instance, Shiland (1997) analyzed the content of eight secondary chemistry textbooks by reference to a "learning as conceptual change" model. Brito et al. (1995) examined the historical reconstruction of the periodic table in 57 freshmen college-level chemistry textbooks and found that such reconstructions diverged from the actual historical development of the periodic table.

A few studies examined secondary science textbooks from a broad NOS perspective. Chiappetta et al. (1991) and Lumpe and Beck (1996) examined the balance of four scientific literacy themes (knowledge of science, the investigative NOS, science as a way of thinking, and the interaction of science, technology, and society) in seven secondary chemistry and seven biology textbooks, respectively. Both studies found that the textbooks focused on the content of science and overemphasized science vocabulary. Lumpe and Beck reported that the analyzed textbooks did not integrate the four target themes resulting in a misrepresentation of the holistic NOS, while Chiappetta et al. found that their textbooks did not pay enough attention to science as a way of thinking or to the interactions between science, technology, and society.

In a series of studies, Mansoor Niaz and his colleagues analyzed secondary and freshmen college-level chemistry textbooks for some NOS themes. Niaz (1998) and Rodriguez and Niaz (2002) analyzed 23 college freshman chemistry textbooks based on criteria derived from recent developments in history and philosophy of science (HPS). Both studies found that the examined textbooks, both old and new, ignored HPS and presented experimental findings as a "rhetoric of conclusions." Textbooks failed to explicate the significant role that competing frameworks and clashing evidence play in scientific progress. Niaz (2000) analyzed 22 chemistry textbooks with a focus on the kinetic molecular theory. He found that most textbooks lacked an HPS framework and failed to deal with the conceptual basis for the development of this chemical theory.

Method

The present study adopted a structured, document analysis approach. Fourteen high school chemistry textbooks were analyzed using a structured scheme and associated scoring rubric, which were developed for the purposes of this study.

Analytical Framework

NOS and approaches to addressing NOS instructionally served as bases for the analytical framework used in this study. Thus, it is important to explicate these bases, which were adopted by the authors for the purpose of analyzing the selected textbooks.

Nature of Science. Lederman (1992) defined NOS as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development and validation of scientific knowledge. It is recognized, nonetheless, that beyond this general characterization, philosophers, historians, and sociologists of science, as well as scientists and science educators do not necessarily agree on a specific definition for NOS (Abd-El-Khalick, Bell, & Lederman, 1998). Such lack of consensus, however, should not be disconcerting given the multifaceted and complex nature of the scientific endeavor, and the fact that scholarship related to understanding this endeavor remains as active today as it has been for the last three centuries. Despite disagreements on a specific definition, there currently is, if you will, a "shared wisdom" about NOS. For example, currently, it should prove very difficult to reject the theory-driven nature of scientific observations, or to defend an absolutist conception of scientific knowledge.

More importantly, for purposes of teaching and learning about NOS at the pre-college level, we believe that some important aspects of NOS are virtually non-controversial and also accessible to pre-college students. Ten aspects, which were emphasized in recent national reform documents in science education (AAAS, 1993; NRC, 1996; NSTA, 2000), were adopted for the purpose of examining textbooks in this study. The 10 aspects are explicated in Table 1. It cannot be overemphasized, however, that these aspects are intricately interrelated. Also, in the present context, two issues require further elaboration beyond what is presented in Table 1. First, the presently adopted definition for NOS, though focused on epistemological dimensions broadly conceived, excludes a focus on science process skills. While NOS and scientific processes are necessarily related, they surely are not one and the same. Scientific process skills, both basic (observing, measuring, inferring, etc.) and integrated (controlling variables, interpreting data, hypothesizing, etc.) could be conceived of as epistemic acts. However, as Kuhn (1970) indicated, practicing scientists might have very little or no idea about the epistemological foundations and assumptions underlying their fields of research despite their daily engagement with scientific practice. In other words, the enactment of such processes in the context of conducting scientific investigations does not necessarily entail an understanding of the underlying epistemological issues. For example, the act of observing is a fundamental scientific process:

Table 1
Explication of the NOS aspects targeted in the analysis of the selected textbooks

NOS aspect	Dimensions emphasized in textbook analysis
Empirical	Scientific claims are derived from, and/or consistent with, observations of natural phenomena. Scientists, however, do not have "direct" access to most natural phenomena: their observations are almost always filtered through the human perceptual apparatus, mediated by the assumptions underlying the functioning of "scientific" instruments, and/or interpreted from within elaborate theoretical frameworks
Inferential	There is a crucial distinction between observations and inferences. Observations are descriptive statements about natural phenomena that are accessible to the senses (or extensions of the senses) and about which observers can reach consensus with relative ease (e.g., objects released above ground level tend to fall to the ground). Inferences, on the other hand, are statements about phenomena that are not directly accessible to the senses (e.g., objects tend to fall to the ground because of "gravity"). Scientific constructs, such as gravity, are inferential in the sense that they can only be accessed and/or measured through their manifestations or effects
Creative	Science is not an entirely rational or systematic activity. Generating scientific knowledge involves human creativity in the sense of scientists inventing explanations and theoretical entities. The creative NOS, coupled with its inferential nature, entail that scientific entities (atoms, force fields, species, etc.) are functional theoretical models rather than faithful copies of "reality"
Theory-driven	Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, and expectations influence their work. These background factors affect scientists' choice of problems to investigate and methods of investigations, observations (both in terms of what is and is not observed), and interpretation of these observations. This (sometimes collective) individuality or mind-set accounts for the role of theory in generating scientific knowledge. Contrary to common belief, science never starts with neutral observations. Like investigations, observations are always motivated and guided by, and acquire meaning in light of questions and problems derived from, certain theoretical perspectives
Tentative	Scientific knowledge is reliable and durable, but never absolute or certain. All categories of knowledge ("facts," theories, laws, etc.) are subject to change. Scientific claims change as new evidence, made possible through conceptual and technological advances, is brought to bear; as extant evidence is reinterpreted in light of new or revised theoretical ideas; or due to changes in the cultural and social spheres or shifts in the directions of established research programs
Myth of "The Scientific Method"	This myth is often manifested in the belief that there is a recipe-like stepwise procedure that typifies all scientific practice. This notion is erroneous: there is no single "Scientific Method" that would guarantee the development of infallible knowledge. Scientists do observe, compare, measure, test, speculate, hypothesize, debate, create ideas and conceptual tools, and construct theories and explanations. However, there is no single sequence of (practical, conceptual, or logical) activities that will unerringly lead them to valid claims, let alone "certain" knowledge
Scientific theories	Scientific theories are well-established, highly substantiated, internally consistent systems of explanations, which (a) account for large sets of seemingly unrelated observations in several fields of investigation, (b) generate research questions and problems, and (c) guide future investigations. Theories are often based on assumptions or axioms and posit the existence of non-observable entities. Thus, direct testing is untenable. Only indirect evidence supports and validates theories: scientists derive specific testable predictions from theories and check them against observations. An agreement between predictions and observations increases confidence in the tested theory
Scientific laws	In general, laws are descriptive statements of relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. Contrary to common belief, theories and laws are not hierarchically related (the naïve view that theories become laws when "enough" supporting evidence is garnered, or that laws have a higher status than theories). Theories and laws are different kinds of knowledge and one does not become the other. Theories are as legitimate a product of science as laws
Social dimensions of science	Scientific knowledge is socially negotiated. This should not be confused with relativistic notions of science. This dimension specifically refers to the constitutive values associated with established venues for communication and criticism within the scientific enterprise, which serve to enhance the objectivity of collectively scrutinized scientific knowledge through decreasing the impact of individual scientists' idiosyncrasies and subjectivities. The double-blind peer-review process used by scientific journals is one aspect of the enactment of the NOS dimensions under this aspect

Table 1
(*Continued*)

NOS aspect	Dimensions emphasized in textbook analysis
Social and cultural embeddedness of science	Science is a human enterprise embedded and practiced in the context of a larger cultural milieu. Thus, science affects and is affected by various cultural elements and spheres, including social fabric, worldview, power structures, philosophy, religion, and political and economic factors. Such effects are manifested, among other things, through public funding for scientific research and, in some cases, in the very nature of ''acceptable'' explanations of natural phenomena (e.g., differing stories of hominid evolution have resulted from the advent of feminist perspectives brought about by increased access, participation, and leadership of females in the biosocial sciences)

Adapted from Abd-El-Khalick (1998).

students and scientists develop varying levels of skill and proficiency in making observations and using various observational instruments. The notion of the theory-driven nature of observation, nonetheless, belongs to the domain of NOS. More importantly, engaging in observation does not necessarily lead the observer to discern or construct the notion of the theory-driven nature of observation. In the context of analyzing science textbooks, the present distinction means that while a focus on scientific processes in a science textbook might provide a context for addressing certain aspects of NOS, it does not automatically qualify as addressing NOS per se.

Second, two of the aspects presented in Table 1 need to be carefully distinguished. The ''social dimensions of the scientific enterprise'' aspect specifically refers to conceptualizations of ''science as social knowledge,'' which should not be confused with relativistic notions of scientific knowledge. It refers to conceptions of science as advanced by philosophers of science such as Helen Longino (e.g., Longino, 1990). Dimensions under this aspect refer to constitutive values associated with established venues for communication and criticism within the scientific enterprise. These values and venues serve to enhance the objectivity of collectively scrutinized scientific knowledge through decreasing the impact of individual scientists' idiosyncrasies and subjectivities. The double-blind peer-review process used by scientific journals is an example of the enactment of aspects of NOS under this dimension. In comparison, the ''social and cultural embeddedness of scientific knowledge'' aspect refers to the impact of the interactions between science and the social and cultural milieu in which it is embedded on, for instance, the sort of research that is pursued. This interaction largely occurs through public funding for scientific research when the latter is deemed crucial to meeting pressing societal needs (e.g., the focus on funding AIDS-related research versus research on the Ebola viruses in the United States) or lack of support and/or endorsement for research domains that conflict with dominant cultural or religious sensibilities (e.g., research related or perceived to be related to human cloning).

Explicit Versus Implicit Approaches to Addressing NOS. The scoring rubric used in this study (see below) significantly builds on a distinction between explicit and implicit attention to NOS aspects in the analyzed textbooks. This focus derives from research on the relative impact of implicit versus explicit approaches to addressing NOS instructionally. Research, including quasi-experimental, pretest–posttest comparison group design studies (e.g., Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002), shows that implicit approaches, which assume that engagement with science-based activities or ''doing science'' would necessarily translate into enhanced understandings of NOS among students, are less effective than explicit approaches (Abd-El-Khalick & Lederman, 2000a). Implicit approaches usually lack any structured opportunities or prompts to help learners reflect on their science-based activities from within a framework that would enable them to build and internalize desired NOS understandings (Abd-El-Khalick & Lederman, 2000b).

It cannot be overemphasized that explicit attention to NOS is *not* to be equated with didactic teaching. Rather, it refers to including NOS among the cognitive outcomes targeted by instruction. Explicit attention to NOS also entails the provision of ample, structured opportunities for reflection aimed at helping learners develop meta-understandings about the characteristics, development, and validation of scientific knowledge, that is, understandings about NOS. Thus, it was crucial for purposes of the present study to fine-tune the analytical framework so as not only to document whether textbooks addressed NOS, but also to document the ways in which they approached NOS. For example, do textbooks only provide contexts (e.g., historical vignettes) that could potentially help teachers address or students construct more informed understandings about NOS, or do the textbooks increase the likelihood of realizing such a potential by including explicit statements, reflective prompts, or guiding questions relevant to NOS?

Selection of Materials for Analysis

Selection of Textbooks. The researchers sought to base the selection of high school chemistry textbooks on market shares within the United States. As it turned out, accurate or comprehensive figures on textbook market shares is well-guarded information. Publishers are very reluctant to disclose such information. Some indirect information about high school science textbook market shares was available through the *Report of the 2000 national survey of science and mathematics education* (Weiss et al., 2001). The report provided information about the availability and use of instructional resources based on surveying a national probability sample of pre-college science teachers in the United States. Four publishers were found to command up to 82% of the high school science textbook market sales: McGraw-Hill/Merrill (now McGraw Hill/Glencoe/Macmillan) (30%); Holt, Rinehart and Winston (21%); Prentice Hall (now Pearson/Prentice Hall) (18%); and Addison Wesley Longman/Scott Foresman (13%). Surveyed teachers also noted that the most commonly used high school chemistry textbooks were *Addison-Wesley–Chemistry* (Addison Wesley Longman/Scott Foresman), *Chemistry: Connections to our changing world* (Prentice Hall), and *Modern Chemistry* (Holt, Rinehart and Winston). Weiss et al. (2001) did not specify the exact year of publication and/or edition of these latter textbooks.

Information about market share provided one of three criteria used to select textbooks for analysis. The other two were: (1) being adopted by one of the four most populace states that mandate state-level textbook adoption (i.e., California, Texas, Florida, and Georgia), and (2) being part of a ‘‘connected textbook series,’’ which meant several editions of the same textbook, or a set of textbooks with the same title, author(s), and/or produced by the same publisher. First, the search focused on such ‘‘textbook series’’ that met a fourth criterion, namely, spanning the last four decades. Two series met all four criteria: (1) The *Modern Chemistry* series published by Holt, Rinehart and Winston (Davis, Metcalfe, Williams, & Castka, 2002; Metcalfe, Williams, & Castka, 1966, 1982); and (2) Four textbooks published by Holt, Rinehart and Winston (Bolton, Lamphere, Menesini, & Huang, 1973; Myers, Oldham, & Tocci, 2004; Tocci & Viehland, 1996; Toon, Ellis, & Brodkin, 1968). Second, another series that met the three basic criteria but spanned only two decades was also included in the analysis. This series comprised three *ChemCom: Chemistry in the Community* textbooks (American Chemical Society [ACS, 1988, 2002]). Even though the *ChemCom* textbooks do not have a significant market share, they are listed among the state recommended textbooks in two of the most populace states. Finally, two other textbook series that met the three basic criteria but spanned only the last decade were analyzed in order to extend the analysis to the most recent editions of widely used chemistry textbooks. These latter series were: (1) Two *Chemistry concepts and applications* textbooks by Glencoe McGraw-Hill (Phillips, Strozak, & Wistrom, 1997, 2005); and (2) Two *Chemistry* textbooks by the same group of authors (Wilbraham, Staley, Matta, & Waterman, 2005; Wilbraham, Staley, Simpson, & Matta, 1987). It should be noted that the selected textbooks: (1) represented all four publishers who command 82% of the high school science textbooks market share, and (2) included two of the three most widely used high school chemistry textbooks, namely *Addison-Wesley–Chemistry* and *Modern Chemistry* (cf. Weiss et al., 2001).

Selection of Chapters and Sections for Analysis. Analyses focused on chapters or sections that cover ‘‘the scientific method,’’ ‘‘the scientific process,’’ ‘‘how science works,’’ etc. (if any), and topics related to atomic structure, kinetic molecular theory, and gas laws. These materials were selected because of their direct relevance to NOS (e.g., chapter on the ‘‘scientific method’’) and because most high school chemistry textbooks include some historical treatment of the development of atomic theory, and, sometimes, kinetic molecular theory, thus, providing a potential context for addressing some NOS themes. Indeed, these theories and gas laws provide rich contexts for addressing several NOS aspects because they mostly deal with unobservable entities, and derive from an interplay between macro (observable) and micro (unobservable) properties and relationships. Finally, the detailed tables of content and subject indexes of the analyzed textbooks were carefully examined for topics and/or key terms that were relevant to NOS, including: "inference," "laws," "models," "observation," "scientific method," "scientific thinking," "scientific process," "scientific theory," "scientific law," "social," "society," etc. The corresponding sections were then identified and included in the analysis.

Scoring Rubric

A detailed scoring rubric was developed for purposes of this study. The rubric targeted the aforementioned 10 aspects of NOS (see Table 1). Selected materials from a textbook were not analyzed and/or scored independently. All such materials (e.g., chart on the "scientific method" and associated text, narrative on the historical development of atomic structure, sections on the interaction between science and society, or bulleted text, activity boxes, and vignettes relevant to one or more NOS aspects) were carefully read and all NOS aspects addressed in these sections were identified. Next, all references and materials targeting the same NOS aspect were grouped together and examined holistically. In other words, the score assigned to a specific NOS aspect within a textbook was based on an examination of all materials relevant to that aspect within the examined textual materials. Scores were assigned in accordance with the following rubric:

(a) Three points = Explicit, informed, and consistent representation of the target NOS aspect: (i) explicit statements that convey an informed representation, (ii) consistency across the selected chapters or sections in addressing the target NOS aspect, and (iii) consistency in addressing other directly related NOS aspects. For example, to receive a score of "3" for the "tentative NOS," textbook materials should explicitly convey the notion that all categories of scientific knowledge are subject to change. An example of the lack of consistency in this case would be stating that scientific theories are subject to change while emphasizing that scientific laws are "facts" or "truths." Representations of a target NOS aspect *could* include supportive examples, such as accurate historical vignettes or other accurate examples [e.g., "that the sun rises... every day" (Phillips et al., 1997, p. 59) is not an accurate example of a scientific law].
(b) Two points = Explicit, partially informed representation of the target NOS aspect: (i) explicit statements that convey an informed, but incomplete representation, and (ii) consistency across the selected chapters or sections in representing the target NOS aspect. An incomplete representation derives from the textbook materials remaining silent in terms of addressing other related NOS aspects that ensure a complete informed representation. For example, emphasizing the role of observation or evidence in science while remaining silent on other related aspects, such as the theory-driven NOS or the role of interpretation in generating scientific claims, would not constitute a complete and informed representation of the "empirical NOS." Representations of a target NOS aspect *could* include supportive examples, such as accurate historical vignettes or other accurate examples.
(c) One point = Implicit, informed, and consistent representation of the target NOS aspect: (i) an informed representation of the target NOS aspect could be *inferred* from the textbook materials (e.g., relevant explanations, activities, examples, or historical episodes *lacking* structured, reflective prompts or explicit statements), and (ii) absence of other explicit or implicit messages that are inconsistent with the inferred implicit representation.
(d) Zero points = The target NOS aspect is not addressed: (i) no explicit or implicit treatment of the target NOS aspect, or (ii) not enough materials (statements, examples, historical vignettes, etc.) to make an informed judgment or to convey to the textbook reader a sense about the target aspect of NOS one way or the other.
(e) Negative one point = Implicit misrepresentation of the target NOS aspect: a naïve representation could be *inferred* from the textbook materials.
(f) Negative two points = The textbook materials convey mixed explicit and/or implicit messages about the target NOS aspect: (i) implicit, informed representations that could be inferred from some parts of the textbook materials are countered by explicit, naïve statements in other parts, or (ii) explicit statements that convey conflicting messages about the same NOS aspect. For

example, a historical vignette about the development of atomic model, which could convey a sense of the tentativeness of scientific knowledge (the vignette is an ''implicit'' instance because it lacks structured, reflective prompts or explicit statements about this NOS aspect) is countered with an explicit statement, such as: ''Certain facts in science always hold true. Such facts are labeled as scientific laws'' (Tocci & Viehland, 1996, p. 20).

(g) Negative three points = Explicit, naïve representation of the target NOS aspect: explicit statement or statements that clearly communicate a naïve representation of the target NOS aspect, such as, ''A scientific law is simply a fact of nature that is observed so often that it becomes accepted as truth'' (Phillips et al., 2005, p. 59).

Analysis Procedures: Validity and Reliability of the Scoring Rubric

The validity of the rubric stems from its conceptual and empirical grounding. To start with, the NOS framework and aspects targeted by the rubric have been emphasized in current science education reform documents as central to developing functional levels of scientific literacy (e.g., AAAS, 1990; NRC, 1996). Also, the dimensions of the target NOS aspects emphasized in this study (see Table 1) derive from scholarship in the history, philosophy, and sociology of science (Abd-El-Khalick, 1998; Abd-El-Khalick & Lederman, 2000a). What is more, the rubric's focus on the manner (i.e., explicit versus implicit) in which NOS is addressed in the analyzed textbooks is based on results from the aforementioned empirical research studies, which showed a differential positive effect in favor of explicit approaches in impacting learners' NOS views.

Nonetheless, the rubric remains inferential. Some factors and measures, however, ensured its reliable use when analyzing the textbooks. A significant factor was the researchers' expertise both in terms of chemistry content and NOS. All three researchers have taught chemistry at the high school and/or university levels. One researcher holds an MS, and another a PhD degree in chemistry. Also, the second and third authors completed a graduate level course on NOS taught by the first author: the course has been shown to help learners develop deep understandings of the philosophical, historical, and sociological underpinnings of current scholarship on NOS (see Abd-El-Khalick, 2005). Additionally, procedures were undertaken to ensure, and check for, inter-rater reliability when analyzing the textbooks. First, all researchers independently analyzed and scored the same sample of selected textbook materials. Each score was to be supported by direct quotes or descriptions of relevant sections, activities, charts, figures, tables, etc., from the textbooks. Next, the researchers compared and contrasted their scores. Differences resulted in extended discussions that helped refine the scoring rubric and standardize the analysis approach. Second, to check for reliability, the second and third authors independently analyzed all selected textbook materials. This process resulted in a high level of inter-rater agreement at 86%. The remaining differences were resolved by negotiation among the three researchers often by further reference to the textbook materials.

Results and Discussion

Tables 2 and 3 present scores for the 10 target NOS aspects in the analyzed textbooks. The textbooks are sorted by year of publication in Table 2 and by ''series'' and year of publication in Table 3. Table 4 presents quotes and/or examples of activities from the textbooks to illustrate both the use of the scoring rubric and the textbooks' treatment of the target aspects of NOS.

Representations of NOS in the Analyzed Textbooks

In general, the analyzed textbooks did not fare well in their representation of the target aspects of NOS. It should be noted that with 10 NOS aspects being targeted in the analysis, the possible cumulative score for a textbook could range from -30 to $+30$ points. An examination of Table 2 indicates that the cumulative scores for the analyzed textbooks ranged from -7 to $+12$ points, with the overwhelming majority of the textbooks (79%) falling in the range from -7 to $+7$ points. Four of the textbooks (29%) had negative cumulative scores and the remaining 10 (71%) had positive cumulative scores ranging from 3 to 12 points.

First, consistent with prior research findings (Chiappetta et al., 1991; Lumpe & Beck, 1996), the analyzed textbooks accorded little attention to NOS. The narrow range (-7 to $+7$ points) within which the overwhelming majority (79%) of the textbooks fell is reflective of a generalized lack of attention to NOS-related themes. Even the few textbooks that dedicated a whole section or parts of a chapter akin to the

Table 2
Textbook scores on the target aspects of NOS (textbooks sorted by year of publication)

	NOS aspect										
Textbook	Empirical	Inferential	Creative	Theory-driven	Tentative	Scientific method	Theories	Laws	Social aspects	Social, cultural	Total score
Metcalfe et al. (1966)	2	3	2	1	−1	−2	2	2	0	0	9
Toon et al. (1968)	2	1	0	0	3	2	2	2	0	0	12
Bolton et al. (1973)	1	3	2	0	0	−2	1	0	1	0	6
Metcalfe et al. (1982)	2	1	0	0	2	−2	2	2	0	0	7
ACS (1988)	1	2	0	0	1	−1	0	0	0	0	3
Wilbraham et al. (1997)	1	0	0	1	1	−3	3	3	0	0	6
ACS (1993)	1	3	−1	−1	1	−1	2	2	0	0	6
Tocci and Viehland (1996)	2	3	−3	−3	−2	−3	2	−3	1	0	−6
Phillips et al. (1997)	1	0	0	1	−2	−3	3	−3	0	0	−3
Myers et al. (2004)	1	2	−3	−2	−2	−3	2	−3	1	0	−7
Davis et al. (2002)	2	2	0	0	0	−2	2	2	1	0	7
ACS (2002)	1	3	−1	0	0	−1	1	0	1	0	4
Phillips et al. (2005)	1	1	0	1	−2	−3	3	−3	0	1	−1
Wilbraham et al. (2005)	1	1	0	0	1	−3	3	2	2	1	8

Table 3
Textbook scores on the target aspects of NOS (textbooks sorted by series)

Textbook	NOS aspect										Total score
	Empirical	Inferential	Creative	Theory-driven	Tentative	Scientific method	Theories	Laws	Social aspects	Social, cultural	
Metcalfe et al. (1966)	2	3	2	1	−1	−2	2	2	0	0	9
Metcalfe et al. (1982)	2	1	0	0	2	−2	2	2	0	0	7
Davis et al. (2002)	2	2	0	0	0	−2	2	2	1	0	7
Toon et al. (1968)	2	1	0	0	3	2	2	2	0	0	12
Bolton et al. (1973)	1	3	2	0	0	−2	1	0	1	0	6
Tocci and Viehland (1996)	2	3	−3	−3	−2	−3	2	−3	1	0	−6
Myers et al. (2004)	1	2	−3	−2	−2	−3	2	−3	1	0	−7
ACS (1988)	1	2	0	0	1	−1	0	0	0	0	3
ACS (1993)	1	3	−1	−1	1	−1	2	2	0	0	6
ACS (2002)	1	3	−1	0	0	−1	1	0	1	0	4
Phillips et al. (1997)	1	0	0	1	−2	−3	3	−3	0	0	−3
Phillips et al. (2005)	1	1	0	1	−2	−3	3	−3	0	1	−1
Wilbraham et al. (1997)	1	0	0	1	1	−3	3	3	0	0	6
Wilbraham et al. (2005)	1	1	0	0	1	−3	3	2	2	1	8

Table 4
Representative textbook excerpts corresponding to the scores assigned to the target NOS aspects

NOS aspect	Score	Representative quote and/or example
(1) Empirical	2	(1.a) "Testing serves to confirm the validity of scientific concepts" (p. 2). "Once a satisfactory theory is developed, it is tested and retested to establish its validity" (Metcalfe et al., 1982, p. 7). [Silent on the theory-driven and creative NOS.]
	1	(1.b) "Roentgen was working with a cathode ray tube covered with a black paper shield. A glow of light from a piece of paper across the room caught his eye. The paper coated with a fluorescent material, would be expected to glow when exposed to radiation. Roentgen quickly investigated and discovered a new form of radiation that could pass unseen through the black paper" (ACS, 1988, p. 273)
(2) Inferential	3	(2.a) "Most of the data that support the kinetic theory come from indirect observation. It is almost impossible to observe the behavior of individual particles of matter. Even if such observations could be made easily, they would be hard to interpret. Scientists, however, can observe the behavior of large groups of particles. From the results of these observations, they can then describe their average behavior" (Metcalfe et al., 1966, p. 125)
		(2.b) "Man has used indirect methods to describe nature since ancient times... Everyone likes to get to the bottom of things. The easiest way to find out what's hidden within a mysteriously-wrapped gift box is to open it. Suppose you were given a box you could not open. Suppose the box were so small and so well-sealed that your fingers could not tear off the wrappings. You know there is something inside because your senses tell you so... Ever since man has been presented with such a problem package; he has searched for ways to get inside it. This is true for the nature of matter... Today scientists believe in the existence of atoms. Why? No one has ever seen one. The atom is something like the mystery box. We have evidence that atoms exist" (Bolton et al., 1973, p. 4–5)
	2	(2.c) Quick lab: Constructing a Model: "How can you construct a model of an unknown object by (1) making inferences about an object that is in a closed container and (2) touching the object without seeing it" *and* a note in the teacher's wrap around text stating that, "Scientists use both indirect and direct observations to gather data" (Davis et al., 2002, p. 69)
	1	(2.d) "If you open a laboratory gas valve, you can smell the escaping gas. Yet you cannot see gas particles in the air of the room, even if you use the most powerful microscope. These observations and many others like them have led scientists to believe that the basic particles of matter must be very, very small" (Metcalfe et al., 1982, p. 59)
(3) Creative	2	(3.a) "A creative imagination may enable him [the scientist] to develop a plausible explanation and to construct a simple physical or mental model which will relate the observed behavior to familiar and well-understood phenomena" (Metcalfe et al., 1966, p. 4)
		(3.b) "Our idea of the nature of things is based on facts and our imagination" *and* "Observation + Imagination = New Theory" (Bolton et al., 1973)
	−1	(3.c) "Scientists often refer to facts as data. Data are objective pieces of information. They do not include interpretation" (ACS, 1993, p. 36)
	−3	(3.d) "Any conclusion scientists make must come directly and solely from the data they obtain in their experiments" (Tocci and Viehland, 1996, p. 19)
(4) Theory-driven	1	(4.a) "A theory that stands up under scientific testing is a valuable asset to scientists because it stimulates the imagination and serves as a basis for predicting behavior not previously investigated" (Metcalfe et al., 1966, p. 5)
		(4.b) "The hypothesis guides the design of new experiments. At the same time, experiments guide the rejection or refinement of the hypothesis" (Wilbraham et al., 1997, p. 3)
	−1	(4.c) "Scientists often refer to facts as data. Data are objective pieces of information. They do not include interpretation" (ACS, 1993, p. 36)
	−2	(4.d) "Models play a key role in science ... models provide guidelines for research that leads to new knowledge. Models also help simplify and organize phenomena that would otherwise be too complex to understand" (Tocci and Viehland, 1996, p. 20). [This representation of the theory-driven NOS would have received a +2. However, the book received a "−2" on this aspect because it contradicted this very notion by explicitly stating that, "Any conclusion scientists make must come directly and solely from the data they obtain in their experiments" (Tocci and Viehland, 1996, p. 19)]
	−3	(4.e) "Any conclusion scientists make must come directly and solely from the data they obtain in their experiments" (Tocci and Viehland, 1996, p. 19)

(*Continued*)

Table 4
(*Continued*)

NOS aspect	Score	Representative quote and/or example
(5) Tentative	3	(5.a) ‘‘Even today, after a number of modifications, our model of the atom continues to undergo constant change as new evidence accumulates and new theories are developed. However, no matter how detailed a model of the atom becomes, it can never depict the true structure of the atom. It is important to avoid falling into the trap of taking models too literally. You must bear in mind their limitations and remember that all of them fall short of reality’’ (Toon et al., 1968, p. 7)
	2	(5.b) ‘‘If, over a long time experimental evidence supports an explanation, it is accepted as valid. If even one observation does not follow the behavior predicted, however, the explanation is no longer valid and must be revised or discarded. Explanations and models are never certain, and scientists must learn to accept and work with a degree of uncertainty’’ (Metcalfe et al., 1982, p. 2–3)
	1	(5.c) ‘‘As often happens in science, a new discovery toppled an old theory. Before the discovery of radioactivity, it was believed that the atom was the smallest, most fundamental unit of matter. After alpha, beta, and gamma rays were identified, scientists were convinced that atoms must be composed of still smaller particles’’ (p. 274–275) *and* ‘‘Since Rutherford’s time, our understanding of the structure of atoms has expanded and in some ways changed. We now know from later research that, although useful, the idea of orbiting electrons is too simplified... Rutherford’s image of a central, massive nucleus surrounded mostly by empty space is still accepted’’ (ACS, 1988, p. 278)
	−1	(5.d) ‘‘In science, a theory is never secure. Each new observation tests it. If the theory does not explain the new observation satisfactorily, the theory is either rejected or revised’’ (Metcalfe et al., 1982, p. 60)
	−2	(5.e) ‘‘Models, like theories, are refined as new information is discovered’’ (p. 20) *and* ‘‘Certain facts in science always hold true. Such facts are labeled as scientific laws’’ (Tocci and Viehland, 1996, p. 20)
(6) ‘‘Scientific Method’’	2	(6.a) ‘‘You should try to develop the characteristics and attitudes and to adopt the techniques of professional scientists, some of which are listed below. (1) Possession of an inquiring mind. (2) Accuracy of observations. (3) Recording of data in a thorough, neat, and organized fashion. (4) Alertness to the recognition of the unexpected. (5) Willingness to reject old ideas and to accept new ones when sufficient data warrants it. (6) Awareness of the tendency to make generalizations on the basis of insufficient data’’ (Toon et al., 1968, p. 10)
	−1	(6.b) ‘‘The activities you have just completed (gathering data, seeking patterns or regularities among the data, suggesting reasons that attempt to account for the data) are typical of approaches used by scientists when they attempt to solve problems. Such scientific methods are based on a combination of systematic, step-by-step procedures and logic, as well as occasional hunches and guesses’’ (ACS, 1988, p. 33)
	−2	(6.c) ‘‘Thinking clearly through problems and testing the decisions are what the scientific method is all about... Why think? Why not act? This is a very logical question. We can go on to ask, ‘‘Why didn’t the early chemists abandon their wrong beliefs and see the plain truth?’’ (Truths, of course, are only plain when they are known.) The important thing is not what the ancient chemists thought. They often came up with wrong answers. The important thing is, that they thought. Now we can use their ideas and test them. You will never find an answer unless you think and research. Even a wrong answer may be a step toward the solution’’ (Bolton et al., 1973) [versus a linear representation of the steps of the scientific method (p. 11)]
	−3	(6.d) ‘‘The way scientists carry out experiments or investigations is referred to as the scientific method. The scientific method is a logical approach to exploring a problem or question that has been raised through observation. In addition, this approach is designed to produce a solution or answer that can be tested, retested, and supported by experimentation. Although different representations are used to describe the scientific method, it consists of the fundamental activities outlined to the left... there is a sequence of events that leads to the formation of a conclusion... [i.e., observe → hypothesize → experiment → evaluate data → state conclusions]’’ (Tocci and Viehland, 1996, pp. 16–17)

Table 4
(*Continued*)

NOS aspect	Score	Representative quote and/or example
		(6.e) "Like all scientists, the biochemist shown in Figure 1.18 is using the scientific method to solve difficult problems. The scientific method is a logical, systematic approach to the solution of a scientific problem. Steps in the scientific method include making observations, testing hypotheses, and developing theories" (Wilbraham et al., 2005, p. 22)
(7) Nature of theories	3	(7.a) "In nonscientific speech and writing, the word theory is often used to mean an unsupported notion about something. As you can see, a scientific theory is heavily supported by evidence gained from experiments and continual observations... Scientists develop theories to organize their knowledge. A theory is an explanation based on many observations and supported by the results of many experiments" (Phillips et al., 1997, p. 59)
		(7.b) "A theory is a thoroughly tested model that explains why experiments give certain results. A theory can never be proved. Nevertheless, theories are very useful because they help us to form mental pictures of objects or processes that cannot be seen. Moreover they give us the power to predict the behavior of natural systems under circumstances that are different from those of the original observations" (Wilbraham et al., 1997, p. 3)
	2	(7.c) "A plausible explanation of an observed natural phenomenon in terms of a simple model which has familiar properties is called a theory" (Metcalfe et al., 1966, p. 4)
		(7.d) "A theory is a group of postulates or assumptions which are advanced to explain the nature and behavior of a system" (Toon et al., 1968, p. 6)
		(7.e) "Scientific laws describe the behavior (the "what") of nature, but do not provide explanations (the "why"). Scientific theories and models address "why" and "how" aspects of our natural world" (ACS, 1993, p. 366)
	1	(7.f) "Let's see how Dalton applied his theory to account for the Law of Conservation of Mass... One of the important parts of a new theory is that it can predict a new situation" (Bolton et al., 1973, pp. 6–7)
(8) Nature of laws	3	(8.a) "A scientific law is a concise statement that summarizes the results of a broad variety of observations and experiments. A scientific law is different from a theory in that it only describes a natural phenomenon. It does not attempt to explain it. Scientific laws can often be expressed by simple mathematical relationships. They usually concern natural behaviors that are not immediately obvious" (Wilbraham et al., 1997, p. 3)
	2	(8.b) "The generalizations which describe behavior in nature are called laws or principles. Natural laws tell us what relations do occur in nature; they do not tell us what relations must occur" (Metcalfe et al., 1966, p. 3)
		"Scientific laws describe the behavior (the "what") of nature, but do not provide the explanations (the "why"). Scientific theories and models address "why" and "how" aspects of our natural world" (ACS, 1993, p. 366)
	−3	(8.c) "Certain facts in science always hold true. Such facts are labeled as scientific laws. A scientific law is a statement or mathematical expression of some consistency about the behavior of the natural world" (e.g., Newton's laws) (Tocci and Viehland, 1996, p. 20)
		(8.d) "A scientific law is simply a fact of nature that is observed so often that it becomes accepted as truth. The sun rises in the east each morning is a law of nature because people see that it is true every day" (Phillips et al., 1997, p. 59)
(9) Social aspects of scientific enterprise	1	(9.a) "Rutherford, assembled a research team to perform an experiment" (p. 16); discussion of publishing and peer reviewing (p. 19); "Collaboration between scientists is common in the search for new information" (p. 20); "Scientists communicate their findings through published accounts in scientific journals" (p. 86) (Tocci and Viehland, 1996)
(10) Social and cultural embeddedness	2	(10.a) Wilbraham et al. (2005) discuss how funding can influence the direction of research and how social debates determine what gets funding

"scientific process" or "how science works" failed to present well rounded or coherent treatments of key aspects of NOS. At best, relatively few, disparate references to certain aspects of NOS were dispersed throughout the analyzed materials. Mostly, the types of textual materials that conveyed implicit or explicit messages about NOS were in the form of statements and, to a much lesser extent, figures or charts (e.g., charts of the steps of the ''Scientific Method''). With the exception of the rare ''black-box'' activity, nearly no activities, questions, or reflective prompts focused on NOS. Indeed, textbook scores indicate that NOS was never a central theme, major topic, or persistent thread in any of these textbooks: The presentation of NOS aspects lacked an overarching consistent framework. The centrality of NOS as a major organizing theme for pre-college science education as emphasized by national reform documents (e.g., AAAS, 1990; NRC, 1996) was not evident in the textbooks. The latest editions of the most widely used textbooks (cf. Weiss et al., 2001) received a score of +7 (Davis et al., 2002) and +6 (Wilbraham, Staley, & Matta, 1997) out of +30 possible points for the target NOS aspects.

Second, an examination of Table 2 indicates that none of the analyzed textbooks attended to (accurately or otherwise) all target aspects of NOS. For instance, the first *ChemCom* textbook in the series (ACS, 1988) had no materials that addressed, implicitly or explicitly, 6 of the 10 target NOS aspects. Even the textbook with the highest cumulative score (Toon et al., 1968; +12 points) remained silent on 4 of these 10 NOS aspects. Indeed, some NOS aspects were rarely addressed in the analyzed textbooks. In particular, the social and cultural embeddedness of science and social aspects of the scientific enterprise were not addressed in 86% and 57% of the analyzed textbooks, respectively. The social aspects of science were addressed mostly through implicit references to the collaborative nature of scientific research, the peer review process, or the need for constant communication between scientists (e.g., Tocci & Viehland, 1996). The epistemic importance of these social practices was highlighted in only one of the six textbooks that addressed this aspect of NOS through a discussion of peer reviewing (Wilbraham et al., 2005). Similarly, the theory-driven NOS was not addressed or inadequately addressed in 71% of the analyzed textbooks. Implicit and informed references to this NOS aspect were evident in four of the analyzed textbooks (29%) (see Table 2). For instance, Wilbraham et al. (1997) noted, ''The hypothesis guides the design of new experiments'' (p. 3). In comparison, two textbooks provided explicit and naïve representations of this NOS aspect (see illustrative quote [4.e] in Table 4).

Most disturbing was the fact that, with one exception (Toon et al., 1968), all analyzed textbooks scored a −3 or −2 with regards to the diehard myth of the ''Scientific Method.'' It seems that a step-wise, single, procedural, and/or universal ''Scientific Method'' continues to thrive and be championed in high school science textbooks despite longstanding and continuous debunking of this myth (AAAS, 1990; Bauer, 1994; Feyerabend, 1993; Shapin, 1996) (see [6.d] in Table 4). In comparison, Toon et al. (1968), which was the *only* textbook that provided more informed views of this NOS aspect, emphasized certain attitudes and habits of mind that typify scientists' work rather than detailing a prescribed way for ''doing science'' (see [6.a] in Table 4).

Third, the analyzed textbooks did better in terms of addressing the inferential and empirical NOS, as well as the explanatory, predictive, and well-supported nature of scientific theories. To start with, the analyzed textbooks did relatively better regarding the inferential NOS (see Table 2). While two textbooks remained silent on the inferential NOS, four (29%) addressed this aspect implicitly, and the remaining eight (57%) addressed it in explicit and consistent ways. Five textbooks received the maximum score of +3 for approaching this NOS aspect through providing well articulated explanations and discussions (see [2.b] in Table 4). Table 2 also indicates that all textbooks adequately addressed the empirical NOS. A majority of the textbooks (64%) did this through implicit messages and the remaining textbooks (36%) made explicit references about the empirical NOS. For instance, Metcalfe et al. (1982) noted that, ''Testing serves to confirm the validity of scientific concepts'' (p. 2), and ''Once a satisfactory theory is developed, it is tested and retested to establish its validity'' (p. 7). What is noteworthy in this and similar statements was the careful choice of terminology by making references to ''establishing the validity'' of scientific claims as compared to the often used naïve notions of ''proving'' scientific claims through repeated testing. Nonetheless, as could be noted from Table 2, none of the textbooks received a score of +3 with regards to the empirical NOS because an informed representation of this aspect entails addressing the theory-driven NOS. Learners' need to appreciate that empirical evidence gains its significance (e.g., confirming or weakening claims to scientific knowledge) in light of the theories used to interpret such evidence. As explicated in the scoring rubric, the five textbooks with explicit and informed references to the empirical NOS received a score of +2 because they either remained silent on, or explicitly misrepresented, the theory-driven NOS.

Additionally, most of the textbooks (79%) conveyed explicit and informed messages about the nature of theories albeit to different extents (see Table 2). Seven of these latter textbooks received a score of +2 for an explicitly informed but partial representation of the nature of theories. Three additional textbooks scored a +3 in this regard as they explicitly highlighted three key aspects of scientific theories. The three textbooks clearly highlighted that a scientific theory is not an ‘‘unsupported notion about something’’ but, rather, highly supported with experimental and/or observational evidence. The explanatory and predictive nature of theories, and the fact that theories cannot be ‘‘proved’’ were also stressed (see [7.a] and [7.b] in Table 4).

Fourth, textbook treatment of the nature of laws, and creative and tentative NOS were mixed, but leaned more toward naïve than informed views. Half of the textbooks either did not address (21%) or inadequately addressed (29%) the nature of laws. The latter four textbooks scored a −3 (see Table 2) for explicitly equating laws with ‘‘facts’’ or attributing ‘‘certainty’’ to them (see [8.d] in Table 4). It is noteworthy that in this latter case (Phillips et al., 1997) the very example touted as an exemplar (i.e., ‘‘the sun rises in the east each morning’’) is simply not a scientific law. Yet, the textbook authors’ very choice of this example represents a pre-dominant and widely held misconception about the nature of laws. Also, by bestowing the status of ‘‘truth’’ and/or ‘‘certainty’’ on scientific laws, the textbooks automatically undermine their representation of the tentative NOS. Wilbraham et al. (1997) provided a fairly complete and informed view in this regard emphasizing the descriptive nature of laws as concise and often mathematical summaries of non-obvious relationships between natural phenomena (see [8.a] in Table 4). This textbook received a +3 for this NOS aspect because it made implicit references to the tentative nature of various types of scientific knowledge and no explicit statement to the contrary.

While eight textbooks (57%) made no implicit or explicit references to the creative NOS, four (29%) explicitly conveyed naïve messages about this aspect (see [3.d] in Table 4). Only two textbooks scored a +2 for making explicit but inconsistent references to the creative NOS (see [3.a] in Table 4). The latter two textbooks did not score a +3 because both provided inconsistent messages about the creative NOS by stating that all scientists follow a universal ‘‘Scientific Method,’’ which necessarily detracts from the role of creativity in scientific investigations in the sense of developing theories, models, or ideas. Finally, a majority of textbooks (57%) either did not address or inadequately addressed the tentative NOS mostly by emphasizing—without qualification—that certain types of scientific knowledge, namely, laws, are ‘‘true’’ or ‘‘certain’’ (see Table 2). Only a single textbook (Toon et al., 1968) presented a rather sophisticated and informed treatment of the tentative NOS (see [5.a] in Table 4). This latter textbook, it should be noted, also provided informed representation of scientific laws (see Table 2).

Changes in Representations of NOS During the Past Four Decades

Table 2 lists the analyzed textbooks by date of publication. Examining the last column in this table reveals a most disconcerting pattern in the data: with a single exception (Wilbraham et al., 2005), the cumulative scores for the textbooks seem to have decreased over the past four decades. Indeed, textbooks published in the late 1960s (Metcalfe et al., 1966; Toon et al., 1968) had the highest of all cumulative scores. Similarly, the textbooks published between 1966 and 1982 had either higher or equal scores compared to those published after 1982. Negative cumulative scores also were evident in the case of textbooks published after the mid 1990s. With the exception of the inferential NOS, this pattern was also evident in the case of the individual 10 aspects of NOS, where scores either decreased or did not increase over the past four decades.

The same applies in the case of the two connected series that spanned the past four decades. As evident in Table 3, the scores for the first series written by Metcalfe and colleagues (Davis et al., 2002; Metcalfe et al., 1966, 1982) decreased slightly from +9 to +7. For the second series of textbooks published by Holt, Rinehart and Winston (Bolton et al., 1973; Myers et al., 2004; Tocci & Viehland, 1996; Toon et al., 1968), the cumulative scores deceased by 19 points from +12 to −7 over the course of the past four decades.

This pattern is especially disconcerting given that the strongest and most widely publicized push for emphasizing NOS in pre-college science education came about in the early to mid 1990s (AAAS, 1990; NRC, 1996). It is clear that the initially meager attention accorded to NOS in the analyzed textbooks did not increase during the past two decades in response to national reform documents. To the contrary, in many cases, the textbooks not only failed to increase their attention to NOS, they also represented key aspects of NOS in ways that are inconsistent with current NOS views as articulated in such reform documents. In other words, treatment of NOS in the analyzed textbooks seemed to run counter to the intent and discourse of these reforms.

Table 3, which lists the analyzed textbooks chronologically within their ‘‘series,’’ suggests a strong ‘‘author effect’’ as compared to a ‘‘publisher effect’’ in terms of addressing NOS. It could be seen, for instance, that the cumulative scores for the Metcalfe and colleagues series that spans 34 years (Davis et al., 2002; Metcalfe et al., 1966, 1982) changed by only two points (from +9 to +7). Indeed, scores in the case of five NOS aspects remained unchanged over this time period, with only small changes in the scores for the remaining five aspects (excepting the creative NOS, whose initial informed treatment was dropped). The same applies to the other two series. The cumulative scores for Phillips et al. (1997, 2005) increased from −3 to −1 with scores for 8 of the 10 target NOS aspects remaining unchanged. Likewise, the cumulative scores for the textbooks by Wilbraham et al. (1997, 2005) increased from +6 to +8 with scores for 5 of the 10 target aspects unchanged over the course of 15 years.

In comparison, the scores for the four textbooks published by Holt, Rinehart and Winston by various authors over the course of 32 years (Bolton et al., 1973; Myers et al., 2004; Tocci & Viehland, 1996; Toon et al., 1968) decreased from +12 to −7 points over that time period corresponding to changes in the ways different authors addressed NOS (see Table 3). Finally, the ‘‘author effect’’ also shows in the case of the *ChemCom* textbook series (ACS, 1988, 1993, 2002). This series is somewhat different in the sense that the ACS is listed as ‘‘author’’ for the textbooks. Even though a board of contributors is often involved in authoring these textbooks, none are listed as authors or editors. In the case of this series, the ACS seems to maintain a consistent philosophy and student-centered, activity-based, and issued-oriented focus for the *ChemCom* textbooks. However, a focus on NOS is not necessarily a major theme in the *ChemCom* series.

A strong ‘‘author effect’’ could be expected. After all, authors are much more likely to impact the content of textbooks—including the treatment of NOS or lack thereof—than publishers. The latter would probably accord priority to the marketability of the produced textbook than to its content. What is disconcerting about this finding, however, is the fact that the authors of the analyzed textbooks series seem to ascribe to certain views of NOS and ‘‘stick to them,’’ even over the course of several decades (e.g., Metcalfe and his colleagues). Authors seem to be totally dissociated both from the discourse of national and international reform documents in science education, as well as from advances in philosophical, historical, and sociological scholarship and thinking about the nature of the scientific enterprise.

Consistency of the Observed Changes with Current Scholarship About NOS

Certainly much has happened in the fields of history, philosophy, and sociology of science since the early 1960s. The 1960s marked the beginnings of post-Kuhnian approaches to HPS and the legitimization of sociological approaches to studying science. A decade or so later also witnessed the launching of the science studies program. To be sure, changes in these scholarly fields brought about numerous changes in thinking about NOS (see Abd-El-Khalick & Lederman, 2000a). An examination of Tables 2 and 3, however, indicate that very little change had occurred in the way the analyzed textbooks addressed NOS in the past four decades, or that the observed changes were incommensurate with changes in scholarship about NOS. A few examples would suffice to support this claim. The first is the unwavering emphasis given to the mythical ‘‘Scientific Method.’’ With a single exception in one of the oldest of the analyzed textbooks (i.e., Toon et al., 1968), these textbooks continued to explicitly convey naïve representations of this NOS aspect. Additionally, while our understanding of the theory-driven, social aspects of the scientific enterprise, and social and cultural embeddedness of science had witnessed significant development over the past four decades; these aspects continue to either be misrepresented or, at best, neglected in the analyzed textbooks. The mutually exclusive development between science education and HPS that spanned the 1960s, 1970s, and 1980s (Duschl, 1985) seem to continue, uninterrupted into the present times.

Implications and Recommendations

Despite the continuing discourse and efforts associated with science education reforms (e.g., AAAS, 1990; NCERD, 1997; NRC, 1996), research indicates—as has been the case for the past 40 years—that a majority of pre-college students continue to harbor naïve views about some important aspects of NOS (e.g., Abd-El-Khalick & BouJaoude, 2003; Bora & Cakiroglu, 2006). Simply put, most pre-college science teachers have not been instructionally addressing, and continue to not address, NOS in accurate, consistent, and effective ways. Several factors underlie this state of affairs. First and foremost is the fact that most science teachers do not have the necessary requisite understandings about NOS (Abd-El-Khalick & Lederman, 2000a,b). Toward addressing this factor, concerted pedagogical, curricular, and professional development efforts continue to be aimed at improving pre-service and inservice teachers' NOS conceptions. These efforts are largely focused within the context of pre-service science methods courses and inservice training programs (e.g., Abd-El-Khalick, 2001, 2005; Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick et al., 1998; Akerson et al., 2000; Bianchini & Colburn, 2000). However, research shows that while understandings about NOS are necessary for addressing NOS instructionally, they are simply insufficient (Abd-El-Khalick & Lederman, 2000a). Thus, a second factor that needed attention was facilitating the translation of teachers' acquired NOS understandings into instructional practices, which turned out to be a substantial challenge. Several issues were found to mediate such translation, including teachers' confidence in their understandings about NOS; the importance that teachers' accord to NOS-related as compared to other instructional outcomes; teachers' perceptions of their students' interest in, and ability to internalize, ideas about NOS; and other situational and contextual aspects that impact classroom instruction (Abd-El-Khalick et al., 1998; Lederman, 1999). To address this second factor, some research efforts have focused on providing teachers with the support and scaffolding needed to address NOS instructionally (e.g., Akerson & Abd-El-Khalick, 2003). The third major factor relates to the question of how best to approach teaching about NOS in science classrooms. Again, this question is the subject of much continuing research dedicated to the development and testing of pedagogical approaches aimed to improving students' views of NOS (e.g., Bell, Blair, Crawford, & Lederman, 2003; Solomon, Duveen, Scot, & McCarthy, 1992). In this regard, evidence suggests that explicit attention to NOS within classrooms, that is, incorporating explicit NOS instructional outcomes in the science curriculum and according instructional attention to these outcomes, is needed to make headway (Khishfe & Abd-El-Khalick, 2002).

This study provides evidence that a fourth, crucial dimension warrants close attention. The present results indicate that efforts aimed at enhancing pre-college students' NOS views need to direct serious attention to the representation and treatment of NOS in commercial textbooks. This need is based on the well-documented and significant impact that science textbooks have on teaching and learning in the majority of classrooms (Chiappetta et al., 2006; Weiss et al., 2001). As noted earlier, most likely to the dislike of science education researchers, the reality is such that textbooks determine student experiences with school science to a large extent (Valverde et al., 2002). Textbooks also embody the curriculum and set priorities for classroom teachers. The present results show that NOS was not a consistent thread, let alone a central or organizing theme, in the analyzed textbooks. At best, a few implicit and explicit messages about NOS were dispersed throughout the analyzed materials. These messages lacked a coherent or overarching framework. More important was the fact that many of these messages were propagating naïve views, which are inconsistent with current scholarship on NOS. Another troubling aspect of the findings is that representations of NOS in the analyzed textbooks remained either unchanged or actually got "worse" over the course of the past four decades. This finding suggests a complete disconnect between the authors and industry involved with publishing commercial textbooks and both the discourse of reform efforts and advances in philosophical, historical, and sociological studies of science. While similar analyses of widely used commercial science textbooks in other disciplinary contexts (biology, physics, etc.) are highly desirable and needed, there is little reason to suspect that the treatment of NOS in such textbooks would be substantially different.

Form a practical perspective, the present findings should leave little wonder about why teachers do not accord instructional priority to addressing, or why pre-college students continue to harbor naïve views about, NOS. After all, the lack of attention to, and naïve messages about NOS, are enacted and encoded *in* the textbooks. Thus, it is crucial to find ways to reverse this pattern. Realizing such change, that is, making informed representations of NOS central and explicitly-targeted themes in commercial science textbooks, would go a long way toward achieving the reforms vision related NOS. To start with, NOS would automatically become a priority for science teachers. Researchers have often noted that it is not clear how to get science teachers to internalize the importance of teaching about NOS (Abd-El-Khalick & Akerson, 2004). This impeding factor is likely to disappear when textbooks accord due attention to NOS. What is more, in this case, teachers are more likely to actively seek professional development related to teaching about NOS, which becomes a topic they need to contend with as they do with other challenging science content. Science education researchers can respond to this professional development need because, as noted above, ample research has been dedicated to this domain. Thus, the question becomes, ‘‘How could substantial changes be brought about to the ways that NOS is represented in widely used commercial science textbooks?’’

The AAAS has long realized that this is a question about changing the mindset of authors and publishers about textbook content as it relates to the very marketability of the textbooks (e.g., Stern & Roseman, 2004). Such reasoning has motivated the above noted efforts by the AAAS to meticulously analyze the fit between the content of commercial textbooks and national science education benchmarks (e.g., AAAS, 1993) and widely publicize the results (mostly about the lack of such fit) among teachers. The primary author was involved with some of the first AAAS textbook analyses focused on NOS more than a decade ago. This study shows that, as of yet, these indirect efforts did not bring about the desired changes in relation to NOS. The difficulties associated with bringing about such change are understandable. The textbook industry is a multi-billion dollar industry with all the characteristic inertias associated with ‘‘big businesses’’ when it comes to change, re-tooling, and major re-investment. Indeed, the industry is so huge that some of the ‘‘best’’ science textbooks often developed through funding from the National Science Foundation, continue to have a minute share, if any, of the textbook market.

How then can we effect change in commercial science textbooks with regards to ‘‘better’’ treatments of NOS? We admit that a viable approach is not necessarily obvious. One possible way would be to make use of another well-understood dimension of the reality of classrooms: the priority of assessment and evaluation. A large number of states in the United States now mandate high-stakes tests at various stages of the school educational ladder. These evaluations are taken very seriously by school districts and teachers alike because school funding often depends on school performance on such tests, especially in the era of the *No Child Left Behind Act* of 2001. (This approach is also valid in several other countries, especially those with national curricula and evaluations.) Science educators could focus on analyzing ways in which NOS is assessed on state-wide tests and widely publicize such analyses with the hope of impacting (and most likely improving) the very content and approach of such assessments. Similar to the AAAS approach, the ultimate aim of such analyses would be to command the attention of textbook publishers and, hopefully, effect changes in the demands that publishers put on their authors in terms of crucial priorities for these textbooks. These efforts, it should be noted, need to focus on local and state assessments and evaluations, because the attention accorded to NOS in large scale assessments, such as the National Assessment of Educational Progress (NAEP), do not seem to substantially impact the nature and emphases of classroom science instruction. A possible explanation for this latter observation is that national assessments, such as NAEP, remain distal from science classrooms and somewhat reserved to discussions of large-scale policy issues.

Another approach would be to focus on textbook authors. The present findings point to a strong ‘‘author effect’’ as compared to a ‘‘publisher effect’’ when it comes to addressing NOS in the analyzed textbooks. Science educators could approach textbook authors with well-formulated and documented arguments as to changes in our understandings about NOS and the need to align their treatments of NOS with such understandings. As could be seen, while both of the above suggestions entail significant research activities, they also require science educators to be involved in advocacy work at the levels of school district and state policy makers largely because of the practical nature of the target task, namely, impacting the very content of science textbooks.

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