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30

Research on Teaching and Learning of Nature of Science

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Introduction

The purpose of this chapter is to update new advances in the research on the teaching and learning of nature of science since the previous *Handbook of Research on Science Education* (Abell & Lederman, 2007). As this is a new volume, the previous handbook will remain in print, and so a complete recapitulation of what was published previously is not necessary. However, some review of research considered in the previous handbook is needed to provide some context for the more recent work. Consequently, reference to some of the more influential studies and findings reported in the previous handbook chapter will be referenced, but an attempt is made not to reprint all that can be found in the first handbook. More than 7 years have passed, and it is debatable if anything new has been revealed relative to nature of science (NOS). One could say that there is more than 7 years of new research. On the other hand, little new about how students learn NOS or how it is best taught has been revealed. However, research on NOS does continue to be a vibrant area of concern. Alternatively, there has been much written that attempts to reconceptualize how NOS is viewed. Indeed, some of this reconceptualization can be found in the Next Generation Science Standards in the United States (NGSS Lead States, 2013), but how well this newly advocated view is consistent with the existing empirical research certainly warrants discussion. That said, this chapter will be organized around a conceptualization of the construct "nature of science" and how it is taught, learned, and assessed. In addition, there will be a discussion of recent trends regarding thinking about nature of science and how these trends may or may not help improve students' and teachers' understandings of nature of science.

Conceptualizing the Construct

The construct "nature of science" (NOS) has been advocated as an important goal for students studying science for more than 100 years and has continued to be advocated as a critical educational outcome by various science education reform documents worldwide (e.g., Australia, Canada, China, New Zealand, South Africa, United Kingdom, and the United States, among others). When it comes to NOS, one is hard pressed to find rhetoric arguing against its importance as an educational outcome.

Volumes have been written arguing why NOS is an important educational objective. Simply put, understanding NOS is often defended as being a critical component of scientific literacy (Lederman & Lederman, 2011; NGSS Lead States, 2013; NSTA, 1982). For more elaborated rationales, the reader is referred to Driver, Leach, Millar, and Scott (1996) and Lederman (2007).

However, at this point, the arguments supporting NOS as an important educational outcome are primarily intuitive with little empirical support. Much like the general goal of scientific literacy, until we reach a critical mass of individuals who possess adequate understandings of NOS, we have no way of knowing whether achievement of the goal has accomplished what has been assumed. Still, students' and teachers' understandings of NOS remain a high priority for science education and science education research. As mentioned before, it has been an objective in science education (American Association for the Advancement of Science [AAAS], 1990, 1993; Klopfer, 1969; National Research Council [NRC], 1996, 2012; National Science Teachers Association [NSTA], 1982) for more than 100 years (Kimball, 1967–1968; Lederman, 1992, 2007).

With all the support NOS has in the science education and scientific community, one would assume that all stakeholders possess adequate understandings of the construct. Even though explicit statements about the meaning of NOS are provided in well-known reform documents (e.g., NRC, 1996), the pages of refereed journals and conference rooms at professional meetings are filled with a wide variety of definitions. Some would argue that the situation is direct support for the idea that there is NO agreement on the meaning of NOS and that the construct should be reconceptualized (Irzik & Nola, 2011). Others (Lederman, 1998; Lederman, Antink, & Bartos, 2014) are quick to note that the disagreements about the definition or meaning of NOS that continue to exist among philosophers, historians, and science educators are developmentally irrelevant to K–12 instruction. The issue of the existence of an objective reality as compared to phenomenal realities is a case in point. There is an acceptable level of generality regarding NOS that is accessible to K–12 students and relevant to their daily lives that can be found in the writings of the aforementioned authors and current reform documents. Moreover, at this level, little disagreement exists among philosophers, historians, and science educators. It is critically important that we not lose sight of the audience for which NOS learning outcomes are designed—that is, K–12 students. Furthermore, arguments about what characteristics of scientific knowledge should be included under the rubric of NOS tend to lose sight of the overarching purpose of these goals. It is not important what definitively constitutes NOS, but rather whether we consider what is being specified for students to know and do are considered important for the intended audience (Lederman, Bartos, & Lederman, 2014; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003).

Among the characteristics of scientific knowledge corresponding to this level of generality are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences and the functions of and relationships between scientific theories and laws. For a more detailed discussion of the aspects of NOS just mentioned, the reader is referred to Lederman (2007).

It is important to note that the aspects of NOS mentioned here are not meant as a comprehensive listing. There are other aspects that some researchers or reform documents include or delete (Abd-El-Khalick, Bell, & Lederman, 1998; Irzik & Nola, 2011; McComas, 2008; NGSS Lead States, 2013; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Scharmann & Smith, 1999). Any of these lists that consider what students can learn, in addition to a consideration of the characteristics of scientific knowledge, are of equal validity. Again, there is no definitive listing of the aspects of nature of science. The primary purpose here is not to emphasize one listing of aspects versus another, but to provide a frame of reference that helps delineate NOS from scientific inquiry/practices and processes of science.

At this point, it is important to note that there is an intuitive assumption held by many science educators that NOS is not a unitary construct across science disciplines. That is, biologists, chemists, physicists, and scientists from other disciplines would have different conceptions of NOS. This is an area in which the assumption has really not been tested. However, one study does exist (Schwartz & Lederman, 2008). The subjects were 24 practicing scientists representing chemistry, life science, physics, and earth/space science. These individuals also represented a broad spectrum of research approaches (i.e., experimental, descriptive, and theoretical). Data were collected by open-ended questionnaires for NOS and scientific inquiry. Qualitative comparisons were made within disciplines and across disciplines. Although there were many differences related to nuances of research design depending on the context of an investigation, there were generally no differences in views of inquiry or NOS at the level of generality used in schools. The authors concluded that there is no need to approach NOS differently for each science discipline given the level of sophistication of K–12 students and the reality of curriculum constraints.

Finally, it is important to note that individuals often conflate NOS with science practices and/or scientific inquiry. Although these aspects of science overlap and interact in important ways, it is nonetheless important to distinguish the two. Scientific processes are activities related to collecting and analyzing data and drawing conclusions (AAAS, 1990, 1993; NRC, 1996). Certainly, both constructs are important, and inquiry and NOS, although different, are intimately related. Making a distinction between NOS and scientific inquiry is in no way meant to imply that the two constructs are distinct. Clearly they are intimately related.

Conceptualization Aside, Murkiness Remains

The conflation of NOS and scientific inquiry has plagued research on NOS from the beginning. Hence, the reader will note that many of the earlier studies (and even continuing to the present) are actually more focused on inquiry than on NOS. These studies are nevertheless included in this review since they have become an accepted part of the history of research on NOS. The definition used by these older studies for NOS is just not consistent with current usage of the construct. Again, the aspects of NOS presented here are not meant to be exhaustive. However, what is presented is directly consistent with what current reform documents state students should know about NOS and is consistent with the perspective taken by an overwhelming majority of the research literature. Still, it is important to note that one of the problems with some of the recent research and rhetoric on NOS is a return to the conflation of NOS and scientific inquiry (Allchin, 2011; NGSS Lead States, 2013). In the case of the latter, "scientific practices" has replaced what was formally called scientific inquiry.

The evolution of the "definition" of nature of science may provide a partial explanation for the continued murkiness created by some sectors of the research community. In the 1970s and early 1980s, the construct was labeled "nature of scientific knowledge." Toward the end of the 1980s the phrase was shortened to "nature of science" (probably at least partially N. G. Lederman's fault). Perhaps this change in wording has contributed somewhat to the continuing conflation of nature of science and scientific inquiry (Lederman, 2013). But as we all know, humans often do not learn from history. Matters remain confusing with the introduction of any new term such as "scientific practices" as a replacement for "scientific inquiry" within the Next Generation Science Standards (NGSS Lead States, 2013), and nature of science, unfortunately, is considered to fall at least partially under the label of scientific practices. Indeed, the relationship of NOS and scientific inquiry has been schizophrenic over the years. Within Project 2061 (AAAS, 1993), NOS is considered to be an overarching label, which includes scientific inquiry, while in the National Science Education Standards (NRC, 1996), NOS and scientific inquiry are considered to be separate, albeit related, categories of standards. Interestingly, the Next Generation Science Standards (NGSS Lead States, 2013) have placed NOS as a subset of the overarching category of scientific practices (formally scientific inquiry). So, within a time span of 20 years, we have totally reversed the relationship of NOS and scientific inquiry. This situation certainly has not helped clear the waters. In general, NOS has typically referred to characteristics of scientific knowledge that necessarily derived from the way the knowledge is constructed (i.e., scientific inquiry/practices). One performs and engages in scientific practices, but one does not "do" NOS. NOS itself can be a moving target. Perceptions of NOS have changed significantly over the past 30 years and, as a consequence, some individuals have dwelled too heavily on such differing perceptions as well as the differences in perceptions between science educators and scientists (e.g., Alters, 1997; Wong & Hodson, 2009, 2010). The recognition that our views of NOS have changed and will continue to change is not a justification for ceasing our research until total agreement is reached, or for avoiding recommendations or identifying what we think students should know. We have no difficulty including certain theories and laws within our science curricula even though we recognize that these may change in the near or distant future. What is important is that students understand the evidence for current beliefs about natural phenomena, and the same is true with NOS. Students should know the evidence that has lead to our current beliefs about NOS and, just as with "traditional" subject matter, they should realize that perceptions may change as additional evidence is collected or the same evidence is viewed in a different way.

Prior to this review, there have been four reviews of research related to the teaching, learning, and assessment of nature of science (Abd-El-Khalick & Lederman, 2000a; Lederman, 1992, 2007; Meichtry, 1992). In addition to revisiting the contents of previous reviews, this review will build on these prior works and hopefully provide some guidance for future research in the field. For practical reasons, the research reviewed is restricted to published reports and to those studies with a primary focus on NOS. These studies have been divided into obvious thematic sections and are presented in a general chronological sequence within each section. Again, all of the studies included in previous reviews could not be presented here, but some of the more prominent and influential studies are reviewed again to provide a context for more recent investigations.

Research on Students' Conceptions

Considering the longevity of objectives related to students' conceptions of NOS, it is more than intriguing that research on NOS only began in earnest in 1961. Klopfer and Cooley (1963) developed the Test on Understanding Science (TOUS), which was, for some time, the most widely used paper-and-pencil assessment of students' conceptions. Using the TOUS and a comprehensive review of several nationwide surveys, Klopfer and Cooley (1963) concluded that high school students' understandings of the scientific enterprise and of scientists was inadequate. Early assessments of students' understandings were not limited to the United States. Mackay (1971) administered pre- and posttests to 1,203 Australian secondary students spanning Grades 7 through 10 using the TOUS instrument. He concluded that students lacked sufficient knowledge of (a) the role of creativity in science; (b) the function of scientific models; (c) the roles of theories and their relation to research; (d) the distinctions among hypotheses, laws, and theories; (e) the relationship among experimentation, models and theories, and absolute truth; (f) the fact that science is not solely concerned with the collection and classification of facts; (g) what constitutes a scientific explanation; and (h) the interrelationships among and the interdependence of the different branches of science. Similar findings resulted from the investigations of Aikenhead (1972, 1973).

During the development of the Nature of Scientific Knowledge Scale, Rubba and colleagues (Rubba, 1977; Rubba & Andersen, 1978) found that 30% of the high school students surveyed believed that scientific research reveals incontrovertible and necessary absolute truth. Additionally, most of Rubba's sample believed that scientific theories, with constant testing and confirmation, eventually mature into laws. With a sample of 102 high-ability seventh- and eighth-grade students, Rubba, Horner, and Smith (1981) attempted to assess students' adherence to the ideas that laws are mature theories and that laws represent absolute truth. The results indicated that the students, on the whole, tended to be "neutral" with respect to both of these ideas. The authors were particularly concerned about the results because the sample consisted of students who were considered to be the most capable and interested in science.

During the past three decades, a decreasing number of studies have focused attention on the assessment of students' conceptions. (Gilbert, 1991; Lederman, 1986;

Lederman & O'Malley, 1990), with no attempt to identify or test causal factors. However, a few notable studies are briefly described here to illustrate the consistency of findings across the decades of research on students' understandings. Most recently, Kang, Scharmann, and Noh (2004) examined the views of 6th-, 8th-, and 10th-grade students in South Korea. Using a multiple-choice test, the views of 1,702 students were assessed. Consistent with prior research, the South Korean students were found to have an empiricist/absolutist view of science. Zeidler, Walker, Ackett, and Simmons (2002) investigated the relationships between students' conceptions of NOS and their reactions to evidence that challenged their beliefs about socioscientific issues. A total of 82 students from 9th- and 10th-grade general science classes, 11th- and 12th-grade honors biology, physics classes, and college-level preservice teachers comprised the sample. Although the authors did not clarify how many of the students in the sample adhered to the array of beliefs presented, it was clear that a significant number of students did not understand scientific knowledge to be tentative, partially subjective, and involve creativity. Overall, there were no clear differences in the understandings of students with respect to grade level.

In an interesting departure from the usual focus of assessments of students' views, Sutherland and Dennick (2002) investigated conceptions of NOS in students with clearly different worldviews. Specifically, this research recognized that individuals from different cultures may have significantly different views of the world and humans' place in the world and that these views may impact how one views NOS. The sample consisted of 72 seventh-grade Cree students and 36 seventh-grade Euro-Canadian students. Although all assessments were done in English, a significant portion of the Cree students spoke English as well as Cree at home. Data were collected using both quantitative (Nature of Scientific Knowledge Scale) and qualitative (interviews) techniques. Although the two groups differed on various aspects of NOS, both groups held views that are considered less than adequate with respect to the following aspects of NOS: tentativeness, creativity, parsimony, unified nature of knowledge, importance of empirical testing, and amoral nature of scientific knowledge. They also found that both language and culture impacted students' views in addition to those factors that impact Western students' views. Certainly, the potential influence of world views, culture, and language may have on understandings of NOS is important in and of itself and is an area of much-needed research. However, the critical point here is that the findings in this study corroborate what has been found throughout the history of studies that simply aim to assess students' conceptions.

More recently, Walls (2012) focused on third-grade African American students, and although he found unique variations in students' conceptions, his findings were still consistent with studies from previous decades. As the longevity of research on NOS has evolved, there has been an obvious expansion beyond the borders of North America. Three particularly interesting studies of students' conceptions are mentioned here. Urhahne, Kremer, and Mayer (2011) studied 221 high school students from four "above-average" schools in Germany, specifically focusing on whether conceptions of NOS were general or context specific. Overall, there really was no definitive pattern that general understandings were different than context-specific understandings. Given the constant discussion among those investigating instructional impacts on NOS, the results here lend credence to the idea that understandings of NOS can be facilitated with general as opposed to context-dependent approaches.

Dogan and Abd-El-Khalick (2008) studied the conceptions of 2,020 10th-grade students in Turkey using a modified version of the Views of Science, Technology, and Society VOSTS (Aikenhead, Fleming, & Ryan, 1987). Students were sampled throughout the country. They found the students had the same misconceptions about NOS found in previous studies. Interestingly, they found a positive correlation between NOS understandings and parents' level of education. They also found differences between students from western Turkey and eastern Turkey. Given the unique cultural diversity in Turkey (i.e., a country that is located on two continents), this latter result lends some credence to the idea that understandings of NOS are influenced by culture.

Ibrahim, Buffler, and Lubben (2009) studied college freshmen in a South African university physics class. The sample was 179 students, and they were surveyed about their views of scientific knowledge, the origin of laws and theories, the relationship of theory and experiment, the purpose of experiments, the role of creativity in experiments, and the precedence of theoretical and experimental results. The results indicated that these students held the general misconceptions previously noted concerning NOS. Of particular interest was the finding that perceptions of experimentation are critically important for an informed view of NOS.

Overall, the emerging findings from more recent and more international studies on students' conceptions reinforce what was found decades before. Without any targeted instructional interventions, students do not possess the currently desired understandings of NOS.

Research on Teachers' Conceptions of NOS

In general, researchers turned their attention to teaching nature of science and teachers' conceptions as data emerged indicating that students did not possess what were considered adequate conceptions of NOS. The logic was simple: A teacher must possess adequate knowledge of what he/she is attempting to communicate to students.

Carey and Stauss (1968) investigated whether 17 prospective secondary science teachers being prepared at the University of Georgia possessed a philosophy of science that exhibited an understanding of NOS. The Wisconsin

Inventory of Science Processes (WISP) was used to assess NOS. In addition to attempting an initial assessment of the conceptions possessed by the preservice teachers, an attempt was made to investigate the effectiveness of a science methods course in improving such conceptions. Pretest scores on the WISP indicated that the science teachers, as a group, did not possess adequate conceptions of nature of science. Based on WISP posttest scores, it was concluded that a methods course specifically oriented toward NOS could significantly improve teachers' viewpoints.

Carey and Stauss (1970a) continued their line of research by assessing experienced teachers' conceptions of NOS. Once again, they used the WISP exam. The results were consistent with their previous study: (a) Teachers of science, in general, did not possess adequate conceptions of NOS; (b) science methods courses produce a significant pre- to posttest improvement of WISP scores, and (c) academic variables such as grade-point average, math credits, specific courses, and years of teaching experience are not significantly related to teachers' conceptions of science. They recommended that courses in the history and philosophy of science be included in teacher preparation programs.

Kimball (1968), using his own Nature of Science Scale (NOSS), compared understandings of NOS of scientists and science teachers. In no case were significant differences found between the groups. Although research focused on teachers' conceptions of NOS (with no attempts to change such conceptions) proliferated during 1950 through 1970, there have been several notable more recent assessments.

Beginning teachers' and preservice science teachers' views about scientific knowledge were described and compared by Koulaidis and Ogborn (1989). A 16-item, multiple-choice questionnaire was administered to 12 beginning science teachers and 11 preservice science teachers. The questionnaire items focused on scientific method, criteria for demarcation of science and nonscience, change in scientific knowledge, and the status of scientific knowledge. Based on their responses, the subjects were categorized into four predetermined categories of philosophical belief. The high frequency of individuals possessing eclectic views is consistent with previous research, which has indicated that teachers do not generally possess views that are consistently associated with a particular philosophical position. Overall, the authors concluded that although science teachers place value on scientific method, they see the procedures involved as contextually situated.

Using a case study approach, Aguirre, Haggerty, and Linder (1990) assessed 74 preservice secondary science teachers' conceptions of NOS, teaching, and learning. Subjects were asked to respond to 11 open-ended questions about science, teaching of science, and learning of science. Most individuals believed that science was either a body of knowledge consisting of a collection of observations and explanations or of propositions that have been proven to be correct. Subjects were evenly divided among the "dispenser of knowledge" and "guide/mediator of understanding" conceptions of science teaching. The authors concluded that these preservice teachers (even though they all possessed undergraduate science degrees) did not possess adequate conceptions of nature of science.

Research on teachers' conceptions of NOS is not limited in focus to secondary teachers. Bloom (1989) assessed preservice elementary teachers' understanding of science and how certain contextual variables contribute to this understanding. Using a sample of 80 preservice elementary teachers (86% female) enrolled in three methods courses, Bloom administered a questionnaire that contained six questions related to knowledge of science, theories, and evolution. Additionally, a 21-item rating scale pertaining to prior experiences with science, the nature of science, science teaching, and evolution/creationism was administered. A qualitative analysis of questionnaire responses revealed that the preservice teachers believed science is people centered, with its primary purpose being for the benefit of humankind. Much confusion concerning the meaning and role of scientific theories (e.g., theories are related to belief in one's own thoughts apart from empirical observation) was also noted. Of most significance was the finding that beliefs significantly affect preservice teachers' understandings of science. In this particular case, the anthropocentric nature of the subjects' beliefs significantly influenced their conceptualizations of science, the theory of evolution, and how one would teach evolution.

Akerson, Buzzelli, and Eastwood (2012) were concerned with K–3 preservice teachers' cultural values and their perceptions of NOS. The Values Inventory, interviews, and the Views of Nature of Science–Form B VNOS–B were used to collect data. Overall, it was found that those teachers whose values were most similar to the values they perceived held by scientists possessed the best understandings of NOS. The authors concluded that if teachers see themselves as more similar to scientists, they will not see science as "alien" to themselves and will more likely be willing to teach science.

Liu and Lederman (2007) were also concerned with values as they tested the intuitive assumption that understandings of NOS may be impacted by one's worldview. The study focused on 54 preservice elementary Taiwanese teachers. Two open-ended questionnaires and corresponding interviews were used to assess the preservice teachers' worldviews and their understandings of NOS. Interviews were primarily used to ensure that the researchers' interpretation of questionnaire responses was the same as what was meant by the respondent. As expected, there was a definite pattern relating worldviews and understandings of NOS. The authors concluded that science curricula need to incorporate sociocultural perspectives and NOS.

There has been a consistent and recent increase in studies focusing, in part or completely, on international teachers' understandings. Fah and Hoon (2011) studied preservice secondary teachers in Malaysia in an effort to see if the findings largely found in North American studies applied to Malaysia. Their results were very similar to what the research community had already determined. The teachers believed scientific knowledge to be absolute, not involving subjectivity, and not a direct function of creativity. Studies like this further reinforced that the findings concerning teachers' understandings were universal.

Finally, there have been some attempts to compare understandings of U.S. preservice teachers with those of other nations. Cobern (1989) used Kimball's Nature of Science Scale (NOSS) to compare the understandings of 21 U.S. preservice science teachers with 32 preservice Nigerian teachers. Two significant differences were noted between the groups. Nigerian preservice teachers were more inclined to view science as a way to produce useful technology. This result is consistent with the findings of Ogunniyi (1982) in his study of 53 preservice Nigerian science teachers. This viewpoint is different from that typically desired in the Western hemisphere, which distinguishes theoretical from applied science. However, an applied view regarding science should not be unexpected in a developing nation. A second difference between the two samples was the Nigerians' view that scientists were nationalistic and secretive about their work.

On a much grander scale, Liang, Chen, Chen, Kaya, Adams, Macklin, and Ebenezer (2009) studied 640 preservice teachers from the United States, China, and Turkey. Data were collected using the Students' Understanding of Science and Scientific Inquiry (SUSSI). The SUSSI assessed the following aspects of NOS: understandings of observations and inferences, tentativeness, scientific laws and theories, social and cultural embeddednes, human creativity and imagination, and diverse scientific methods. In general, the preservice teachers possessed the general misunderstandings found in other studies, but they scored best on understanding that scientific knowledge is tentative and worst on understandings of the relationship between theories and laws. The Chinese subsample scored best on five of the six aspects of NOS studied. The U.S. subsample demonstrated informed views of observation and inference, while the Turkish group scored lowest in all six subscales. Overall, this large international study confirmed what had been found in studies focusing solely on North American teachers.

Teaching and Learning of Nature of Science (the Early Years: 1960–1980s)

Research on Students' Conceptions

Klopfer and Cooley (1963) developed the first curriculum designed to improve students' conceptions of NOS. The curriculum was called History of Science Cases for High Schools (HOSC). The rationale for the curriculum was that the use of materials derived from the history of science would help to convey important ideas about science and scientists. A sample of 108 geographically representative science classes, including biology, chemistry, and physics (2,808 students in total), was used to assess the effectiveness of the HOSC curriculum as measured by the TOUS instrument. After a 5-month treatment period, students receiving the HOSC curriculum exhibited significantly greater gains on the TOUS than the control groups. In addition, HOSC students showed significant gains on the TOUS subscales (i.e., the scientific enterprise, the scientist, and the methods and aims of science) as well as on the overall test. It was concluded that the HOSC instructional approach was an effective way to improve students' conceptions of NOS. The large sample size used in this investigation gave it much credibility, and it was followed by widespread curriculum development.

Crumb (1965) compared the Physical Science Study Curriculum (PSSC) to traditional high school physics with respect to gains on the TOUS exam. The PSSC program is a laboratory-centered, experimental approach to physics that is designed to emphasize process as opposed to simply science content. Using a sample of 1,275 students from 29 high schools, Crumb found that PSSC students showed greater gains on the TOUS than students exposed to the traditional physics curriculum.

Aikenhead (1979) developed and field tested a curriculum titled Science: A Way of Knowing. The primary goals of the curriculum were to have students develop (a) a realistic, nonmythical understanding of the nature, processes, and social aspects of science; (b) a variety of inquiry skills and a realistic feeling of personal competence in the areas of interpreting, responding to, and evaluating their scientific and technological society; and (c) insight into the interaction of science and technology and, in turn, into the interaction of these with other aspects of society. Using the Science Process Inventory (Welch, 1967), Grade 11 and Grade 12 students were found to make significant pre- to posttest gains.

The findings related to the effectiveness of curriculum specifically designed to teach NOS were not all positive. Trent (1965) investigated the relative value of the PSSC course and traditional physics (as did Crumb, 1965). A sample consisting of 52 California high schools was used, and the TOUS exam was used to assess students' conceptions of science. Half of the students in the PSSC classes and half of those in traditional courses were not pretested on the TOUS, and the remaining students were. At the end of the school year, all students were given a posttest. When prior science understanding and student ability were statistically controlled, no differences were found between the students in the traditional and PSSC courses as measured by the TOUS.

Troxel (1968) compared "traditional" chemistry instruction to both CHEM Study and the Chemical Bond Approach (CBA). In theory, CHEM Study and CBA stress inquiry and are laboratory centered, which theoretically should promote better understandings of NOS. However, when teacher background in terms of teaching within the discipline, experience in teaching the course, general philosophy, and student background relative to school size were held constant, no significant differences were found in students' conceptions of NOS.

Two other studies using the 1960s curricula were conducted with Israeli high school students. Jungwirth (1970) attempted to investigate the effectiveness of the BSCS Yellow Version, which was first introduced in Israel in 1964. A total of 693 10th-grade students (from 25 schools) comprised the sample. Scores on both the TOUS and the Processes of Science Test (Biological Sciences Curriculum Study [BSCS], 1962) were used to assess students' understandings of scientific knowledge. Students were given pre- and posttests over the course of one academic year. No significant differences were found between those students studying BSCS biology and those in the comparison group. Thus, Jungwirth concluded, the curriculum was not any more effective with respect to the enhancement of students' conceptions of science. He concluded that pupil achievement in this area could best be enhanced through "redirected teacher effort and emphases."

Tamir (1972) compared the relative effectiveness of three curriculum projects with each other as well as with "traditional" instruction. Using the BSCS Yellow Version, CHEM Study, PSSC, and traditional instructional approaches, Tamir assessed changes in students' conceptions of the nature of science on the Science Process Inventory (Welch, 1967). A total of 3,500 students in Grades 9 through 12 were randomly selected from the four types of Israeli high schools (i.e., city academic, cooperation settlement, agricultural, and occupational) so as to allow comparisons among the different school types. The results indicated no significant differences among students studying any of the curriculum projects and those following traditional courses of study.

More recently, Carey, Evans, Honda, Jay, and Unger (1989) assessed the effectiveness of a unit specifically designed to introduce the constructivist view of science on seventh graders' epistemological views. All classes, in the 3-week unit, were taught by the regular teacher, and each lesson was observed by one or two research assistants. Twenty-seven of the students were randomly selected to be interviewed prior to and after being exposed to the instructional unit. In general, the preinstruction interview indicated that most students thought scientists seek to discover facts about nature by making observations and trying things out. However, postinstruction interviews showed many students understood that inquiry is guided by particular ideas and questions, and experiments are tests of ideas. In short, the instructional unit appeared to have been at least partially successful in enabling students to differentiate ideas and experiments.

There was an implicit assumption that clearly guided research that focused solely on the development of curricula and/or instructional materials. It was assumed that student conceptions could be improved if a concerted effort was made in that direction. Unfortunately, for the most part, the teacher's interpretation and enactment of the curriculum was ignored. The following statement from two of the earliest investigators of the curriculum development movement (Klopfer & Cooley, 1963) did little to establish the importance of the teacher: "The relative effectiveness of the History of Science Cases Instruction Method (a curriculum which strongly emphasized using history of science), in teaching TOUS-type understandings does *not* depend upon whether the teacher rates 'high' or 'low' in his initial understanding" (p. 45).

The implication of this statement is clear. That is, a teacher could promote understandings of certain concepts without having an adequate understanding of the concepts. Fortunately, others, such as Trent (1965), felt that the equivocal findings with respect to the effectiveness of NOS–oriented curricula could only mean that the instructional approach, style, rapport, and personality of the teacher are important variables in effective science teaching. He reasoned, if the same curriculum is effective for one teacher and ineffective for another and the variable of student ability is controlled, a significant factor must be the teacher.

Spears and Zollman (1977) assessed the influence of engagement in scientific inquiry on students' understandings of the process of science. Participants were randomly assigned to the four lecture sections and associated laboratory sections of a physics course. Data from about 50% of the original sample were used in the final analysis. The "structured" approach emphasized verification, whereas the "unstructured" approach stressed inquiry or discovery. Both approaches asked students to investigate problems related to physical principles discussed in the lectures. Beyond this point, the two approaches differed in a major way. In the "structured" laboratory, students were provided with explicit procedures with which they attempted to verify the physical principles concerned. Students in the "unstructured" laboratory, however, were free to investigate the problem in whichever way they deemed appropriate. They made their own decisions regarding what data to collect, how to collect these data, how to treat the data, and how to interpret and present their results. Data analyses indicated that there were no statistically significant differences between the adjusted scores of the two groups on the Assumptions, Nature of Outcomes, and Ethics and Goals components of the Science Process Inventory SPI Form D (Welch & Pella, 1967–1968).

Research on Teachers' Conceptions of NOS

The equivocal results concerning the effectiveness of curricula designed to improve students' conceptions of NOS, perhaps, motivated other researchers to focus their attentions on the teacher as a significant variable. In the 1960s, the distinction between implementation and enactment of a curriculum had not taken hold in the science education community. Yager & Wick (1966) selected eight experienced teachers to use an inquiry-oriented curriculum (BSCS Blue Version). All teachers utilized the same number of days of discussion, laboratories, examinations, and instructional materials. Students were pre- and posttested on the TOUS exam. Using an analysis of covariance, it was concluded that there were significant differences in students' ability to understand NOS when taught by different teachers. Further direct confirmation of the important influence of teachers upon students' conceptions came from Kleinman's (1965) study of teachers' questioning.

When one considers the influence of the individual teacher on student learning, there are at least two directions that can be pursued. One would be to study what a teacher does that impacts students' understandings of NOS. The other can be a focus on teachers' knowledge. Few would argue against the notion that a teacher must have an understanding of what he/she is expected to teach. Unfortunately, the latter was initially pursued in the research to the exclusion of attention to the former. Those studies focusing on teachers' knowledge are briefly described here. A more detailed discussion of each study can be found in the previous *Handbook* (Lederman, 2007).

Of critical importance here is that the following studies relied on two assumptions: (1) A positive relationship existed between teachers' knowledge of NOS and their students' knowledge and (2) teachers' knowledge of NOS necessarily impacted their classroom practice. Consequently, researchers interested in NOS never thought it necessary to go beyond attempts to improve teachers' knowledge of NOS. The two aforementioned assumptions arguably compromised efforts to improve students' conceptions of NOS for 30 years. It is also important to note that what researchers did to improve teachers' knowledge was poorly described and generally did not explicitly address NOS.

Carey and Stauss (1970b) had 35 prospective secondary science teachers and 221 prospective elementary teachers complete the WISP. Scores were correlated with background variables such as high school science courses, college science courses, college grade-point average, and science grade-point average. No relationship was found between either secondary or elementary teachers' conceptions of science, as measured by WISP, and any of the academic background variables. During the validation of the NOSS, Kimball (1968) noted that philosophy majors actually scored higher than either science teachers or professional scientists. He intuitively concluded that inclusion of a philosophy of science course as part of the undergraduate science major curriculum might improve the situation. Welch and Walberg (1968) did find success in a summer institute designed for 162 physics teachers at four institute sites. The teachers at all four sites showed significant gains on both the TOUS and Science Process Inventory. Unfortunately, no documentation of the specific activities at each of the various institutes was available.

Lavach (1969) attempted to expand on the success that Klopfer and Cooley (1963) had documented with a historical approach. Twenty-six science teachers participated; 11 constituted the experimental group and 15 served as the control group. The experimental group received instruction in selected historical aspects of astronomy, mechanics, chemistry, heat, and electricity. The teachers in the control group did not receive lectures or laboratories presented from a historical perspective. All teachers were pre- and posttested on the TOUS. The teachers in the experimental group exhibited statistically significant gains in their understanding of NOS. Further analysis indicated that these gains were not related to overall teaching experience, subjects taught, undergraduate major, previous inservice participation, or length of teaching experience in the same subject.

Six years later, Billeh and Hasan (1975) attempted to identify those factors that affect any increase in the understanding of NOS by science teachers. Their sample consisted of 186 secondary science teachers in Jordan. The teachers were divided into four groups: biology, chemistry, physical science, and physics. A 4-week course for the chemistry, physical science, and physics teachers consisted of lectures and demonstrations in methods of teaching science, laboratory investigations emphasizing a guided-discovery approach, enrichment activities to enhance understanding of specific science concepts, and 12 lectures specifically related to nature of science. The biology group did not receive any formal instruction on nature of science, thus establishing a reference group with which the other groups could be compared. The Nature of Science Test (NOST) was used to assess understanding of NOS. Those lectures that stressed nature of science were not oriented toward the specific content of the NOST. Each group of teachers was administered pre- and posttests on the NOST, and an analysis of covariance showed significant increases in the mean scores of the chemistry, physical science, and physics groups. The biology group did not show a significant gain, a finding consistent with Carey and Stauss (1968). A second result was that there was no significant relationship between teachers' gain scores on NOST and their educational qualifications, a finding in agreement with previous research (Carey & Stauss, 1970a; Lavach, 1969). Finally, science teaching experience was not significantly related to NOST gain scores. The conclusion that teaching experience does not contribute to a teacher's understanding of NOS was also consistent with previous research (Carey & Stauss, 1970b; Kimball, 1968; Lavach, 1969).

Riley (1979) argued that teachers' understandings of and attitudes toward science would improve as a result of first-hand, manipulative experiences and enhanced proficiency in the processes of science. Riley labeled an understanding of NOS as an "affective" outcome and attempted to teach NOS by involving teachers in "doing science." The study investigated the influence of hands-on versus nonmanipulative training in science process skills on preservice elementary teachers' understandings of NOS. The treatment had three levels: active-inquiry (hands-on), vicarious-inquiry (nonmanipulative), and control. The four 1.5-hour session treatment involved activities that focused on various science process skills, such as observing, classifying, inferring, predicting, communicating, measuring and the metric system, and using space/time relationships. The only difference between the aforementioned levels of treatment was participant involvement. Data analyses indicated that there were no significant differences between the groups' mean TOUS (Cooley & Klopfer, 1961) scores related to the treatments. As such, participants in the active-inquiry, vicarious-inquiry, and control groups did not differ in their understandings of NOS.

Akindehin (1988) argued that attempts to help science teachers develop adequate conceptions of NOS need to be *explicit* (i.e., NOS directly introduced and discussed, as opposed to just having teachers do investigations). The author assessed the influence of an instructional package, the Introductory Science Teacher Education (ISTE) package, on prospective secondary science teachers' conceptions of NOS. The package contained nine units including lectures, discussions, and laboratory sessions.

A statistically significant result was obtained for the experimental group. Out of 58 possible points on the NOSS, the mean score was 51.84. This mean score was the highest reported NOSS score among the studies reviewed here. It should be noted, however, that the author did not report the mean pretest and posttest scores. Thus, it was difficult to assess the practical significance of the gains achieved by the student teachers.

Scharmann and Harris (1992) assessed the influence of a three-week National Science Foundation NSF–sponsored summer institute on participants' understandings of NOS. The authors noted that "changes in an understanding of the nature of science can be . . . enhanced through a more indirect and applied context . . . and through a variety of readings and activities" that help participants to discuss their NOS views (p. 379). The NOSS (Kimball, 1968) was used to assess participants' understandings of the "philosophical" NOS, and an instrument developed by Johnson and Peeples (1987) was used to assess participants' "applied" understandings of NOS. During the first 2 weeks of the institute, participants were presented with biological and geological content relevant to evolutionary theory. In addition, various instructional methods and teaching approaches including lectures, small-group and peer discussions, field trips, and other inquiry-based approaches were taught and modeled by the authors. The authors noted that the "theme" of promoting participants' conceptions of NOS pervaded all the activities. However, no direct or explicit NOS instruction was used. Data analyses did not reveal significant differences between pretest and posttest mean NOSS scores. However, statistically significant differences were obtained in the case of the Johnson and Peeples (1987) instrument. The authors concluded that even though participants' conceptions of the "philosophical" NOS were not changed, their understandings of the "applied" NOS were significantly improved. Scharmann and Harris (1992) did not comment on the practical significance of the gain achieved by the participants. Out of 100 possible points for the latter instrument, the pretest and posttest mean scores were 61.74 and 63.26, respectively.

Looking at research investigations that attempted to change teachers' conceptions from an alternative perspective can be enlightening. Overall, these studies took one of two approaches. The first approach was advocated by science educators such as Gabel, Rubba, and Franz (1977) and Rowe (1974). This approach is labeled the "implicit" approach for this review, as it suggests that an understanding of NOS is a learning outcome that can be facilitated through process skill instruction, science content coursework, and "doing science." Researchers who adopted this implicit approach utilized science process skills instruction and/or scientific inquiry activities (Riley, 1979) or manipulated certain aspects of the learning environment (Scharmann & Harris, 1992; Spears & Zollman, 1977) in their attempts to enhance teachers' NOS conceptions. Researchers who adopted the second approach to enhancing teachers' understandings of NOS (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970a; Jones, 1969; Lavach, 1969; Ogunniyi, 1982) utilized elements from history and philosophy of science and/or instruction focused on various aspects of NOS to improve science teachers' conceptions. This second approach is labeled the "explicit" approach for this review and was advanced by educators such as Billeh and Hasan (1975), Hodson (1985), Kimball (1968), Klopfer (1964), Lavach (1969), and Rutherford (1964).

Teaching and Learning of Nature of Science (Contemporary Years: A Shift in Perspective)

During the past 20 years, research on the teaching and learning of NOS has experienced a gradual but clear change in perspective. This change in perspective has influenced how we attempt to change the conceptions of both teachers and students.

Research on Teachers' Conceptions of NOS

The results of the initial research on NOS (which are supported by more recent investigations) may be summarized as follows: (a) Science teachers do not possess adequate conceptions of NOS, irrespective of the instrument used to assess understandings; (b) techniques to improve teachers' conceptions have met with some success when they have included either historical aspects of scientific knowledge or explicit attention to NOS; and (c) academic background variables are not significantly related to teachers' conceptions of NOS. Two underlying assumptions appear to have permeated the research reviewed thus far. The first assumption has been that a teacher's understanding of NOS affects his/her students' conceptions. This assumption is clear in all the research that focused on improvement of teachers' conceptions with no expressed need or attempt to do anything further. This rather intuitive assumption remained virtually untested, with the exception of two studies that only referred to the assumption in an ancillary manner. Unfortunately, both of these research efforts (Klopfer & Cooley, 1963; Rothman, 1969) contained significant methodological flaws. Klopfer and Cooley (1963) failed to properly monitor teachers' conceptions of NOS throughout the investigation, while Rothman (1969) created a ceiling effect by sampling only high-ability students.

The second assumption underlying the research reviewed thus far is closely related to the first. If it is assumed that teachers' conceptions of science affect students' conceptions, some method of influence must exist; naturally the influence must be mediated by teacher behaviors and classroom ecology. In short, initial research concerned with teachers' and students' conceptions of NOS assumed that a teacher's behavior and the classroom environment are necessarily and directly influenced by the teacher's conception of NOS. Although this assumption was explicitly stated by many, including Hurd (1969) and Robinson (1965), it remained an untested assumption into the early 1980s (Lederman & Zeidler, 1987).

As can be seen from the research reviewed thus far, several decades of research on NOS focused on student and teacher characteristics or curriculum development to the exclusion of any direct focus on actual classroom practice and/or teacher behaviors. The two assumptions guiding these lines of research compromised efforts to ultimately improve students' conceptions of nature of science for approximately 30 years. Although research designed to assess students' and teachers' conceptions continues to the present, there is clearly less willingness to accept the assumptions that guided earlier research, and the focus is now clearly moving toward teachers' classroom practice.

The presumed relationships between teachers' conceptions of science and those of their students as well as that between teachers' conceptions and instructional behaviors were finally directly tested and demonstrated to be too simplistic relative to the realities of the classroom (Duschl & Wright, 1989; Lederman & Zeidler, 1987; Zeidler & Lederman, 1989; among others). Duschl and Wright (1989) observed and interviewed 13 science teachers in a large urban high school. Their results convincingly indicated that the nature and role of scientific theories are not integral components in the constellation of influences affecting teachers' educational decisions. NOS was not being considered or taught to students as a consequence of perceived students' needs, curriculum guide objectives, and accountability.

Lederman and Zeidler's investigation (1987) involved a sample of 18 high school biology teachers from nine schools. The data clearly indicated that there was no significant relationship between teachers' understandings of NOS and classroom practice. Presently, several variables have been shown to mediate and constrain the translation of teachers' NOS conceptions into practice. These variables include pressure to cover content (Abd-El-Khalick, Bell, & Lederman, 1998; Duschl & Wright, 1989; Hodson, 1985), classroom management and organizational principles (Hodson, 1993; Lantz & Kass, 1987; Lederman, 1999), concerns for student abilities and motivation (Abd-El-Khalick et al., 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Lederman, 1995), institutional constraints (Brickhouse & Bodner, 1992), teaching experience (Brickhouse & Bodner, 1992; Lederman, 1995), discomfort with understandings of NOS, and the lack of resources and experiences for assessing understandings of NOS (Abd-El-Khalick et al., 1998).

More recently, Lederman (1999) attempted to finally put to rest (old habits die hard) the assumption that teachers' conceptions of NOS directly influence classroom practice. In a multiple case study involving five high school biology teachers with varying experience, Lederman collected data on teachers' conceptions of NOS and classroom practice. All teachers were former students of the author and all possessed informed understandings of NOS. Over the course of a full academic year, data were collected from questionnaires, structured and unstructured interviews, classroom observations, and instructional materials. Data were also collected on students' conceptions of NOS though questionnaires and interviews. The author was unable to find any clear relationship between teachers' conceptions and classroom practice. The two most experienced teachers (14 and 15 years' experience) did exhibit behaviors that seemed consistent with their views of NOS, but interview and lesson plan data revealed that these teachers were not attempting to teach NOS. Data from students in all teachers' classes indicated that none of the students had developed informed understandings of NOS. The results of the investigation indicated that, although the teachers possessed good understandings of NOS, classroom practice was not directly impacted. Furthermore, the importance of teachers' intentions relative to students' understandings was highlighted. Even in the classrooms that exhibited some similarity with teachers' understandings, students did not learn NOS because the teachers did not explicitly intend to teach NOS. Overall, the research was consistent with emerging findings about the relationship between teachers' understandings and classroom practice as well as the research indicating the importance of explicit instructional attention to NOS.

Although it is now clear that teachers' conceptions do not necessarily translate into classroom practice (but teachers do need to know NOS if they are expected to teach it), concern about teachers' conceptions persists. As was previously mentioned, the past 20 years have been marked by a slow but definite shift in perspective related to how we go about changing teachers' conceptions of NOS. In short, there has been a shift to more explicit and reflective instructional approaches in research related to teachers' conceptions of NOS.

In a study of preservice teachers' conceptions of NOS, Bell, Lederman, and Abd-El-Khalick (2000) looked at teachers' translation of knowledge into instructional planning and classroom practice. The subjects were 13 preservice teachers. The teachers' views of NOS were assessed with an open-ended questionnaire before and after student teaching. Throughout the student teaching experience, daily lesson plans, classroom videotapes, portfolios, and supervisors' clinical observation notes were analyzed for explicit instances of NOS in either planning or instruction. Following student teaching, all subjects were interviewed about their questionnaire responses and factors that influenced their teaching of NOS. Although all of the preservice teachers exhibited adequate understandings of NOS, they did not consistently integrate NOS into instruction in an explicit manner. NOS was not evident in these teachers' objectives, nor was any attempt made to assess students' understandings of NOS. The authors concluded that possessing an understanding of NOS is not automatically translated in a teacher's classroom practice. They further concluded that NOS must be planned for and included in instructional objectives as any other subject matter content.

Akerson, Abd-El-Khalick, and Lederman (2000) were concerned solely with developing elementary teachers' understandings of NOS and not with the translation of this knowledge into classroom practice. The subjects were 25 undergraduate and 25 graduate preservice elementary teachers enrolled in two separate methods courses. Before and after the courses, teachers' views about the empirical, tentative, subjective, creative, and social/cultural embeddedness of scientific knowledge were assessed. In addition, the preservice teachers' views on the distinction between observation/inference and between theories and laws were assessed. The courses explicitly addressed these aspects of NOS using a reflective, activity-based approach. The results indicated that explicit attention to NOS was an effective way to improve teachers' understandings of NOS. However, taken in the context of studies such as the previous one (Bell, Lederman, & Abd-El-Khalick, 2000), the authors were quick to point out that mere possession of adequate understandings will not automatically change classroom practice.

Abell, Martini, and George (2001) monitored the views of 11 elementary education majors during a science methods course. The particular context was a moon investigation in which the authors targeted the following aspects of NOS: empirically based, involves invention and explanations, and is socially embedded. Students were asked to observe the moon each day during the course and record their observations. An attempt was made by the instructors to be explicit as possible with respect to NOS. After the investigation, students realized that scientists make observations and generate patterns, but they did not realize that observations could precede or follow the development of a theory. Students were able to distinguish the processes of observing from creating explanations, but they could not discuss the role of invention in science. In various other instances, students were capable of articulating aspects of NOS but were unable to see the connection between what they learned in the activity and the scientific community. The authors recognized the importance of being explicit in the teaching of NOS. They also recognized that their students' failure to generalize what they learned beyond the learning activities themselves to what occurs in the scientific community in general was a consequence of not making an explicit connection between what scientists do and the activities completed in class.

Abd-El-Khalick (2001) used an explicit, reflective approach to teach about NOS in a physics course designed for prospective elementary teachers at the American University of Beirut. The explicit, reflective approach is not to be confused with direct instruction or a lecture. Rather, it engages students in scientific investigations and demonstrations and then has students reflect on what they did and the implications this has for the knowledge and conclusions reached. Data were collected through pre and posttests on open-ended surveys about NOS. The author reported significant improvement in the aspects of NOS providing focus for the investigation: tentative, empirically based, theory-laden, inferential, imaginative, and creative characteristics of scientific knowledge. In addition, the relationship between theory and law, as well as the distinction between observation and inference, were investigated. The author definitely concluded that the explicit, reflective approach to instruction was successful.

The use of history of science has long been advocated as a means to improve students' conceptions of science. Lin and Chen (2002) extended this logic to a program designed to improve preservice teachers' understanding of NOS. Sixty-three prospective chemistry teachers in Taiwan were divided into experimental and control groups. The teachers in the experimental group were exposed to a series of historical cases followed by debates and discussions that highlighted how scientists developed knowledge. The historical cases were promoted as a way for these prospective teachers to teach science. Different from previous attempts to use history of science to achieve outcomes related to NOS, the historical materials explicitly addressed NOS. The results clearly showed significant improvement in understandings of NOS by the experimental group relative to the control group. In particular, teachers in the experimental group showed significant improvement of their knowledge of creativity in science, theory-bound nature of observations, and the functions of scientific theories.

Abd-El-Khalick and Akerson (2004) studied 28 preservice elementary teachers in a science methods course. In particular, they investigated the effectiveness of an explicit, reflective instructional approach related to NOS on these prospective teachers' views of various aspects of NOS. Data were collected from a combination of questionnaires, interviews, and reflection papers. As expected, participants initially held naïve views of NOS; however, over the course of the investigation, substantial and favorable changes in the preservice teachers' views were evident.

Using a combination of authentic research experiences, seminars, and reflective journals, Schwartz, Lederman, and Crawford (2004) studied changes in secondary preservice teachers' conceptions of NOS. Prior research had indicated that providing teachers with authentic research experiences did not impact understandings of NOS. Consequently, the researchers supported such research experiences with explicit attention to NOS through seminars and a series of reflective journal assignments. The participants were 13 Master of Arts in Teaching (MAT) students. Data were collected via questionnaires and interviews. Most of the interns showed substantial changes in their views of NOS. Participants identified the reflective journal writing and seminars as having the greatest impact on their views, with the actual research internship just providing a context for reflection.

Abd-El-Khalick (2005) considered the perennial recommendation that teachers should take courses in philosophy of science if we want to impact that knowledge of NOS. The sample was 56 undergraduate and graduate preservice secondary science teachers enrolled in a two-course sequence of science methods. Participants received explicit, reflective NOS instruction. Ten of the participants were also enrolled in a graduate philosophy of science course. The Views of Nature of Science—Form C (VNOS-C) was used to assess understandings of NOS at the beginning and end of the investigation. Participants were also interviewed about their written responses. Other data sources included lesson plans and NOS-specific reflection papers. Results indicated that the students enrolled in the philosophy of science course developed more in-depth understandings of NOS than those just enrolled in the science methods course. The methods course, with explicit instruction about NOS, was seen as providing a framework that the 10 students enrolled in the philosophy of science course could use to significantly benefit from the philosophy course.

Scharmann, Smith, James, and Jensen (2005) used an explicit, reflective approach to teaching NOS within the context of a secondary teaching methods course. Nineteen preservice teachers were the subjects. Overall, the authors decided that the instructional approach was successful and supported the emerging literature on the value of an explicit approach to teaching NOS.

Since the last review of research on the teaching and learning of NOS, continued efforts to improve teachers' understandings of NOS at both the elementary and secondary levels consistently document the effectiveness of an explicit and reflective teaching approach. At the elementary level, McDonald (2010) used a combination of explicit NOS instruction along with instruction on argumentation in a college-level science course to improve the conceptions of five preservice elementary teachers. The study originally had 16 preservice teachers, but complete data sets were only available from 5 of the teachers. Celik and Bayrakceken (2012) successfully used an activity-based explicit approach to teaching secondary preservice teachers about NOS. In a similar vein, Posnanski (2010) worked with 22 elementary preservice teachers during a 2-year professional development program focusing on NOS. It was an activity-based program with explicit attention to NOS. The program was successful in developing teachers' understandings of and ability to teach NOS, but the author was concerned about the sustainability of the of the program's impact. Akerson, Buzzelli, and Donnelly (2010) worked with 14 K–3 teachers and were successful teaching NOS with an explicit and reflective approach. Of importance here is that the authors found that those preservice teachers who worked with cooperating teachers who provided support for the teaching of NOS were able to sustain a NOS focus, while those in classrooms with cooperating teachers who did not provide support were unable to maintain a NOS focus. These findings are provocative, as they raise an issue not yet prominent in the research community. Much effort has been placed on preparing preservice teachers to teach NOS, but these same teachers move into a school environment in which very few teachers address NOS. In short, there is no support for these teachers to continue stressing NOS. The situation is analogous to what we know about the impact of the differences between the values of teacher education programs and the values of the existing teaching community.

The research on developing teachers' conceptions of NOS continues to grow at all levels and in varied contexts: with elementary teachers (Abd-El-Khalick & Akerson, 2009; Akerson, Buzelli, & Donnelly, 2008; Akerson, Cullen, & Hanson, 2010; Akerson & Hanuscin, 2007; Akerson, Townsend, Donnelly, Hanson, Tira, & White, 2009), middle school teachers (Seung, Bryan, & Butler, 2009), secondary teachers (Smith & Scharmann, 2008), and elementary and secondary teachers in authentic laboratory contexts (Morrison, Raab, & Ingram, 2009; Sadler, Burgin, McKinney, Lyle, & Ponjuan, 2010). Although the variety of programs and contexts may differ, the one common element used to significantly improve teachers' conceptions of NOS is the use of an explicit and reflective approach. The research community acknowledged the importance of explicit and reflective instruction during the 1990s, and the research continues to provide support. It is important to reiterate, yet again, "explicit" does not refer to lecture, direct instruction, or a didactic (in the North American sense) approach but rather an approach that makes aspects of NOS "visible" in the classroom through discussion and hands-on activities followed by pertinent debriefing discussions.

In addition to the typical studies investigating ways to change and improve teachers' conceptions of NOS, there is a slowly emerging attention to the rationales that have been used to justify the importance of teaching NOS to K–12 students. One justification for teaching NOS has been that an understanding of NOS will contribute to informed decisions on scientifically based societal and personal issues. Bell and Lederman (2003) tested this assumption using a group of 21 highly educated individuals (i.e., individuals possessing a Ph.D.). These individuals were faculty members from various universities. Individuals completed an open-ended questionnaire, followed by an interview, designed to assess decision-making on science and technology related issues. A second questionnaire was used to assess participants' understandings of NOS, and an interview followed the completion of the questionnaire. Participants were separated into two groups based on the adequacy of their understanding of NOS. No differences were found between the two groups. Both groups used personal values, morals/ethics, and social concerns when making decisions, but NOS was not used. The authors concluded that decision making is complex, and the data did not support the assumption that an understanding of NOS would contribute prominently in one's decisions. The authors also speculated that NOS may not have been considered because individuals need to have instruction on how NOS understandings could be used in aiding the decision-making process.

Research on Students' Conceptions of NOS

It is safe to assume that teachers cannot possibly teach what they do not understand (Ball & McDiarmid, 1990). Research on the translation of teachers' conceptions into classroom practice, however, indicates that even though teachers' conceptions of NOS can be thought of as a *necessary* condition, these conceptions, nevertheless, should not be considered *sufficient* (Lederman, 1992, 2007). At least one implication for research related to NOS is apparent. Research efforts, it is argued, should "extend well beyond teachers' understandings of nature of science, as the translation of these understandings into classroom practice is mediated by a complex set of situational variables" (Lederman, 1992, p. 351). Clearly complex issues surround the possible influence of teachers' understandings of NOS on classroom practice and have yet to be resolved. It is safe to say, however, that there is general agreement among researchers concerning the strong influence of curriculum constraints, administrative policies, and teaching context on the translation of teachers' conceptions into classroom practice. In addition to investigations that assessed the relationship between teachers' conceptions and classroom practice, efforts to identify those factors that do influence students' conceptions have also been pursued.

The significance of teacher–student interactions to conceptual changes in students' views of science motivated a study with 18 high school biology teachers and 409 students (Zeidler & Lederman, 1989). In this investigation, specific attention was focused on the nature of teacher–student interactions and the specific language used. In general, when teachers used "ordinary language" without qualification (e.g., discussing the structure of an atom without stressing that it is a model), students tended to adopt a realist conception of science. Alternatively, when teachers were careful to use precise language with appropriate qualifications, students tended to adopt an instrumentalist conception. At the time, this investigation provided clear empirical support for Munby's thesis (1976) that implicit messages embedded in teachers' language provide for varied conceptions of NOS. Most recently, Olivera, Akerson, Colak, Pongsanon, and Genel (2012) studied the language use of two elementary teachers. Drawing on semiotic theory, they found that the use of "unhedged or boosted" language (e.g., absolutely) relative to "hedged" language (e.g., maybe, could) lead to students perceiving scientific knowledge to be absolute, while "hedged" language more likely lead to a tentative view of scientific knowledge. Thus, although aspects of NOS are predominantly taught with an explicit approach, there are instances in which implicit messages are sent to students through language use.

Inclusion of history of science has often been touted as being a way to improve students' understandings of NOS. The value of history of science, however, has been held mostly as an intuitive assumption as opposed to being an idea having empirical support. Abd-El-Khalick and Lederman (2000b) assessed the influence of taking history of science courses on college students' and preservice teachers' conceptions of NOS. The subjects were 166 undergraduate and graduate students and 15 preservice secondary science teachers. All subjects were pre- and posttested with an open-ended questionnaire. A representative sample of students was also interviewed in an effort to establish face validity for the questionnaires. The results showed that most individuals entered the history of science courses with inadequate views of NOS and there was little change after completing the course. When change was noted, it was typically with respect to some explicit attention to NOS in one of the courses. In addition, there was some evidence that the preservice teachers learned more about NOS from the history of science courses than the other students did. This was attributed to the possible benefits of having entered the course with a perceptual framework for NOS provided in their science methods course. More recently, Hottecke, Henke, and Riess (2012) combined history and philosophy of science with an explicit approach to teaching NOS in high school physics classes as part of the European History, Philospliy, and Science Teaching (HIPST) Project. They used historical case studies, hands-on activities, reflective activities, role playing, and replications of historical apparatus in designing a curriculum over 2 years. This was an ambitious collaboration between scientists and teachers. Although there is not extensive empirical support for the effectiveness of the instructional approach, it is one of the few integrations of history and philosophy of science into instruction that heavily references the empirical literature.

Few studies have studied the relative effectiveness of explicit, reflective approaches to teaching NOS relative to implicit approaches with K–12 students. One such study was completed by Khishfe and Abd-El-Khalick (2002) in Lebanon. A total of 62 sixth-grade students in two intact groups (n = 29 & 32) experienced inquiry-oriented instruction related to energy transformation and sedimentary rocks. One group was taught with an approach that explicitly addressed the tentative, empirical, inferential, imaginative, and creative aspects of scientific knowledge, while in the other class only implicit attention to NOS was included. The same teacher taught both classes. Students' knowledge of NOS was assessed through a combination of an open-ended questionnaire and semistructured interviews. Both groups entered the investigation with naïve, and equivalent, views on the various aspects of NOS. After instruction, the implicit group showed no changes in views of NOS, while students in the explicit group all exhibited improvement in their understandings of one or more aspects of NOS. Again, this particular study is important in that it demonstrated the relative effectiveness of explicit instructional approaches with a sample of K–12 students as opposed to preservice and inservice teachers.

Science apprenticeship programs have been a popular approach to engaging high-ability students in science, with an eye on promoting their interest in future careers in science. A commonly stated goal of such apprenticeship programs is that students will develop improved conceptions of NOS. Bell, Blair, Crawford, and Lederman (2003) systematically tested this assumed benefit of an apprenticeship program. The apprenticeship program was 8 weeks long during the summer. Ten high-ability high school students (juniors and seniors) were pre and posttested on their understandings of NOS and scientific inquiry before and after the apprenticeship. Both students and their mentor scientists were interviewed after the program. Although the scientists were of the opinion that their students had learned a lot about inquiry and NOS, student data (from interviews and questionnaires) indicated that changes occurred only in students' abilities to do inquiry. The authors ultimately concluded that students' conceptions of NOS (and knowledge about inquiry) remained unchanged because there was no explicit instruction about either associated with the apprenticeship.

On the other hand, the recent review of research on the impact of research apprenticeships (Sadler, Burgin, McKinney, & Ponjuan, 2010) and an investigation of the impact of interactions with scientists on teachers (Morrison, Raab, & Ingram, 2009) indicated that improvements of NOS are found when NOS is made explicit.

Most of the research related to the impact of explicit instruction has been completed with teachers. However, in recent years there has been a clear increase of studies with K–12 students. Paraskevopoulou and Koliopoulos (2011) studied the understandings of 24 high school students in a physics class designed for students who had indicated that the natural sciences were not part of their career plans. Using an explicit and reflective approach, within instruction about the Millikan-Ehrenhaft dispute, one of the authors focused on the empirical nature of science, observation and inference, creativity, and subjectivity. Statistically significant improvements were noted on each these aspects of NOS using the VNOS—D instrument.

Yacoubian and BouJaoude (2010) studied the relative effects of using reflective discussions following an inquiry-based laboratory and implicit inquiry-based instruction. The study involved 38 sixth-grade students. Following a pretest–posttest control group design, students' understandings of NOS were determined based on an open-ended questionnaire, classroom observations, and interviews. Students in the experimental group showed improvement on the tentative nature of scientific knowledge, the empirical basis of scientific knowledge, and the social nature of science. Students in the control group did not show any improvement. This study clearly provided support for the effectiveness of an explicit teaching approach with students.

Many researchers have concerns about whether very young students can understand something as abstract as NOS. Akerson and Donnelly (2010) taught NOS explicitly to 27 K–2 students during a Saturday Science program. Instruction included contextualized and decontextualized activities, children's literature, debriefings of activities, and student-designed investigations. Using the VNOS—D to assess student understandings, the researchers found that students' knowledge increased on all aspects of NOS except cultural embeddedness and the distinction between theories and laws. Data with teachers shows that they have difficulty with cultural embeddedness and the theory and law distinction, so it is not surprising that these young students had difficulty with the same aspects. More importantly, this study showed not only that explicit instruction is effective but also that K–2 students can comprehend a variety of aspects of NOS. In a replication study, Quigley, Pongsanon, and Akerson (2010) taught 25 K–2 students NOS in Saturday Science program. The results of this investigation replicated the previously described investigation.

With older students (i.e., seventh grade), Khishfe (2008) implemented an explicit instructional approach for approximately 3 months. Instruction included various activities followed with in-depth debriefing sessions. Students' knowledge was assessed through a combination of open-ended questions and interviews. Students all held naïve views of NOS before instruction, intermediate views during instruction, and informed views by the end of instruction. Not all students exhibited the same magnitude of gain. The author proposed that students progress along a developmental scale with time.

Khishfe (2012) studied the effects of a combination of instruction on NOS and argumentation. The subjects were 219 Grade 11 students in Lebanon. The instruction included a focus on several socioscientific issues. Instruction focused around a unit on genetic engineering, with the controversial issue discussed being genetically modified foods. The treatment group was also taught how to use NOS in their arguments on the socioscientific issue. Students showed improvement in NOS understandings (i.e., tentative, subjective, and empirical) by the end of instruction. Strong correlations were found between NOS understandings and counterargument as opposed to argument and rebuttal. Given the context of socioscientific issues, the author felt that argumentation skills significantly contributed to students' understandings of NOS.

Debate still exists regarding the importance of teaching NOS embedded in science content or as a decontextualized topic. Khishfe and Lederman (2007) attempted to see if there was a difference in student learning in the two contexts. Participants in the investigation were three teachers and their students. There were six classes and 89 students in Grade 9 and 40 students in a mixed Grade 10 and 11 class. Students achieved equal understandings of NOS regardless of the integrated or nonintegrated context. The key issue here is that both treatments used an explicit approach to instruction on NOS. More research is still needed to determine if the difference in contexts is important.

Schalk (2012) developed a college-level microbiology course that used socioscientific issues to teach NOS aspects explicitly. Data were collected on 26 undergraduate students at a community college. Qualitative data were collected on students' reasoning and understandings of NOS. These data were analyzed inductively and the author found that, in addition to scientific reasoning skills, students developed an in-depth understanding that scientific knowledge is not absolute, but subject to change.

As can be expected, not all studies involving explicit instruction related to NOS have met with success (Leach, Hind, & Ryder, 2003). In this particular investigation, the explicit instructional approach was not effective in promoting improved student views.

Among the volumes of research that focus on effecting change in conceptions of NOS, a small minority of studies focus on the impact that one's conceptions of NOS have on other variables of interest. Sadler, Chambers, and Zeidler (2004) focused on how students' conceptions of NOS impacted how they interpreted and evaluated conflicting evidence on a socioscientific issue. Eighty-four high school students were asked to read contradictory reports related to global warming. A subsample of 30 students was interviewed in order to corroborate their written responses. The participants displayed a range of views on three aspects of NOS: empiricism, tentativeness, and social embeddedness. The authors claimed that how the students reacted to conflicting evidence was at least partially related to their views on NOS.

It is important to reiterate that not all of the existing research on teaching and learning of NOS could be presented here because of space considerations. An attempt was made to present the most prominent studies in terms of their impact on current research. However, the research studies that have not been included have provided findings that are consistent with what has been presented.

Assessing Conceptions of Nature of Science

Although there have been numerous criticisms of the validity of various assessment instruments over the years, students' and teachers' understandings have consistently been found lacking. This consistent finding, regardless of assessment approach, supports the notion that student and teacher understandings are not at the desired levels.

The history of the assessment of nature of science mirrors the changes that have occurred in both psychometrics and educational research design over the past few decades. The first formal assessments, beginning in the early 1960s, emphasized quantitative approaches, as was characteristic of the overwhelming majority of science education research investigations. Prior to the mid-1980s, with few exceptions, researchers were content to develop instruments that allowed for easily "graded" and quantified measures of individuals' understandings. In some cases, standardized scores were derived. Within the context of the development of various instruments, some open-ended questioning was involved in construction and validation of items. More recently, emphasis has been placed on providing an expanded view of an individual's beliefs regarding nature of science. In short, in an attempt to gain more in-depth understandings of students' and teachers' thinking, educational researchers have resorted to the use of more open-ended probes and interviews. As mentioned previously, a new critical analysis of assessment, which uses a significant and important perspective, is provided in the following chapter by Abd-El-Khalick.

Research on Nature of Science: Quo Vadis?

After more than 50 years of research related to students' and teachers' conceptions of NOS, a few generalizations can be justified. The following list is the same as the one included in the previous handbook (Lederman, 2007) because the overwhelming majority of research since 2005 has served to further reinforce and give the research community more confidence in what we had previously determined:

- K–12 students do not typically possess "adequate" conceptions of NOS.
- K–12 teachers do not typically possess "adequate" conceptions of NOS.
- Conceptions of NOS are best learned through explicit, reflective instruction as opposed to implicitly through experiences with simply "doing" science.
- Teachers' conceptions of NOS are not automatically and necessarily translated into classroom practice.
- Teachers do not regard NOS as an instructional outcome of equal status with that of "traditional" subject matter outcomes.

Although volumes of research have been completed since the 1950s, at this point in the history of research on nature of science, the research has been relatively superficial in the sense of an "input-output" model with little known about the in-depth mechanisms that contribute to change in teachers' and students' views. Even the more recent efforts that have documented the efficacy of explicit, reflective approaches (Abd-El-Khalick & Lederman, 2000a) to instruction are superficial in the sense that students and/or teachers are pre-tested and post-tested relative to an instructional activity or set of activities. The specific mechanisms of change and/or the dynamics of change have yet to be explored in depth. We simply have found out under what situations change has occurred in the desired direction. Clearly, much more work is needed before we, as a research community, can feel confident in making large-scale recommendations to teachers and professional developers.

Still Waters Run Deep

It is easy to look at the research on NOS since the last handbook and conclude that there have not been many new insights into students' and teachers' understandings of NOS, how to effectively teach NOS, and how to assess NOS. The recent research has effectively provided stronger support for what we knew about these matters in 2005. However, beneath the surface of our empirical research literature, theoretical discussions and debates have been turbulent. One must wonder if the undercurrents promise to be productive. What follows is a discussion, in no particular order, of some of the major issues currently confronting our community.

Conceptualizing the Construct

Recently there has been much conversation about how NOS is conceptualized in our professional journals and at our professional meetings. The phrase/question often heard is, "Whose NOS are we measuring?" Actually the discussion is not new, and it began with Alters (1997) and it continues today (Irzik & Nola, 2011; Wong & Hodson, 2009, 2010). In the end, the argument always rests on the voice of scientists and how what they think is important is not being heard or used. Actually, the international reform documents specifying outcomes regarding NOS have had strong input from the scientific community. More importantly, the audience for which these outcomes have been specified is consumers of science, K–12 students, not scientists. However, some would rather engage in arguments about why "lists" of outcomes or outcomes derived from others than scientists are anathema (Allchin, 2011; Irzik & Nola, 2011; Wong & Hodson 2009, 2010) instead of focusing on what is appropriate for K–12 students to know and be able to do. We need to continually remind ourselves for whom the NOS outcomes have been written. The knowledge specified is for what is considered important for the attainment of scientific literacy by the general citizenry. Yes, you can dissect the construct of NOS down to its very esoteric levels (Irzik & Nola, 2011), but doing so reveals a construct that is far too abstract and esoteric for the general public. This really is no different than why we do not expect all high school graduates to understand the most in-depth aspects of the dark reactions of photosynthesis. Relying too heavily on what scientists think is appropriate for K–12 students can be problematic. For example, Allchin (2011) and Wong and Hodson (2009) point out that scientists do not think it is important to discuss the differences between scientific theories and laws. After all, scientists do not sit around and argue about whether a colleague's work amounts to a theory or law. However, most of us have heard about or experienced debates concerning the teaching of evolution and creationism side by side in the science classroom. Such debates impact students, teachers, the general public, and even the Supreme Court of the United States. Scientific creationists proudly state that "evolution is just a theory" just as creationism is a theory. Knowing the difference between theories and laws and what constitutes a scientific theory and/or law is necessary to diffuse the creationists' claims. Again, this aspect of NOS is stressed for the general public and students, not scientists.

What Is So Bad About Lists?

Discussions about what ideas should be considered under the rubric of NOS often include concerns about lists. Some worry that lists of NOS aspects (and there are many) end up as "mantras" for students to memorize and repeat (Matthews, 2012). Others (Allchin, 2011; Clough & Olson, 2008; Irzik & Nola, 2011; Wong & Hodson, 2009, 2010) feel lists provide too simplistic a view of NOS. Lists serve an important function, as they help provide a concise organization of the often complex ideas and concepts they include. Each item on a list is just a label or symbol for a much more in-depth and detailed elaboration. If "tree" is included in a list, it is simply a referent for all the structures and processes that are involved in what is to be a "tree." The table of contents at the beginning of this book is a list, just as the index at the end of the book is. There are numerous science education reform documents that specify and delineate what students should know and be able to do (i.e., standards). These are also lists of learning outcomes, even though the standards can be as long as a paragraph. The only problem with a list is related to how it may be used. If students are asked to simply and mindlessly memorize a list, then there is a problem. But the problem is with pedagogy and not with the list. In their article concerned with conceptualizing NOS in terms of *family resemblance,* Irzik and Nola (2011) point out that they have produced a depiction of NOS that is much more informative and comprehensive than a list. However, what is presented is no different than a list. Their outcomes are formatted as a matrix as opposed to a linear format, but it is still a list. Often these "lists" are considered a product of the consensus approach to conceptualizing aspects of NOS. An excellent discussion about the consensus model and other criticisms concerning current views about NOS, discussed by Wong and Hodson (2010), among others, can be found in Abd-El-Khalick (2012). All is not lost, however; there remains support for the usefulness of lists (Abd-El-Khalick, Bell, & Lederman, 1998; McComas, 2008). Indeed, the knowledge and outcomes specified in the Next Generation Science Standards (NGSS Lead States, 2013) is a list as well.

Again, lists are a valuable tool that humans use to summarize key points or ideas. In the hands of an expert teacher, listings of desired student outcomes help guide instruction and help identify prerequisite knowledge students need to master before they can achieve a sophisticated understanding of the concept on the list. The value of a list is in how it used, but lists are not inherently good or bad.

There is one other issue when it comes to lists and consensus models. Some researchers (Duschl & Grandy, 2013) appear content to characterize "consensus-based heuristic principles" (i.e., lists) as out-of-date and too general, in contrast to "scientific practices in domain-specific contexts" as can be found in the Next Generation Science Standards (NGSS Lead States, 2013). Unfortunately, this position not only constitutes a gross misrepresentation of the views of nature of scientific knowledge represented in these "lists" but also shows a considerable lack of understanding of how these "lists" are used in actual classroom practice, and of general science pedagogy for that matter. Duschl and Grandy (2013) contend that this vision "focuses on the use of heuristic principles and domain general consensus-based statements taught in the context of lessons and activities," where by an aspect of NOS is connected to a specific activity meant for its explication. By contrast, the view of NOS undergirding the work of the researchers they criticize (Abd-El-Khalick, 2012; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Niaz, 2009) is one that strongly advocates NOS as an overarching instructional objective that permeates a science curriculum. The simple conception forwarded by Duschl and Grandy could only be characterized as simply poor teaching. Perhaps such inaccurate characterizations of how "lists" are used persist because many individuals fail to carefully consider the science curriculum, classroom practice, and the audience of students.

Why Can't We Agree to Disagree?

Recently, far too much discussion at professional meetings and on journal pages has focused on the lack of consensus on a definition or characterization of NOS. In short, scholars would rather argue about the need to reach consensus before an assessment of NOS can be developed. Why is NOS held to a higher standard than other content in science? How many of the concepts and ideas in science have achieved absolute consensus before we attempt to teach these ideas to students and assess what they have learned? Does every curriculum worldwide focus on the same structures of the human heart? As previously discussed, when one considers the developmental level of the target audience (K–12 students), the aspects of NOS stressed are at a level of generality that is not at all contentious. Nevertheless, if one is not willing to let go of the idea that the various aspects of NOS lack consensus and that assessment of NOS is, therefore, problematic, the "problem" is easily handled. One's performance on a NOS assessment can simply be used to construct a profile of what the student knows/believes about scientific knowledge. In terms of the aspects of NOS to be assessed, there is no reason to require that all assessments measure the exact same understandings. If the focus is just upon the assessment of understandings that are considered to be important for scientifically literate individuals to know, then there is no reason to require an agreed-on domain of NOS aspects. Different assessments may stress, to one degree or another, different aspects of NOS. This is no different than assessing students' understandings of the human heart. Different valid and reliable assessments stress and include different structures.

Knowing Versus Doing

There has been a perennial problem with developing assessments of nature of science that is connected to the research literature. All too often, assessments include students' performance or inquiry skills/procedures within instruments on NOS. In spite of more than half a century of research on NOS, some science education researchers (e.g., Allchin, 2011) continue to conceptualize NOS as a skill as opposed to knowledge and espouse the belief that engagement in the practices of science is sufficient for developing understandings of NOS. The view that NOS is a skill, thus conflating it with scientific inquiry, minimizes the importance of understanding both of these constructs and their related characteristics and further obfuscates their associated nuances and interrelationships. Moreover, this view is not consistent with the National Science Education Standards (NRC, 1996), Benchmarks for Science Literacy (AAAS, 1993), the Framework for K–12 Science Education (NRC, 2011), and the Next Generation Science Standards (NGSS Lead States, 2013), all of which describe NOS as knowledge. Admittedly, the Next Generation Science Standards is not always clear on this matter. While focusing on scientific inquiry, the Benchmarks stress that students should develop understandings about SI beyond the ability to do SI, as this understanding is *sine qua non* to being scientifically literate, as is the case for understandings of NOS. Unfortunately, the Next Generation Science Standards (NGSS Lead States, 2013), which are derived from the Framework for K–12 Science Education, are not so clear regarding their "vision" for promoting understandings of NOS.

NOS has been a central theme underlying the goals of science education since the 1950s. The reason for this is that NOS understandings (irrespective of how these are defined at the time) are considered central to the goal of scientific literacy. While almost every other meaningful theme underlying past reform documents such as the Benchmarks for Science Literacy (AAAS, 1993), National Science Education Standards (NRC, 1996), and Framework for K–12 Science Education appear in the NGSS, the same cannot be said for NOS. Although NOS was eventually included in the NGSS, it has been trivialized as knowledge that will naturally follow the mastering of science practices, an assumption that runs contrary to the research of the past 20 years. In addition, NOS is sparingly included in any of the Performance Expectations. Consequently, regarding the teaching of NOS and the assessment of students' understandings, we may indeed be moving forward into the past.

The conflation described is inherently linked to the assumption that NOS is learned by having students DO science. That is, if students are involved in authentic scientific investigations, they will also come to an understanding about NOS. The empirical research reviewed in this handbook has consistently shown this assumption to be false. Clearly, students' ability to DO science is an important educational outcome, but it is not the same as having students reflect on what they have done and its implications for the knowledge developed. In terms of developing assessments of NOS, there must be a more concerted effort to realize that NOS is a cognitive outcome, not a "performance" outcome. Indeed, the lack of clarity in the NGSS may be promoting the continuance of the confusion about NOS and science practices (or inquiry). Quite recently, Salter and Atkins (2014) found a disconnect between measures of NOS understandings and students' ability to engage in science practices. The literature reviewed in this handbook, and the previous handbook, would have predicted such a disconnect (i.e., doing science does not necessarily result in learning of NOS). However, the authors chose to interpret their findings as meaning that current measures of NOS are not adequate to assess students' abilities in doing inquiry. They advocated that we need instruments that assess "procedural NOS." Unfortunately, "procedural" means doing science and totally ignores prior research on NOS.

Related to this last issue is that a small minority of individuals (e.g., Sandoval, 2005) who insist that students' and teachers' understandings of NOS are best assessed through observations of behavior during inquiry activities (i.e., knowledge in practice). The literature clearly documents the discrepancies that often exist between one's beliefs/knowledge and their behaviors. More concretely, if an individual believes that scientific knowledge is tentative (subject to change) and another individual believes the knowledge to be absolute/static, how would this be evident in their behavior during a laboratory activity? If a student recognizes that scientific knowledge is partly subjective, how would this student behave differently during a laboratory investigation than would a student with differing beliefs? This assessment approach only adds an unnecessary layer of inference. In the end, we must not forget that NOS is a cognitive outcome, not a behavior as some continue to insist (Allchin, 2011).

Epilogue

There is little doubt that the arguments described in this chapter will continue. At times it appears that our goal in academia is more about the debate than the purpose we are trying to accomplish. At the beginning of this chapter, the question was asked, "Why should students learn about NOS?" Our ultimate goal in science education has primarily been to have a literate citizenry, to have students develop into scientifically literate individuals. However, the relationship between scientific literacy and NOS has been made before (AAAS, 1993; NRC, 1996; NSTA; 1982, among others). Often arguments about the parameters and meaning of NOS lose sight of the ultimate goal of scientific literacy. Understanding NOS does not make a scientifically literate person by itself. Literate individuals also have a functional understanding of science content (interestingly, most consider NOS content knowledge), know how the content was developed (i.e., ability to do and know about inquiry/practices), and the ability to make informed decisions about scientifically based personal and societal issues. All of these abilities and knowledge are important. There are more than a few individuals who want to parcel out the knowledge and skills previously discussed in a different manner than it has been, but in the end we should keep our attention on what we decide is important for students to know and be able to do. For this reason, it is not at all productive to argue about what should be included under the rubric of NOS. It makes little sense to argue about whether lists are good or bad. The focus of our attention should always be on what we consider important for students and teachers and the general public to know and be able to do, not the label we use. And when we consider the knowledge and abilities to be assessed, let us not forget the audience, their emotional and cognitive developmental levels, and their needs as citizens. It is for this reason we often get into trouble: when the advice of well-meaning individuals, with little knowledge or experience with K–12 instruction, curriculum, and K–12 students, is given priority over those who have such experience and knowledge.

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