Science & Education 7: 511–532, 1998.

The Nature of Science in Science Education: An Introduction

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ABSTRACT. After providing a definition of the nature of science (NOS) for science education, we argue that a pragmatic consensus exists regarding NOS topics most important for a scientifically literate society. Hence, NOS instruction should take a more prominent role in the science curriculum. While the relationship between a teacher's NOS knowledge and their pedagogical decision-making is not straight-forward, we maintain that a complex interplay does exist. While more science coursework and research experience have been suggested to improve science teachers' understanding of NOS, neither approach is empirically supported. However, explicit attempts at NOS instruction in science teacher education have been effective. This article, which is an abridged version of one appearing in McComas (1998), concludes with the suggestion of a desired state for NOS instruction.

Hence, it is vital that science teachers and their students gain an understanding of the nature of science, a hybrid field blending aspects of various social studies of science such as the history, sociology and philosophy of science with research from the cognitive science into a rich and useful description of what science is and how it functions.

Science has an ever present but often subtle. impact on virtually every aspect of modern life – both from the technology that flows from it and the profound philosophical implications arising from its ideas. However, despite this enormous effect, few individuals even have an elementary understanding how the scientific enterprise operates. This lack of understanding is potentially harmful, particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence provided in legal proceedings. At the foundation of many illogical decisions and unreasonable positions are misunderstandings of the character of science.

CONSENSUS VIEWS REGARDING THE NATURE OF SCIENCE

Before embarking on the development of any course or unit of study designed to assist teachers or students in the acquisition of an understanding of the nature of science, one must have some notion of what knowledge is worth possessing for incorporation into curricula and classroom discourse. In spite of significant progress toward characterizing science, much

disagreement remains. Almost thirty years ago, Herron (1969) claimed that no sound and precise description exists concerning the nature and structure of science, and more recent voices echo that sentiment. As an example, Lauden states that '. . . we have no well-confirmed general picture of how science works, no theory of science worthy of general assent' (in Ginev, 1990, p. 64). Duschl (1994) also cites the lack of consensus regarding the appropriate image of scientific inquiry and the growth of scientific knowledge while Lederman (1992) notes that the nature of science is neither universal nor stable. While we agree that particular philosophical issues and even the content of the nature of science will always be somewhat contentious, views regarding topics most important for a scientifically literate society are far less controversial. We concur with Welch's (1984) view acknowledging a lack of complete agreement regarding what science is and how it works, but maintain that significant consensus exists regarding fundamental issues in the nature of science relevant to science education.

During the past three decades, a number of scholars including Robinson, 1968, 1969; Martin, 1972; Ennis, 1979; Giddins, 1982; Lederman, 1983; Duschl, 1988, and Matthews, 1994 have provided both explicit and implicit suggestions for the characteristics of science to be included in science instruction.

For example, the nature of science recommendations contained in eight international science education standards documents (McComas & Olson, 1998) show significant overlap (Table 1). Of course, the issues included in the following table are complex, but we are making recommendations for K-12 science students and their teachers – not future philosophers of science.

Knowing who the recommendations are for and the degree of sophistication appropriate for that target group is an important consideration when crafting nature of science standards. Moreover, the image of science emerging from the social studies of science is sufficiently robust that science educators can move forward with confidence and provide a more realistic picture of the strengths and limitations of this thing called science (Smith *et al.*, 1997). Where consensus does not exist, science teachers should present a plurality of views. As Matthews (1997) argues, the purpose of nature of science education is not to indoctrinate, but to address reasons for accepting a particular position.

THE NATURE OF SCIENCE IN SCIENCE EDUCATION: HISTORICAL PERSPECTIVE

Advocacy for students' understanding of science and its nature can be traced back to the early years of this century. Although at that time the phrase 'understanding the nature of science' was not clearly stated, some elements and characteristics of science were noted as goals worth pursuing

TABLE 1
A consensus view of the nature of science objectives extracted from eight international science Standards Documents

- Scientific knowledge while durable, has a tentative character
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism
- There is no one way to do science (therefore, there is no universal step-by-step scientific method)
- Science is an attempt to explain natural phenomena
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence
- People from all cultures contribute to science
- New knowledge must be reported clearly and openly
- Scientists require accurate record keeping, peer review and replicability
- Observations are theory-laden
- Scientists are creative
- The history of science reveals both an evolutionary and revolutionary character
- Science is part of social and cultural traditions
- Science and technology impact each other
- Scientific ideas are affected by their social and historical milieu

in science teaching. For example, Lederman (1992) reported that the Central Association of Science and Math Teachers in 1907 strongly emphasized the scientific method and processes of science in science teaching. Hodson (1991) cites Dewey's 1916 argument that understanding scientific method is more important than the acquisition of scientific knowledge. Jaffe (1938) in his high school textbook *New World of Chemistry* listed nature of science objectives such as a willingness to swing the judgment while experiments are in progress, willingness to abandon a theory in light of new evidence, and knowledge that scientific laws may not be the ultimate truth.

In 1946 James Bryan Conant delivered his famous Terry Lectures at Yale on the general topic of a historical approach to science instruction (1951). He suggested that all students must understand the tactics and strategies of science. It was not until the second half of this century that the construct we now call the nature of science was stated explicitly as a major aim of science teaching by the National Society for the Study of Education:

> There are two major aims of science-teaching; one is knowledge, and the other is enterprise. From science courses, pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts . . . A student should learn something about the character of scientific knowledge, how it has been developed, and how it is used. (Hurd, 1960, p. 34)

One of the primary justifications for the inclusion of the nature of science in science education comes from Schwab (1964) who was both a philosopher and science educator. He correctly observed that science is taught as an 'unmitigated rhetoric of conclusions in which the current and tempo-

ral constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths' (p. 24).

With the advent of the 1960s science curriculum projects, an effort was made by some developers to shift science instruction away from the primary focus concerning, 'what do scientists know', to an examination of the question 'how do scientists know' – reflecting Schwab's (1960) emphasis on 'what do scientists do?' Klopfer's (1964–66, 1969) *History of Science Cases* and *Harvard Project Physics* (Rutherford, Holton and Walton, 1970) and Schwab's (1963) seminal contributions to the Biological Science Curriculum Studies programs were important attempts to illustrate both the process and products of science in formal curricula.

At the end of the nineteen sixties, several important books were published advocating and defining elements of the nature of science necessary for inclusion in school science curricula. Robinson (1968) in *The Nature of Science and Science Teaching* provided science educators ready access to the philosophy of science for the first time. In his book, Robinson provided an overview of the nature of physical reality, aspects of physical description including probability, certainty and causality, and view of the nature of science in various science disciplines. He concluded with considerations for the interplay between science instruction and the nature of science. In *Concepts of Science Education: A Philosophical Analysis*, Martin (1972) reiterated many of the arguments put forward by Robinson in supporting NOS in science instruction. In addition, he reviewed many of the important concepts from the philosophy of science including the value of inquiry learning, the nature of explanation, and the character of observation both in science and in science learning. In the section on goals of science education he specifically stated that the student should acquire a range of scientific propensities.

Despite these early and now-neglected plans and rationales, science teachers and science curricula seem rigidly bound to a tradition of communicating the facts or end products of science while generally neglecting how this knowledge was constructed. After almost fifty years of interest concerning the nature of science in science curricula, little change has occurred. For example, in 1982, Kilborn suggested that science instruction does not present the essential background for understanding the meaning of science. Ten years later, Gallagher (1991) observed that science lessons revealed an emphasis on the body and terminology of knowledge in science rather than the nature of science. Fleury and Bentley (1991) refer to the way that science knowledge comes to exist as the 'infrastructure of scientific knowledge' and argue that if knowledge of the infrastructure is faulty then any understanding constructed on it will be fallible.

Most sobering is the assertion of Bentley and Garrison (1991) that for most science students, a description of the NOS is relegated to a few paragraphs at the beginning of the textbook quickly glossed over in favor of the facts and concepts that cram the remainder of the book and generally fill the course. And the ideas put forth in textbooks and school

science concerning the nature of science are almost universally incorrect, simplistic, or incomplete. Duschl (1994) recently argued that students are learning facts, hypothesis, and theories of science – the 'what' of science – but they are not learning where this knowledge originated – the 'how' of science.

Recently this disheartening situation is facing more aggressive attack. Discussions concerning a role for nature of science in school science have increased rapidly and few now argue with the proposition that school science experiences should include significant attention to how science works including how knowledge is created and established. In the past decade alone a number of conferences of the International History, Philosophy and Science Teaching Group have addressed the role of the social studies of science in science education.[1] Furthermore, the main objective of a number of additional meetings (Pavia in 1983, Munich in 1986 and Paris in 1988) has been to investigate why and how history and philosophy of science may be integrated in school science. Michael Matthews' 1994 book – *Science Teaching; The Role of History and Philosophy of Science* – provides an extensive argument for the inclusion of the nature of science in science instruction.

Incorporating the nature of science in school science has been widely embraced by organizations such as the Association for Science Education (1981) in Britain and organizations in the United States such as the National Science Teachers Association (1995), the American Association for the Advancement of Science (1989, 1993) and the National Research Council (1996). Many contemporary science educators agree that encouraging students' understanding of the nature of science, its presuppositions, values, aims, and limitations should be a central goal of science teaching. As an example, Morris Shamos (1995) argues in *The Myth of Scientific Literacy* that while knowledge of science content may not be necessary for obtaining science literacy, understanding the nature of science *is* prerequisite to such literacy.

THE NATURE OF SCIENCE IN SCIENCE EDUCATION. A RATIONALE

The Current State of Students' and Teachers' Knowledge of the Nature of Science

A number of studies exist that document students' misconceptions concerning the nature of science (Clough, 1995; Lederman, 1992; Meyling, 1997; Rowell & Cawthron, 1982; Rubba, Horner & Smith, 1981). Ryan and Aikenhead (1992) collected the responses of more than two-thousand upper secondary students, concluded that they confused science with technology, and were only superficially aware of the private and public side of science and the effect that values have on scientific knowledge. Moreover, they reported that:

- 46% held the view that science could rest on the assumption of an interfering deity;
- Only 17% were quite certain of the inventive character of scientific knowledge;
- 19% believed that models are actual copies of reality;
- Only 9% chose the contemporary view that scientists 'use any method that might get favorable results'; and
- 64% of students expressed a simplistic hierarchical relationship in which hypotheses become theories and theories become laws, depending on the amount of 'proof behind the idea'.

While acknowledging that a number of out-of-school factors misrepresent the nature of science, overwhelming evidence exists that school science is at least equally culpable. Almost 50 years ago (Anderson, 1950) concluded that teachers were more concerned with imparting scientific facts than helping students understand the processes of science – an indication that something was awry regarding teachers' notions of the nature of science. Miller (1963), after conducting one of the earliest and frequently cited studies of teachers' views of the image of science, concluded that many science teachers and their students failed to demonstrate understanding of how science works. Several years later, Schmidt (1967) replicated Miller's study and made essentially the same conclusions. Elkana (1970) claimed that teachers' understanding of the philosophy of science trailed developments in the philosophy of science by some twenty to thirty years. In 1978 Cawthron and Rowell concluded that science teachers take a naive-realist position of science, maintain that scientists have particular characteristics, and employ scientific method to account for the achievements of science. Four years later they argued (Rowell and Cawthron, 1982) that many science teachers subscribe to an inductivist-empiricist outlook of science. Brush (1989) noted that science teachers are not generally aware of the social and cultural construction of scientific thought. DeBoer (1991) in his review of the history of science education states that the positivist view of the philosophy of science from the last century still informs much classroom practice and pervades most available curriculum materials. Melado (1997) reports that while the preservice science teachers in his small study showed more multi-faceted NOS views than a positivist empirical label implies, they were insecure and contradictory in their statements and admitted they had never before reflected on the epistemology of science. Tragically, too often science teachers simply do not consider such issues important in teaching and learning (Bell *et al.*, 1997; King, 1991; Lakin and Wellington, 1994).

The Value of Nature of Science for Teaching and Learning

The significant misconceptions that both students and teachers hold regarding the nature of science, by themselves, represent an important justification for including the social studies of science in science courses

and preservice science teacher education programs. Driver et al. (1996) have suggested five additional arguments supporting the inclusion of the nature of science as a goal of science instruction. The arguments include the utilitarian view that 'an understanding of the nature of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter . . .' (p. 16). This is related to the democratic view that people must understand the NOS 'to make sense of socio-scientific issues and participate in the decision-making process' (p. 18) and the cultural argument that such understanding is necessary 'in order to appreciate science as a major element of contemporary culture' (p. 19). The fourth rationale is moral, to understand the '. . . norms of the scientific community, embodying moral commitments which are of general value' (p. 19). Driver's final justification for including the nature of science in science instruction is that it 'supports successful learning of science content' (p. 20).

Matthews (1997) argues that questions regarding the nature of science are inherent in many education issues such as multicultural science, the evolution/creation public education controversy, feminist critiques of modern science and their suggestions for science program reform, the place of religion in science education, environmentalism and new-age science, and the notion that learning science will result in an understanding of its nature while at the same time causing students to become more scientific in solving life's problems.

Moreover, students in a recent study by Meyling (1997) showed significant interest in the nature of science. Two-thirds of the physics students who experienced instruction regarding epistemological issues showed interest in more epistemology. In contrast, only one-third of students not experiencing such instruction showed interest. Students in this study approved of NOS discussions and most indicated their epistemological conceptions had changed.

NOS to Enhance the Learning of Science Content

Evidence suggests that knowledge of the nature of science assists students in learning science content. For example, Songer and Linn (1991) illustrated the importance of students having dynamic rather than static views of science in developing a conceptual understanding of topics such as thermodynamics. In a sample of 153 eighth-grade physical science students with instruction emphasizing hands-on experiments, the authors were able to characterize students' views of science as either static, mixed, or dynamic. The static view of science is the idea that science is a group of facts that are best memorized. The dynamic view of science posits that scientific knowledge is tentative, and the best way to understand this knowledge is by understanding what scientific ideas mean and how they are related. Although the authors did not address the mixed view, they

did find that students with dynamic views of science acquired a more integrated understanding of thermodynamics than those with static views.

NOS Knowledge to Enhance Understanding of Science

Understanding how science operates is imperative for evaluating the strengths and limitations of science, as well as the value of different types of scientific knowledge. For instance, science teachers may understand the atomic model, Boyle's law, and evolutionary theory, but may not understand what law, theory, and model mean in the discipline of science. Hence, ridiculous statements like, 'evolution is *only* a theory' or 'when such-and-such a theory is proven it will become a law' may result. One of the major theses of Michael Martin's (1972) book '*Concepts of Science Education: A Philosophical Analysis*' is that philosophy of science study is beneficial to the science educator. Studies in philosophy of science will clarify teachers' thought about the nature of science and help them understand the roles and methods which guide study in the discipline. As Manuel (1981) writes:

> This more philosophical background advocated for teachers would, it is believed, enable them to handle their science teaching in a more informed and versatile manner and to be in a more effective position to help their pupils build up the coherent picture of science-appropriate to age and ability – which is so often lacking (p. 771).

Furthermore, those who comprehend the durable, yet revisionary, nature of scientific knowledge will not be confused by changing science concepts or the disappearance of particular science ideas learned earlier. Individuals who understand how science works will likely be less cynical about the scientific enterprise (Connelly *et al.*, 1977, pp. 7–8). Because science is often wrongly perceived primarily as a body of literal truths, entire fields of knowledge are sometimes questioned when single facts are revised. Perceiving science as a process of improving our understanding of the natural world turns the notion of tentativeness into a strength rather than a weakness.

Surely, lack of knowledge about the history and philosophy of science would hinder teachers' incorporation of philosophical aspects of science in their teaching. In a 1991 study, King showed that the science teachers he investigated attributed the difficulties of incorporating ideas such as discovery and relevance in their science instructions to their ignorance about history and philosophy of science.

NOS to Enhance Interest in Science

A sensitivity to the development of scientific knowledge may also make science itself and science education more interesting. Tobias (1990) maintains that a number of potential university science students – those she calls the second tier – lament that science classes ignore the historical, philosophical, and sociological foundations of science. Incorporating the

nature of science while teaching science content humanizes the sciences and conveys a great adventure rather than memorizing trivial outcomes of the process. The purpose is not to teach students philosophy of science as a pure discipline hut to help them be aware of the processes in the development of scientific knowledge (Matthews, 1989). Here we see justification for Driver's (1996) 'cultural argument' for learning about the nature of science.

NOS Knowledge to Enhance Decision Making

The 'democratic argument' for the nature of science instruction (Driver *et al.*, 1996, p. 18) may be illustrated in a number of ways, but certainly having accurate views about how science functions is vital for informed decision making. For example, the funding of scientific and technological research is an increasingly important topic with respect to governmental budget decisions. Ample evidence exists (Ryan and Aikenhead, 1992) to suggest that science is often confused as technology leading the public to support science because they wrongly see it as providing society with gadgets, vaccines, and other practical outcomes that improve everyday living. However, basic research is not directly concerned with practical societal outcomes, but rather an understanding of the natural world for its own sake. The public's failure to see the importance of basic research in technological innovations may have significant societal consequences when funding decisions are made (Elmer-Dewitt, 1994).

The public education controversy involving evolution and creationism nicely illustrates the importance of an informed citizenry regarding the nature of science. John Moore (1983) writes:

> It becomes evermore important to understand what is science and what is not. Somehow we have failed to let our students in on that secret. We find as a consequence, that we have a large and effective group of creationists who seek to scuttle the basic concept of the science of biology . . . It is hard to think of a more terrible indictment of the way we have taught science . . .

Far too many secondary science teachers avoid teaching biological evolution. However, Scharmann and Harris (1992) found that promoting an applied understanding of the nature of science reduced teachers' anxiety toward teaching this fundamental idea. Johnson and Peeples (1987) found that as students' understanding of the nature of science increases, they are more likely to accept evolutionary theory. Dagher and Boujaoude (1997) investigated how students with different religious backgrounds accommodated their beliefs with biological evolution and recommended that teachers devote significant attention to values, beliefs and the nature of science. Clough (1994) made several practical suggestions regarding NOS instruction for reducing students' conflicts with the theory of evolution. If students and teachers simply understood the distinction between science and religion, that alone would ease the occasional tension caused by discussions of evolution.

NOS Knowledge to Enhance Instructional Delivery

Matthews (1994) has argued for the inclusion of NOS courses in science teacher education programs. The examples he provided demonstrates that a firm grounding in the nature of science is likely to enhance teachers' ability to implement conceptual change models of instruction. Studying the process of historical conceptual development in science may shed some light on individual cognitive development (Wandersee, 1986). For example, many students' ideas parallel that of early scientific ideas, suggesting that 'alternative conceptions' may sometimes be a better description than 'misconceptions'. The persistence of students' naive ideas in science suggests to some that teachers could use the historical development of scientific concepts to help illuminate the conceptual journey students must make away from their own naive misconceptions. In other words, teachers' interest in NOS could assist in understanding the psychology of students' learning (Matthews, 1994). Understanding the nature of science illuminates the construction and reconstruction of ideas and facilitates an understanding of how children also construct meaning from their experiences.

The social studies of science also makes clear that knowledge, as well as being a product, is also a tool for further research. A careful reading of the history of science confirms the view that scientific knowledge is not exclusively determined by empirical data. Particular views regarding how scientific knowledge is constructed (Latour, 1987; Latour & Woolger, 1986; Knorr-Cetina, 1981; Kuhn, 1970; Mendelsohn, 1977; Mulkay & Gilbert, 1982; Shapin, 1982) has much in common with conceptual change theory. This makes the nature of science useful as a disequilibrating agent in changing science teachers' views of learning and teaching. For example, some of the resistance to conceptual change theory among classroom teachers arises from the mistaken notion that knowledge of the natural world is completely objective – existing independently of the searching individual. This view of science gives the impression that learning is a fairly straightforward process of replacing what is known with that which the scientific community has *discovered* is right. However, the history of science may also reveal a fierce battle to *construct* meaning concerning the natural world. This construction, sometimes requiring enormous effort and time, is not a straightforward process. When science is seen in this light, children's misconceptions and difficulties in learning contemporary science ideas are understandable. Moreover, Duschl (1987) goes so far as to claim that in order to teach science as inquiry, teachers themselves must have an understanding of the nature of science.

COMMUNICATING THE NATURE OF SCIENCE

The Role of Textbooks and Activities

Science teachers' over-dependence on textbooks is well documented (Weiss, 1993) and the United States has the disconcerting distinction of ranking first in frequency of textbook reading as a means of instruction (Lapointe, Mead, and Phillips, 1989). The situation is much the same as described by Stake and Easley (1978) who found that more than 90 percent of the science teachers surveyed indicated they used textbooks or other instructional materials 90 to 95 percent of the time. They write

> Behind nearly every teacher-learner transaction . . . lay an instructional product waiting to play its dual role as medium and message. They command teacher's and learner's attention. In a way, they virtually dictated the curriculum. The curriculum did not venture beyond the boundaries set by the instructional materials (p. 66).

Thomas Kuhn, in *The Structure of Scientific Revolutions* (1970) makes clear that science textbooks convey an image of what science is and how it works. He writes that '[m]ore than any other single aspect of science, [the textbook] has determined our image of the nature of science and of the role of discovery and invention in its advance' (p. 143).

The significant role in instruction played by textbooks necessitates a look at how they portray the nature of science. Munby (1976) speculated that the language appearing in curriculum materials may significantly affect students' understanding of the nature of science. In the science textbooks he analyzed, two distinct positions regarding the nature of scientific knowledge were implicit in the language used instrumentalism and realism. Consider the following passage taken from *Physics: Matter, Energy, and the Universe* by Harnwell and Legge (published in 1967):

> If a glass rod and a piece of fur are chosen as the test materials, it is found initially that they show no tendency either to attract or repel one another. If they are rubbed smartly together and quickly separated, it is found that they tend to attract one another. Our description of the process says that the materials have become electrified or charged, and that the force of attraction arises in consequence . . . On the evidence of such simple experiments . . . , early experimenters were led to construct a qualitative description of electrification in terms of the separation of some quality or substance associated with the materials being rubbed together. (in Munby, 1976, p. 121)

Munby (1976) states that when students read phrases like '. . . our description of the process says . . .' and '. . . experimenters were led to construct . . .', they may easily interpret this to mean that science ideas have an inventive character and, thus, may not exactly describe reality. The position that scientific ideas are useful tools to help us understand the natural world fits nicely with an instrumentalist view of science knowledge.

Consider a second passage from *Conceptual Physics: A New Introduction to Your Environment* by Hewitt (published in 1971):

> Although the innermost electrons in an atom are bound very tightly to the oppositely charged nucleus, the outermost electrons of many atoms are bound very loosely and can be easily dislodged. The force with which the outer electrons are held in the atom varies for different substances. The electrons are held more firmly in rubber than in fur, for example. Hence, when a rubber rod is rubbed by a piece of fur, electrons transfer from the fur to the rubber rod. The rubber therefore has an excess of electrons and is said to be negatively charged. The fur, in turn has a deficiency of electrons and is said to be positively charged. (In Munby, 1976, p. 121)

The description of electrical phenomena in this passage (e.g., electrons are bound, dislodged, transferred) conveys an entirely different message concerning the ontological status of electrons. Here the role of humans in producing explanations for phenomena is missing and students are left to infer that scientists simply found electrons while doing experiments. Therefore, Munby argued, students may derive different views about the nature of science depending on the way that science knowledge is communicated in textbooks. He further suggested that the societal attitudes toward science can be explained by the way that science has been coimnunicated in schools. 'The fact that science is viewed as a source of true, reliable, and dependable knowledge might be a consequence of it being taught that way' (Munby, 1976, p. 123).

Other curricula decisions also impact students' notions about the nature of science. As an example, the form of laboratory activities conveys much about science processes and the construction of knowledge. Unfortunately, these experiences are often cookbook or verification type laboratory activities which again portray science as a rhetoric of conclusions totally divorced from human influence. Clough and Clark (1994) have suggested a different approach to laboratory exercises that more actively engages students in science content and accurately portray many significant issues in the nature of science. They advocate placing students in small research teams that are responsible for developing experiments to investigate a particular question posed by the instructor. Students must make important decisions concerning the experimental set-up, collection of relevant data, its interpretation, and judgements regarding the veracity of their work. Ensuing negotiation of meaning conveys a very different picture of science than typical cookbook verification lab work where students are following recipes to get preordained results. This suggestion is supported by the work of Burbules (1991) who suggests that classrooms should look like a research laboratory where students participate in science activities as part of a social group. Earlier, Haukoos and Penick (1983) compared the influence of two classroom climates on students' learning of science process skills and content achievement in college level classes. While maintaining even gains in biology content, the students in the discovery climate classroom achieved significantly higher scores in science process skills as measured by the Welch Science Process Inventory.

The Role of the Teacher

Despite the pervasive and critical role of curricula, evidence is clear and substantial that teachers are the most influential factor in educational change (Duffee & Aikenhead, 1992; Eylon & Linn, 1989; Fullan, 1991; Good & Brophy, 1987; Koballa & Crawley, 1985; Laforgia, 1988; Langer & Applebee, 1987; and Shymansky & Penick, 1981) and that teachers make exemplary programs (Penick, Yager & Bonnstetter, 1986). For instance, after observing how science teachers assimilated new writing activities into their old ways of thinking, Langer and Applebee (1987, pp. 87, 137) wrote:

> For those who wish to reform education through the introduction of new curricula, the results suggest a different message. We are unlikely to make fundamental changes in instruction simply by changing curricula and activities without attention to the purposes the activities serve for the teacher as well as for the student. It may be much more important to give teachers new frameworks for understanding what to count as learning than it is to give them new activities or curricula. . . . (T)o summarize bluntly, given traditional notions of instruction, it may be impossible to implement successfully the approaches we have championed.

Teachers translate the written curriculum into a form ready for classroom application and decide what, how and why to learn. As Eisner (1985, p. 59) writes, 'In the final analysis, what teachers do in the classroom and what students experience define the educational process'. In fact, curricula has been claimed to constitute only 5 percent of the variance in students' learning (Welch, 1979), while science teachers' beliefs, knowledge, and practices represent the bulk of what the science instructional experience is for students (Smith, 1980).

One of the dominant activities in the classroom is teacher talk, and, therefore, important implications for student understanding could be derived from an analysis of teachers' verbal behavior. Munby's analysis of language applies equally well to teachers' verbal patterns.

Zeidler and Lederman (1989) extended Munby's findings by investigating whether or not teachers' presentation of subject matter has an impact on students' formulation of a world view of science. They administered the Nature of Scientific Knowledge Scale (NSKS) to 18 science teachers and their 409 students at the beginning and end of a semester and isolated six variables that 'reflected Munby's distinction between Realist and Instrumentalist language'. The six variables 'represent teachers' conceptions of the nature of science by way of the language teachers use to convey the subject matter'. In an earlier paper Zeidler and Lederman (1987) concluded from this analysis (pp. 6–7) that:

> The results reveal that the variables Testable, Developmental, Arbitrary Constructs, Anthropomorphic Language, Creativity and Subjective were highly significant in distinguishing between instrumental and realist conceptions of the nature of science with respect to teachers' language and subsequent changes in students' orientation. . . . It is concluded that the ordinary language teachers use to communicate science content does provide the context in which students formulate their own conceptions of the nature of science.

For example, when the teacher used ordinary language in discussing science constructs, the students tended to have a realist conception of science. A selection in which this is clear comes from Zeidler and Lederman (1989): 'This portion of the amino acid is called the amino group. It contains a nitrogen atom and two hydrogens. Always and forever . . . Exactly, always and forever' (p. 780).

Alternatively, students tended to have an instrumentalist view of science when the teacher used precise language in presenting science constructs. For example, . . . the periodic table is just something created by scientists to organize all the elements . . . This brings up again another problem that always exists in classification. Remember I told you that living organisms don't always fit into the neat little classifications that we have made up . . ' (Zeidler & Lederman, 1989, p. 778).

The conclusion is inescapable. The teachers' use of language influences their students' views of the nature of science. Lederman (1986), Haukoos and Penick (1983), Yager (1966), and Dibbs (1982) have all concluded that the way teachers conduct instruction in the classroom influence the way students think of science. In particular, the way teachers verbally present scientific enterprise has implications for the way in which students will form their views of science (Munby, 1976 & Ziedler and Lederman, 1989).

NATURE OF SCIENCE IN SCIENCE TEACHER EDUCATION

A dynamic understanding of science requires significant background in the social studies of science – taught to teachers in a manner so this knowledge is connected to what Lederman (1992) argues and Clough (1997) describes are those 'specific instructional behaviors, activities, and decisions implemented within the context of a lesson'. Obviously, science teacher education programs are in the best position to ensure that these practices are taught to science teachers. Without question, the calls for improving teachers' views of the nature of science through the inclusion of history and philosophy of science (HPS) courses in teacher education programs has a long history (Abimbola 1983; Anderson *et al.*, 1986; Gill 1977; Harms & Yager, 1981; Kimball, 1967; King, 1991; Loving, 1991; Manuel, 1981; Martin, 1972; Matthews, 1989, 1990, 1994; Nunan, 1977; Robinson, 1969 and Summers, 1982).

However, Summers (1982) noted that undergraduate science and science teacher education curricula do not emphasize the philosophical background of science content. As recently as 1988, Hodson lamented that 'the frequent calls for philosophy of science to become a major component in teacher-training courses have gone largely unheeded, so that there are now several generations of serving teachers with little or no understanding of basic issues in the philosophy of science and their significance in the design of effective learning experiences'. More recently, Gallagher (1991) indicated that science teacher education programs do

not seem to value nature of science instruction, and so, not surprisingly, teachers do not know how to teach about the nature of science. Loving (1991) surveyed 17 science educators whose institutions have undergraduate and/or graduate science education programs and found that only '13% of undergraduate science education majors and 19% of graduate students have a philosophy of science course in their degree plan . . .' (p. 828). Sadly, these numbers are likely optimistic. Matthews (1994) reports that in the United States, only the state of Florida requires prospective science teachers to complete a course in the history and philosophy of science. The lesson is clear that preservice science teachers arrive with largely unexamined beliefs about the nature of science, and, too often, graduate with such beliefs unchallenged in their teacher education programs (Haggerty, 1992; O'Brien & Korth, 1991). What this means is that teachers' ideas about the nature of science are 'picked up indirectly' (Matthews, 1994) rather than deliberately during their formal science teacher education experience.

The Effectiveness of Nature of Science Instruction

The lack of formal nature of science instruction in science teacher education programs is particularly disappointing when the evidence indicates that explicit instruction in the social studies of science does succeed in changing teachers' views concerning the nature of science. For example, Carey and Strauss (1968) investigated the influence of a science methods course on prospective secondary science teachers' views of science. The methods course started with an introduction to the nature of science through lectures, discussion, and outside readings. The pretests and posttests indicate significant enhancement in understanding the nature of science as measured by the *Wisconsin Inventory Science Process* (WISP). Similar results were obtained with experience science teachers using WISP (Carey & Strauss, 1970).

Billeh and Hasan (1975) conducted a four-week summer program for Jordanian secondary science teachers. The program consisted of lectures and demonstrations in teaching science, laboratory investigations emphasizing a guided discovery approach, twelve fifty-minute lectures on the nature of science, and enrichment activities designed to further promote understanding of science concepts and scientists at work. The findings indicated a significant positive difference when the posttest results were compared with the pretest measures of understanding the nature of science as measured by the *Nature of Science Test* (NOST).

Lavach (1969) studied an inservice program emphasizing the historical development of selected physical science concepts and noted that participants made statistically significant gains in their understanding regarding the nature of science as measured by the total score on TOUS. King (1991) surveyed and interviewed thirteen student teachers at Stanford University about their beliefs, knowledge, and attitudes toward the history and philosophy of science. He found that the three participants who were

formally exposed to the history or philosophy of science had more reasoned responses to the philosophical questions. Ogunniyi (1983) and Akindehin (1988) report on the effect of an independent NOS course in their preservice science teacher programs. They found a significant difference in the understanding of science between students who took such a course and those who did not.

While the knowledge gains reported in these studies are encouraging, sadly, little attention or research has been directed to the role science teacher education should play in ensuring such knowledge is forcefully implemented in science curricula and teaching strategies. Fortunately, exceptions to the rule do exist. In Australia, Matthews (1990) designed a course in the history and philosophy of science (HPS) to stimulate teachers' interest in science and help them to identify the HPS issues that arise in science teaching. In Nigeria, Ogunniyi (1983) devoted an independent course in history and philosophy of science in the science teacher preparation program for his students. Recently, Eichinger, Abell, and Dagher (1997) presented their experience in developing and teaching a NOS course to science education graduate students at both Purdue and the University of Delaware. At the University of Iowa, two semester-length courses in the nature of science have been required of all preservice teachers and graduate students for more than two decades.

Description of a Desired State

While acknowledging the existence of institutional constraints that thwart efforts to incorporate the nature of science in science teacher education programs, significant explicit attention to the social studies of science and relevant teaching strategies are imperative to ensure such instruction is extensively integrated in school science programs. Without this attention, the overwhelming demands placed on science teachers will prolong the current sorry state of affairs. For example, Bell *et al.* (1997) recently followed several preservice teachers through their student teaching experience to determine how extensively they implemented the nature of science. Most of these teachers did not show significant explicit attention to teaching the nature of science, and one subject in their study made the following statement:

> I don't plan to teach the nature of science . . . I don't think it is something that I would spend a great deal of time on.

While many science teachers likely take this same position, ironically, some view of the nature of science will always be communicated to students whether or not it is done purposefully or accurately. Consider a typical day in the life of a science teacher. Class begins with an opening statement, then an activity or demonstration occurs followed by some sort of discussion before a textbook assignment is given as homework.

Throughout these daily experiences are explicit and implicit cues regarding how science works and the status of scientific knowledge.

Clearly, a rationale for the social studies of science in science education should spiral through all aspects of a science teacher education program. Nature of science concepts will likely seem esoteric to teachers so practical classroom applications must be extensive. Examining nature of science instruments is imperative to address the daunting task teachers face in identifying and tracking 125 students' views regarding the nature of science. Scrutinizing readings, audiovisual materials, and activities that accurately portray the nature of science while teaching science content is also imperative. The paucity of such materials necessitates that teachers be prepared to revise curricula so they effectively teach both the nature of science and science content. Presentations by practicing science teachers who implement nature of science instruction in their classes may be particularly useful in convincing skeptical teachers. Critical incidents illustrating the inseparable ties between science content instruction and the nature of science (Nott & Wellington, 1995) are valuable for increasing the sensitivity of preservice teachers to this subtle, but very real, juxtaposition. Alongside these efforts, science teacher educators must model behaviors, strategies, and language that accurately portray the nature of science. Literature and organizations devoted to the social studies of science and its implications for science teaching should be introduced so teachers have resources to seek out when a need arises. Finally, research and anecdotal reports indicating positive changes in students' views and actions regarding the nature of science are needed to bolster teachers confidence that attention to these issues will reap the desired effects (Clough 1995; Meyling, 1997).

CONCLUSIONS

This paper has explored the dynamic arena called the nature of science by examining both its history and ways that the nature of science has informed and should guide science teaching. We have taken the position that a pragmatic consensus exists regarding some of the most important elements regarding the process of science, but have demonstrated that, as in any dynamic field, constructive debate exists. We have also shown that research and discussion continues regarding the relationship between what teachers believe about the nature of science and what they then communicate to students. We assert that teachers must have experiences where they explore the social studies of science and contemplate the methods by which that content may be shared with students. It is vital that the science education community provide an accurate view of how science operates to students and teachers. Contributions to the book *The Nature of Science in Science Education: Rationales and Strategies* (McComas 1998) does just this. We are confident that science education will be a richer discipline

and our students will be more adequately prepared for their lives as citizens when they are afforded a fuller understanding of the nature of this thing called science.

NOTES

[1] International conferences addressing the nature of science and science teaching have been held at the University of Florida, Tallahassee, FL USA (1989); Kingston, Ontario, Canada (1992); University of Minnesota, Minneapolis, MN, USA (1995) and Calgary, Alberta, Canada in June of 1997. The next conference is scheduled for September 1999 in Pavia, Italy.

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