Teachers' Understanding of the Nature of Science and Classroom Practice: Factors That Facilitate or Impede the Relationship

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Abstract: The purpose of this multiple case study was to investigate the relationship of teachers' understanding of the nature of science and classroom practice and to delineate factors that facilitate or impede a relationship. Five high school biology teachers, ranging in experience from 2 to 15 years, comprised the sample for this investigation. During one full academic year, multiple data sources were collected and included classroom observations, open-ended questionnaires, semistructured and structured interviews, and instructional plans and materials. In addition, students in each of the teachers' classrooms were interviewed with respect to their understanding of the nature of science. Using analytical induction, multiple data sources were analyzed independently and together to triangulate data while constructing teacher profiles. The results indicated that teachers' conceptions of science do not necessarily influence classroom practice. Of critical importance were teachers' level of experience, intentions, and perceptions of students. The results have importnat implications for teacher education as well as the successful implementation of current reforms. © 1999 John Wiley & Sons, Inc. J Res Sci Teach 36: 916–929, 1999

Efforts to reform science education in the United States are being significantly informed by the *Benchmarks for science literacy* [American Association for the Advancement of Science (AAAS), 1993] and the *National science education standards* [National Research Council (NRC), 1996]. Although the perspectives of each of these specific recommendations for reform differ in a variety of ways, a strong emphasis on the nature of science is clearly a common theme. This emphasis should not be surprising, since students' understanding of the nature of science has been identified as an educational outcome in the United States since 1907 (Lederman, 1992). In general, students' understanding of the nature of science is currently being emphasized as an important educational objective worldwide. Such an understanding is considered to be a significant aspect of scientific literacy. The assumption, which has yet to be tested, is that an understanding of the nature of science will enable students (and the general public) to be more informed consumers of science, which will empower them to make more informed decisions when scientific claims and data are involved.

Although no general consensus exists concerning all aspects of the nature of science, the aforementioned U.S. reform documents and prior research in science education (Lederman,

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1992) indicate that the following aspects are accessible by, and important for, K–12 science students: (a) Scientific knowledge is tentative (subject to change), (b) empirically based (based on and/or derived from observations of the natural world), (c) subjective (theory laden), (d) necessarily involves human inference, imagination, and creativity (involves the invention of explanations), (e) necessarily involves a combination of observations and inferences, and (f) is socially and culturally embedded. One additional aspect, that has not been addressed by reform documents, but is closely related to an understanding of observation and inference is the function of, and relationships between, scientific theories and laws.

Although there appears to be a perennial concern about students' conceptions of science, little progress has been made toward the achievement of this instructional goal. Indeed, there is presently much dissatisfaction with the levels of both teachers' and students' understandings of the nature of science (Duschl, 1990; Lederman, 1992). In addition, disagreement continues about the nature and extent of the relationship between a teacher's understanding and classroom practice (Abd-El-Khalick & Lederman, 1998; Brickhouse, 1989, 1990; Duschl & Wright, 1989; Gallagher, 1991; Lederman & Zeidler, 1987; Palmquist & Finley, 1997) despite the fact that there are serious concerns about how well one's philosophical conceptions can be inferred from one's behaviors (Noddings, 1995). Whether a teacher's understanding of the nature of science is necessarily reflected in planning for instruction and/or classroom practice is largely an academic question. It has been researched thoroughly, and although disagreements still exist, recent research indicates that such reflection is not automatic and is extremely complex in nature (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 1998). The factors that contribute to this complexity must be identified and systematically investigated so we can facilitate changes in teachers' classroom practice toward the visions of science education reform. Therefore, of far more practical importance is the relative lack of research and knowledge concerning how teachers who understand the nature of science transform or translate their understandings into classroom practices that impact students. Consequently, this investigation was guided by the following research questions: (1) Do teachers' understandings of the nature of science influence classroom practice? (2) What factors facilitate or impede the influence of teachers' understandings on classroom practice?

Sample

Five biology teachers (3 males, 2 females) constituted the sample for this investigation. These teachers possessed a wide range in experience (the two beginning teachers had 2 and 4 years, while the experienced teachers had 9, 14, and 15 years) and taught in separate schools representing four school districts and both urban and rural locales. Gender was balanced among the 5 teachers, with 1 female and 1 male constituting the beginning teachers, and with 2 of the 3 experienced teachers male.

Context is critically important in any investigation of teachers' practices and beliefs. Consequently, a more in-depth discussion of each teacher as opposed to the aggregated summary presented above is useful in the interpretation of results. Barry was 42 years old and the least experienced of the five teachers, having just 2 years of experience. The investigation occurred during his third year of teaching. He teaches in a small rural school district with a total of 175 students. Most of the families in the district are employed in the waning logging industry. The school houses Grades K–12, but Barry only works with the 62 students enrolled in Grades 9–12. Although he was a third-year teacher, Barry had six different class preparations (i.e., general biology, general chemistry, horticulture, earth and space studies, general science, and introduction to computers) with class sizes ranging from 9 to 22. There were 19 students in the biology class directly observed in this investigation. Barry was teaching in the same school where he completed his student teaching, under the supervision of the most experienced teacher in this investigation, John, and the researcher. The students in Barry's classes (and the school district in general) were not college-bound students, and 80% would typically spend the remainder of their lives within 50 miles of the school. Barry has a B.S. degree in biology and a Master of Arts in Teaching degree. Prior to becoming a teacher, Barry spent 7 years as a commercial fisherman in Alaska and 5 years as truck driver along the Pacific coast.

Lisa was entering her fifth year of teaching during the investigation. Her teaching responsibilities involved two preparations (i.e., general biology, general science). She had four sections of biology and two in general science. Lisa worked in an urban setting (according to Oregon standards) in a high school with 1,141 students. Lisa's class sizes ranged from 22 to 28 students, with 26 students in the biology class directly observed in this investigation. In contrast to Barry's situation, most of Lisa's students would be attending college and were from families employed in various white-collar professions. Lisa had student taught in a neighboring city in a school very similar to the one in which she was teaching during the investigation. Lisa possesses a B.S. in biology and an M.S. in science education. The researcher supervised Lisa's student teaching experience and served as major professor for her M.S. degree. Lisa was 27 years old and had worked various secretarial jobs in the insurance industry prior to becoming a teacher.

Alice was 32 years old and had been teaching for 9 years prior to the investigation. She was teaching in an urban high school in the same city as Lisa. The high school had 1,064 students and Alice only had two class preparations (i.e., biology, general science). All but one of her six classes were biology classes. Class sizes ranged from 24 to 32 students in Alice's classes, with 32 students enrolled in the biology class directly observed in this investigation. Alice has a B.S. in biology, an M.S. in biology, and extensive coursework toward a Ph.D. in entomology. Alice completed her student teaching in a middle school in a neighboring town. Her student teaching was in a rural logging community, working with students that were not college-bound, while her teaching position during the investigation was in a situation quite similar to Lisa's. Alice was in her third teaching position at the time of the investigation, having experiences in both rural and urban environments. Prior to becoming a teacher, Alice was pursuing a Ph.D. in entomology. She decided to become a teacher fairly suddenly and completed her certification within the context of an M.S. degree in science education. The researcher served as Alice's major professor for her M.S. degree.

Mary had been teaching for 14 years prior to the investigation. She was 38 years old and had just completed an M.S. degree in science education. The researcher served as major professor on Mary's graduate committee. Mary also has a B.S. degree in biology and received her teaching certificate from Oregon State University prior to the arrival of the researcher. She teaches biology, chemistry, physics, and general science in a rural high school. The high school has an enrollment 218 students, with Mary's class sizes ranging from 15 to 26. There were 25 students enrolled in the biology class directly observed in this investigation. The student body in Mary's school is a mixture of that described for the other teachers' students. That is, the majority (approximately 65%) of Mary's students attend college, while the remaining find jobs in the immediate area or in other areas of Oregon. The community is blue-collar in nature, but it is not a logging community. Most local business are related to the farm industry, either equipment or supplies. Mary, as with all teachers in Oregon, teaches six classes per day as her regular instructional responsibility. The researcher first met Mary as a student enrolled in a 2-year grant designed to enhance science teachers' understanding of science subject matter and the teaching of inquiry. There was a heavy emphasis on scientific inquiry and the nature of science in the grant activities. Mary also supervised two student teachers for whom the researcher served as university supervisor. Mary is originally from Hawaii and worked as a secretary before deciding to become a teacher.

John had just turned 50 during the year of the investigation and was just beginning his 16th year as a science teacher. As was mentioned, John was the mentor teacher for Barry, but was now teaching in a different, but rural school district. A total of 555 students are enrolled in John's school, and he is responsible for classes in biology, horticulture, general science, and advanced biology. Three of John's six classes are general biology. Class sizes range from 19 to 25 in John's classes, with 24 enrolled in the biology class directly observed in this investigation. John is unique to the sample of five teachers in that he is recognized throughout the state as an excellent teacher of projects-based science and scientific inquiry. John's school is located in a logging community, and as such, has a depressed economy. About 50% of John's students attend college, while the rest usually seek employment in various blue-collar jobs. John has a B.S. in biology and an M.S. in science education. The researcher has supervised three student teachers under the mentorship of John, including Barry. John's current position is his third teaching position. His teaching career began in southern California following a 5-year career as a self-employed beekeeper. The researcher first met John as part of the same 2-year grant in which Mary participated.

The five teachers comprising the sample for this investigation are quite diverse in backgrounds and teaching situations. Clearly, all five teachers had worked with the researcher in a variety of situations over the years other than the current investigation. It was believed that the close working relationship between the teachers and researcher would add to the authenticity of data collected. All the teachers had one experience in common of particular relevance to the current investigation: They all attended classes or workshops conducted by the researcher that stressed both the nature of science and the teaching of the nature of science. Selection of these teachers was based on the researcher's close working and personal relationship with each teacher and the teachers' possession (as inferred by the researcher) of a view of the nature of science consistent with that advocated in the current reforms (AAAS, 1993; NRC, 1996). In particular, these teachers were believed to possess the views that (a) scientific knowledge is tentative; (b) observations and inferences are both necessarily used to construct scientific knowledge, and observations and inferences are subjective to some degree as a consequence of the scientist's prior experiences, background knowledge, and scientific paradigms; (c) the development of scientific knowledge necessarily involves human creativity and imagination (it is not totally objective); and (d) scientific knowledge is empirically based. Furthermore, these teachers were believed to understand the difference between scientific law and theory and that no single/universal scientific method exists. With the exception of the difference between theory and law, an issue on which the reform documents are silent, these views are explicitly emphasized by both of the aforementioned U.S. reform documents. Finally, although each of the teachers was aware of an existing science curriculum within the school district (only two actually had a copy of the document), each teacher was free to follow a curriculum of his or her own choosing. Analysis of the district curricula clearly indicated that "students' understanding of the nature and limitations of science" was a stated goal/objective. None of the four districts imposed formal or informal assessment approaches (as derived from teacher interviews) to ensure that the stated curriculum had been followed.

Method

This investigation involved an in-depth year-long assessment of the classroom practices and goals of five biology teachers. A combination of semi-structured interviews (one at the beginning and one at the end of the investigation), an open-ended questionnaire, classroom observations, lesson plans, instructional materials, periodic informal interviews/discussions, and student interviews was used to investigate the relationship between teachers' conceptions of the nature of science and classroom practices, and to elucidate those factors that impede or enhance the relationship.

One general biology class (10th grade) for each of the teachers was randomly selected for investigation. Teachers were interviewed 1 week prior to the beginning of the school year. These interviews were semi-structured and designed to collect data on each teacher's academic background, teaching experience, significant aspects of the school context, general student body characteristics, specific characteristics of the students enrolled in the selected biology class, and goals and objectives for the biology class. In addition, each teacher was asked to complete a questionnaire that focused on teachers' understandings of the nature of science.

The questionnaire related to teachers' conceptions of the nature of science has been used and at least face validated elsewhere (Abd-El-Khalick et al., 1997; Lederman & O'Malley, 1990). The instrument globally focuses on the complexities of tentativeness in scientific knowledge, and specifically on (a) the use of human creativity and imagination in the development of scientific knowledge, (b) the subjectivity resulting from scientists' background experiences, knowledge, and scientific paradigms, (c) the difference between scientific theory and law, (d) the importance of both observation and inference to the development of scientific knowledge, and (e) the empirical basis of scientific knowledge. In particular, teachers were asked to respond to the following open-ended questions:

1. After scientists have developed a theory (e.g., atomic theory—does the theory ever change? If you believe that theories change, explain why we bother to teach students theories. Defend your answer with examples.
2. What does an atom look like? How do scientists know that an atom looks like what you have described or drawn?
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
4. How are science and art similar? How are they different?
5. Scientists perform scientific experiments and investigations when trying to solve problems. Do scientists use their creativity and imagination when doing these experiments and investigations?
6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.
7. Some astrophysicists believe that the universe is expanding, while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

The open-ended questionnaire was reviewed and discussed during the latter stages of the second (and final) semi-structured interview in an effort to ensure that the questions were understood and that answers were correctly interpreted by the researcher. This approach further ensures the authenticity of questionnaire responses for these particular teachers. The completed questionnaire was placed in a sealed envelope and not viewed by the researcher until just prior to the second semi-structured interview in an effort to avoid the biasing of classroom observations or subsequent informal interviews and discussions. Naturally, bias can never be removed from a set of observations or discussions. However, given the focus of the first research question (i.e., "Do teachers' understandings influence classroom practice?"), it was important to make at least some attempt to prevent the researcher from projecting known teacher understandings into observations of classroom practice. The problems of knowing teachers' understandings prior to making classroom observations, in studies focusing on the relationships between beliefs and teaching practice, have been thoroughly discussed elsewhere (Lederman, 1992).

The selected biology classes were directly observed once per week without teachers' knowledge of the exact day of observation so as to avoid any additional and unnecessary influence of the researcher on classroom practice. In addition to the field notes taken during observations, all lesson plans and copies of instructional materials (for all of each teacher's biology classes) were collected each week. Consequently, although observations were made in only one class, complete records of planned instructional occurrences in the teachers' other biology classes were collected. This approach allowed the researcher to have as complete a picture as possible of each teacher's instruction across all biology classes. Following each of the classroom observations, an informal interview/discussion was conducted to collect data related to the teacher's intentions and reasons for organizing and implementing the observed lesson. Additional data were collected concerning the overall organization for the week's instruction and the teacher's reasons for proceeding as planned. When time was not available immediately following the observed lesson, this information was collected by telephone the same evening. As a consequence of the researcher's close working and personal relationship with each of the teachers, there were weekly opportunities for informal discussions about instruction after school each Friday during "happy hour" at the Peacock Tavern. The tavern is a local establishment that the researcher and teachers had been frequenting for several years prior to the investigation. The Peacock Tavern serves food, libations, and has numerous T.V.s and billiard tables. Gathering reliable research data from teachers about teaching in such settings is not unique. It has a long and respected history that dates back to 1897 and has affectionately be labeled "teacher bar" research (Blumberg & Kleinke, 1980; Cavan, 1966; LeMasters, 1975; Pajak & Blasé, 1980). At the end of the investigation, each teacher participated in a 1-hour semi-structured interview during which the open-ended questionnaire was discussed in detail. Again, allowing the teachers to discuss their responses on the questionnaire helped to minimize misinterpretations that often occur when only written responses are analyzed.

Finally, upon completion of data collection for the teachers (i.e., following the second semi-structured interview), a random sample of 10 students (class sizes ranged from 19 to 32, with a mean size of 24) in each teacher's observed class was selected for interviews related to students' understandings of the nature of science. Although these students were randomly selected, teachers later verified that the students were representative of all students' attitudes and abilities in the particular class that was observed. The specific focus of the interviews was on tentativeness of scientific knowledge and the role of subjectivity, creativity, empirical evidence, inference, and observation in the development of scientific knowledge. The interview questions directly followed (with slight modifications so questions would be more appropriate for students) those used on the questionnaire administered to the teachers, as well as those posed in teacher interviews. The interviews were conducted in an effort to gather direct evidence of the possible influence of the teachers' classroom practices on students' understandings of the nature of science. Although neither of the two research questions was directly related to student achievement, such data were considered important with respect to research Question 2. In particular, there has been much debate about whether the nature of science is learned implicitly while doing scientific investigations (Palmquist & Finley, 1997) or learned primarily when teachers explicitly address various aspects of the nature of science during instruction (Abd-El-Khalick et al., 1998). It was anticipated that teachers may have students experience scientific inquiry, for example, but not explicitly address the nature of science. Data on student achievement were considered necessary so the researcher could discern differences between implicit and explicit instruction.

Results

All data sources were analyzed individually using a model of analytical induction (Bogdan & Biklen, 1992; Miles & Huberman, 1994) and then together in an effort to challenge developing assertions and conceptualizations. In this analytical approach, conceptions or working hypotheses to explain the phenomenon of interest are continually formed as data are analyzed. Emerging hypotheses and explanations are consistently tested against subsequent data (of either different type or source) and typically expanded to encompass new cases (in this situation, other teachers) that do not fit the previous formulation. The ultimate goal is to arrive at a relatively universal explanation (for the particular sample under investigation) that has been derived from the consistent formulation and then reformulation of emerging explanations during data analysis. The numerous sources and types of data (e.g., interviews, observations, instructional materials) allowed for triangulation of data and the construction of valid profiles of each teacher's beliefs and classroom practices. Following the construction of profiles, each teacher was allowed to read and critique how he or she had been described. Without exception, the teachers corroborated the accuracy of the profiles that had been constructed, lending further credence to the validity of profiles. The results reported are the outcome of systematic analyses and contrasting of all data sources. Furthermore, the reader is reminded that the researcher conducted classroom observations and subsequent interviews without knowledge of the content of the completed questionnaire related to the teachers' understandings of the nature of science. Therefore, as much as possible, the assessment of a relationship between classroom practice and teachers' beliefs was unbiased by a priori knowledge of the teachers' beliefs.

Conceptions of the Nature of Science

Analysis of teachers' interviews and subsequent analyses of their completed questionnaires indicated that each teacher exhibited views of the nature of science consistent with those identified in the various reforms. For example, teachers expressed a clear understanding that scientific knowledge is tentative, based at least partially on human creativity and imagination, and subjective (theory laden) yet based at least partially on empirical evidence. In addition, they illustrated an understanding of the difference between observation and inference, the relationships and functions of theories and laws, and the social and cultural embeddedness of scientific knowledge. These data corroborated, to some degree, that the teachers learned and maintained the views of science they were exposed to in classes and/or workshops conducted by the researcher in previous years.

Overall, the teachers were strongest in their commitment to the idea that scientific knowledge is tentative and many of the ideas in science are constructed explanations for observable phenomena (as derived from the completed questionnaires). The following representative comments were made during the interviews spanning the entirety of the investigation. When asked to define science, the teachers typically replied with comments such as the following. The teachers have been identified parenthetically by pseudonym following each comment.

> False knowledge. (Meaning that the knowledge could never be considered as absolutely true) (John)
>
> Our best attempt to make sense of our surroundings, our universe. Of course, we never really know if our "sense" is correct. (Barry)
>
> Naturally, no matter how hard we try, our observations and inferences are influenced by our backgrounds and knowledge. It's the same with scientists. (Mary)

> A systematic way of learning about the world. It may not be correct in an absolute sense, but it is knowledge that we can rely on to a reasonable degree. (Alice)

As a follow-up probe to the teachers' clearly articulated beliefs on the tentativeness of science, they were asked why it should be studied and learned by students. Comments similar to the following were typical.

> It's a funny thing about science. We never know if any of it's true and yet we base our whole lives on it. But, we need some frame of reference. (John)

> The kids ask me that whenever I say that we don't know anything for sure. I just tell them we need a starting point to make sense of anything, but we have to keep in mind that, starting point is just a starting point. (Lori)

> Theories are our best inference or explanation. Laws serve a very similar function. Sure, they both can change, but without these we have no framework of understanding to guide our actions. (Mary)

The data from the teachers' questionnaire responses and interviews clearly corroborated the researcher's a priori perceptions of these teachers' understandings of the nature of science and their consistency with the current visions of U.S. reforms. This finding supported the initial reason for selection of these particular teachers for participation in the investigation.

Instructional Practices and Teachers' Conceptions

Classroom observations, inspection of lesson plans, and interviews indicated clear differences between the classroom practices of the beginning teachers ($<$5 years of experience: Barry and Lisa) and those of the experienced teachers. The two most experienced teachers (14 and 15 years' experience: Mary and John) exhibited classroom practices consistent with their professed views about the nature of science, a finding generally consistent with Brickhouse (1989, 1990). That is, these teachers included many inquiry-oriented activities (i.e., demonstrations and laboratories) that required students to collect data and infer explanations for the data that had been collected. These inferences were often subsequently tested and revised accordingly. However, interviews (formal and informal) and analysis of lesson plans clearly indicated that neither of these two teachers was intentionally attempting to teach in a manner consistent with their perceptions of the nature of science. Indeed, neither teacher had students' understandings of the nature of science as an instructional objective or specified it as a goal. When asked about the purpose and goal of activities seemingly oriented toward the nature of science, the teachers explained their lessons as follows:

> My main purpose for this demonstration is that the students really enjoy it, and it is a good way for me to get them to see that science is fun and that they can do it. How the students feel about themselves is a big thing for me. (John)

> I want students to consistently see things that help them develop process skills. At the same time, I want them to develop thinking skills that they can use outside of science class. (Mary)

> Students need to learn how to think. They also need to know that they can think and solve scientific problems. This is the first step in getting them to enjoy science. (John)

> My primary purpose in introductory biology is to have students appreciate science and have confidence in their ability to do it. (Mary)

This finding is also consistent with prior research (Abd-El-Khalick et al., 1998; Duschl & Wright, 1989; Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994) indicating that teachers rarely consider the nature of science when planning for instruction or making instructional decisions. When specifically questioned about the importance of the nature of science in the seemingly appropriate activities or its emphasis in overall instruction, the teachers consistently responded with comments such as:

> Sure, I want to model science as it done and I do think students should see this. But I think the most important thing for these kids at this point in their lives is to feel good about science and their ability to do science. (Mary)

> I know the nature of science is interesting. You taught me that. But first I need students to feel that they can do science. Then, I can hit them with the more abstract stuff. (John)

The two beginning teachers (<5 years of experience: Barry and Lisa) were still struggling to develop an overall organizational plan for their biology courses and were each a bit frustrated by the discrepancy between what they wanted to accomplish versus what they were capable of accomplishing with their students.

> I want students to have a global view of science as a way of knowing in addition to the factual stuff I need to teach. I just can't deal with that right now with all the management concerns I have. (Barry)

> I want to teach more process and nature of science, but I need to feel that I have things under control first. (Lisa)

> At this point in my life as a teacher, I better focus on the easy stuff first, like getting students interested and staying that way for the whole class period. (Lisa)

Management, of course, appeared to be a primary and persistent concern of both Barry and Lisa. Although each clearly expressed an interest in addressing the nature of science in their classes, each felt that they were not ready to take on the challenge. Naturally, with the researcher having been their former teacher and advisor, Barry and Lisa were only providing the answers they felt were desired. Nevertheless, their understandings of the nature of science were not evident in their classroom instruction. The multitude of factors that mediate beginning teachers' classroom practice routinely experienced by teacher educators and is well documented in the research literature by Abd-El-Khalick et al. (1998), Gess-Newsome and Lederman (1993), and Hollingsworth (1989), among others, and corroborate the findings in this investigation.

One of the experienced teachers (9 years of experience: Alice) did not teach in a manner consistent with her view of science. She was overly concerned with students getting the basic foundational knowledge of biology and she felt that the substantive aspects of the nature of science were too abstract for 10th-grade students to learn "effectively and functionally":

> I have always felt that there has been much too much concern for process skills. It's not that process is not important, but you can't process in a vacuum. Students need to have some basic knowledge to use with their process skills. (Alice)

> Nature of science has always been interesting to me, but I also know how complex and abstract it is. I remember how difficult it was for me to learn, let alone my 10th graders. (Alice)

Alice possesses, perhaps, the most subject matter knowledge among the five teachers. She was enrolled in a Ph.D. program in entomology prior to deciding to become a teacher. Perhaps some her dedication to foundational knowledge is partially derived from her more extensive subject-matter background.

At first glance, it becomes clear that a teacher's conceptions of the nature of science do not necessarily influence his or her classroom practice. At the most superficial level, it appears that teaching experience mediates the relationship between a teacher's beliefs about science and classroom practice, as indicated by the consistency between views of the nature of science and the classroom practice of only the two most experienced teachers. It also appears that teachers' intentions, goals, and perceptions of students are factors that influence teachers' instructional attention to the nature of science. The two experienced teachers (i.e., John and Mary) who did teach in a manner consistent with their views of science are quite intriguing. After all, neither reported attempting to teach the nature of science. One is compelled to ask whether these individuals provided evidence for the necessary influence of one's beliefs on classroom practice and counter-evidence for the idea that teachers' intentions are critical. That is, do the teacher's perceptions of science become manifest regardless of the teacher's intentions?

John and Mary consistently professed the importance of students "feeling successful" in science, developing "positive attitudes" toward science, "feeling good about themselves," and seeing the relationship of science to their daily lives. These reasons were consistently used to support the teachers' use of the various projects, discrepant events, and inquiry activities noted in their classes. However, there are many classroom practices and instructional approaches that can be used for a variety of instructional outcomes. In short, although the aforementioned instructional approaches could be used to teach the nature of science in a manner consistent with the reforms and the views of the teachers in this investigation, the same activities could also be used to promote success, positive attitudes, and relevancy in science. Consequently, John and Mary's instructional behaviors can just as easily be used to lend further support for the idea that teachers' intentions are of paramount importance when trying to ascertain the relationship between teachers' beliefs about science and classroom practice. This finding is clearly consistent with the empirical research on teachers' thinking and decision making (Clark & Peterson, 1986). With respect to the research discussed by Clark and Peterson, they also point out that there is a reciprocal relationship between teachers' beliefs and classroom practice. One must also consider the influence the classroom has had on the teachers' beliefs about teaching, students, and the nature of science. It seems plausible that the teachers' beliefs about students and teaching have been influenced by the classroom experience and students. With respect to beliefs about the nature of science, it does not appear that the teachers views have been influenced by classroom and curriculum experiences. In particular, these teachers appear to have maintained the same beliefs about science stressed in the researcher's courses and workshops on the topic.

Previous research concerning the relationship between teachers' conceptions of science and classroom practice have consistently alluded to the curriculum as a factor that significantly inhibits teachers' attention to the nature of science (Brickhouse, 1990; Duschl & Wright, 1989; Lederman & Zeidler, 1987). The reader is reminded, however, that each of the teachers in this investigation was free to follow a curriculum emphasis of his or her own choosing, and consequently was not significantly influenced by the stated science curriculum. As a check, the researcher asked teachers toward the end of the interview how they reconciled their attention to the nature of science with the stated emphasis in the district curriculum:

> I have no problem doing what I do. There really is no vested interest that I follow the stated curriculum line by line. (Lisa)

> Is that what it says? See how much attention I pay to the official curriculum? (John)
>
> You can't just follow a curriculum blindly. I have to consider my students' needs and my needs as a teacher. (Alice)

Students' Understanding of the Nature of Science

Many would claim that teachers' modeling of the nature of science is the most effective approach to promoting students' understanding (e.g., Duschl, 1990; Lederman, 1986, 1992, among others). If such were the case, then the intentions of John and Mary (the two teachers who appeared to teach in a manner consistent with their views) would be relegated to a theoretical concern as their students would be learning about the nature of science regardless of their intentions. It is for this reason that data were collected from students to supplement conclusions reached regarding Research Question 2.

Contrary to the aforementioned belief about instructionally modeling the nature of science, the overwhelming majority of the students interviewed across all five teachers (46 of the 50) did not exhibit an understanding of the nature of science consistent with current wisdom and science education reforms. Although these students were selected randomly, each teacher verified that the students were representative of the students' attitudes and abilities in the class observed. The teacher from whose class the student was selected is indicated parenthetically following the quoted comment. Comments such as the following were the norm:

> Theories change all the time, but laws come out the same way all the time and so we know they are right. (John)
>
> Scientists need to be creative in developing experiments, but the results should be seen the same way regardless of the scientist. This is why scientists do the same experiment many times. (Mary)
>
> Scientists have their own opinions about things, but the strength of science is that in the end, it is objective. (Alice)
>
> Scientists disagree all the time, but this is just because they don't have all the information or someone is interpreting the data wrong. (Lisa)
>
> Anyone can have a theory, but with evidence it eventually becomes a law because we now know it's the case. Things in the world happen in certain ways and we can eventually figure it out with science. (Barry)
>
> There really is no room for subjectivity in science. Otherwise, anyone could say whatever they want. (John)

In general, the students believed that only certain types of scientific knowledge were tentative (i.e., theories) and that creativity, imagination, and subjectivity had a limited place, if any, in the development of scientific knowledge. This was as true for the classes of the two teachers that modeled the nature of science (i.e., John and Mary) as it was for the classes of the other teachers. The data for this sample of five teachers appear to indicate that unless a teacher clearly intends to address the nature of science and follows through with explicit emphasis during instruction (as opposed to simple modeling), students will not develop an understanding of the nature of science that happens to be consistent with the organization of a particular lesson or activity. Although the relationship between teachers' conceptions and students' conceptions was not a question pursued in this research, it is clear that such a relationship is far from being direct or simple. Rather, such a relationship is contingent upon a teacher's explicit attention to his/her views of the nature of science during instruction.

Implications for Science Teacher Education

Consistent with previous research, it seems clear that teachers' conceptions of the nature of science do not necessarily influence classroom practice (Abd-El-Khalick et al., 1998; Abd-El-Khalick & Lederman, 1998; Brickhouse, 1990; Lederman, 1992; Lederman & Zeidler, 1987). Indeed, this was the case for this sample of five biology teachers, all of whom possessed views consistent with those advocated by current reforms in science education, but who differed widely in terms of experience and teaching contexts. Although additional research explicating the relationship among teachers' beliefs, classroom practices, and student achievement is needed, some preliminary recommendations can be gleaned from the results of the current investigation. It appears to be important for science teacher education programs (preservice and inservice) to continue their efforts well beyond the often advocated development of teachers' conceptions of the nature of science (Duschl, 1990; Gallagher, 1991) and directly address teachers' abilities to translate such understandings into classroom practice (Abd-El-Khalick & Lederman, 1998; Lederman, 1986, 1992). A systematic and concerted effort to help teachers develop their conceptions and the classroom skills and abilities that will enable them to transform their understandings of science into classroom practice should be pursued and systematically evaluated.

The initial focus of these efforts should be on promoting the internalization of the view that the nature of science is an important instructional objective that should be considered during the development and implementation of every instructional unit, lesson, and activity. As indicated in the current investigation, and in prior research on teachers' instructional decisions (Clark & Peterson, 1986), even though the teachers possessed what would be considered to be desired views of the nature of science, it was the teachers' instructional intentions that significantly affected what occurred in classroom practice. Helping teachers to internalize the instructional importance of the nature of science may help avoid the lack of attention to the nature of science evidenced in teachers' instructional decisions (Duschl & Wright, 1989; Gess-Newsome & Lederman, 1993; Lederman et al., 1994; Lederman & Latz, 1995) and facilitate teachers' intentions focused on trying to promote students' understandings of the nature of science. Once teachers have internalized the importance of the nature of science and their intentions to address the topic are firmly in place, both beginning and experienced teachers will need to develop the instructional skills and abilities necessary to transform their knowledge into classroom practice (Abd-El-Khalick et al., 1997; Lederman, 1986, 1992; Lederman & Zeidler, 1987). At this point, there are limited practical suggestions available to classroom teachers for promoting students' conceptions of the nature of science. In addition, more professional development activities should focus on teachers' understandings of the nature of science and ways to translate these understandings into classroom practice.

Classroom management has been a perennial concern of beginning teachers. Given the significant concern for classroom management evidenced by the beginning teachers in this investigation and in other investigations (Hollingsworth, 1989; Gess-Newsome & Lederman, 1993; Lederman et al., 1994), the development of a wide variety of instructional routines and schemes that allow beginning teachers to feel comfortable with the organization and management of instruction appears to be a critical prerequisite for any efforts to assist beginning teachers' attempts to promote students' understandings of the nature of science.

For experienced teachers, the focus should be on those specific instructional approaches identified in prior research (Abd-El-Khalick & Lederman, 1998; Lederman, 1986, 1992) that can be used to influence students' conceptions of science. In addition to this investigation, recent research (Abd-El-Khalick, 1998; Abd-El-Khalick et al., 1998) indicates that it is important for teachers to address the nature of science explicitly instead of assuming that its mere modeling will accomplish the desired outcomes. These results appear to contradict recent research by Palmquist and Finley (1997), who claimed that implicit approaches do influence student (in this case, preservice teachers) conceptions of science. However, a careful reading of their research indicates that virtually all areas in which the preservice teachers exhibited change in understanding were in fact those areas in which explicit instruction was provided. Quite simply, the assumption that students are likely to learn the nature of science through implicit instruction (i.e., performance of scientific inquiry with no reflection on the nature of the activity) should be called into question. In many ways, it is analogous to assuming that students will come to understand the physiology of breathing simply because they have experienced it throughout their lifetime. This is not meant to deny that many things can be learned implicitly (especially in the skill areas), but there is a difference in this case between doing something and understanding something. The visions of reform in the United States (AAAS, 1993; NRC, 1996) have clearly recognized the distinction by carefully using the phrases "students will know" and "students will be able to [do]" to distinguish between students performing certain tasks (e.g., inquiry) and understanding the tasks. Providing students with experiences in scientific inquiry is certainly a start, but students also need to have the nature of science made explicit through discussions and reflections about the nature of inquiry.

The implications of the present findings are clearly relevant for the successful implementation of the reforms advocated by the *Benchmarks for science literacy* (AAAS, 1993) and *National science education standards* (NRC, 1996) related to the nature of science. These reforms place a significant emphasis on students' understandings of the nature of science. As with any curriculum reform, success will be contingent upon teachers internalizing the importance of the stated goals (Clark & Peterson, 1986) of the reform and their ability to transform these goals into classroom practice.

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