

Chapter 24

Nature of Scientific Knowledge and Scientific Inquiry: Building Instructional Capacity Through Professional Development

Norman G. Lederman and Judith S. Lederman

Students' and teachers' conceptions of nature of scientific knowledge have been a concern since the early 1900s (Norman Lederman 2007). Similarly, students' abilities, and more recently their understandings of scientific inquiry, have been a concern within the science education community (National Research Council 1996). However, little research exists concerning the role of professional development in facilitating the desired change in students' and teachers' conceptions (i.e. how to help teachers to translate what they know into effective classroom practices). The existing literature reviews related to nature of science and scientific inquiry do not document the nature and impacts of sustained professional development in bringing about change. This chapter focuses on two large-scale professional development approaches (i.e. a localised teacher enhancement grant and a systemic change initiative) and a university-level programmatic effort in which our group has been involved in Chicago. Of particular importance are the relative impacts of these different approaches and the lessons learned that have impacted the nature of the professional development provided. Much debate permeates the literature on nature of science and scientific inquiry. Unfortunately, writers have not consistently considered the audience (i.e. K-12 students) of the desired instructional outcomes. In particular, it is important to consider the developmental appropriateness of stated instructional outcomes, empirical research related to students' and teachers' learning about inquiry and nature of science, as well the relevance of students' and teachers' understandings to the goal of scientific literacy. Consequently, using these criteria, it is important to clearly explicate our perspectives/views of the constructs of nature of science and scientific inquiry, as well the rationale for the importance of teachers' and students' understandings of nature of science and scientific inquiry.

N.G. Lederman (✉) • J.S. Lederman (✉)

Department of Mathematics and Science Education, Illinois Institute of Technology,
Chicago, IL, USA

e-mail: ledermann@iit.edu; ledermanj@iit.edu

What Is Nature of Scientific Knowledge?

At this point, there could be some confusion about our use of the phrase ‘nature of scientific knowledge’ versus ‘nature of science’. Originally (during the 1960s), the phrase ‘nature of scientific knowledge’ was used to describe instructional outcomes related to the characteristics of scientific knowledge (Lederman 1992) that were directly derived from the way in which scientists develop scientific knowledge (i.e. scientific inquiry). However, during the 1980s, ‘scientific knowledge’ was dropped from the original label of the construct and ‘nature of science’ was used to refer to the same idea. Unfortunately, this change of language might have led to the consistent conflating of nature of science and scientific inquiry (Lederman 2007). A clear delineation between the two constructs is provided below.

When one attempts to answer the question, ‘What is science’, it seems clear that one valid answer delineates science into a body of knowledge, process/method and nature of scientific knowledge. The body of knowledge refers to the various concepts, laws, theories and ideas that are well represented in our various science textbooks. The ‘process/method’ refers to what scientists do to develop/construct the body of knowledge. Finally, nature of science refers to the characteristics of scientific knowledge that are directly derived from the process/method used to develop the knowledge. Clearly, one can elaborate on the categories used to answer the original question, but few would validly disagree with the three-pronged answer provided here.

With all the support that Nature of Science (NOS) has in the science education community, it might be assumed that all concerned individuals have adequate understandings of NOS. Even though explicit statements about the meaning of NOS are provided in well-known reform documents (e.g. NRC 1996), the pages of refereed journals are filled with definitions that run contrary to the consensus reached in the National Science Education Standards (National Research Council 1996) and other reform documents. Some would argue that the situation is direct support for the idea that there is no agreement on the meaning of NOS (Alters 1997). More recently, Hipkins et al. (2005) have expressed concerns about the lack of consensus about NOS in New Zealand curricula. However, counter-arguments by Michael Smith (Scharmann and Smith 2001; Smith et al. 1997) suggest that more consensus exists than disagreement. Others (Lederman 1998) are quick to note that the disagreements about the definition or meaning of NOS that continue to exist among philosophers, historians and science educators are irrelevant to K-12 instruction. At the level of generality concerning NOS that is targeted for K-12 students, little disagreement exists among philosophers, historians and science educators. Among the characteristics of scientific knowledge corresponding to this level of generality are that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background and biases and/or is theory-laden), necessarily involves human inference, imagination and creativity (involves the invention of explanations), and is socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between, scientific theories and laws.

What follows is a brief consideration of these characteristics of science and scientific knowledge related to what students should know. Although listings of the 'important' characteristics of NOS exist, the primary purpose here is to provide a frame of reference that helps to distinguish NOS from scientific inquiry and the resulting body of knowledge.

First, students should understand the crucial distinction between observation and inference. Observations are descriptive statements about natural phenomena that are 'directly' accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. Inferences are explanations about what is observed in the natural world, but are the result of human interpretation as opposed to being directly observed by the senses.

Second, there is a distinction between scientific laws and theories. Individuals often hold a simplistic and hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence. It follows from this notion that scientific laws have a higher status than scientific theories. Both notions, however, are inappropriate because, among other things, theories and laws are different kinds of knowledge that do not develop or become transformed into each other. Laws are *statements or descriptions of the relationships* among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, are *inferred explanations* for observable phenomena. So, kinetic molecular theory is the inferred explanation for what Boyle's law describes. It is important to note, however, that theories are as legitimate a product of science as laws. They are simply two different types of scientific knowledge and one does not evolve into the other.

Third, even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e. empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a totally rational and orderly activity. Science involves the *invention* of explanations and this requires a great deal of creativity by scientists.

Fourth, scientific knowledge is subjective. Scientists' theoretical commitments, beliefs, previous knowledge, training, experiences and expectations actually influence their work. All these background factors form a *mindset* that *affects* the problems that scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they make sense of, or interpret, their observations. It is this individuality that accounts for the role of subjectivity in the development of scientific knowledge. Although objectivity might be a goal of science, subjectivity necessarily creeps into the development of scientific knowledge because humans do science.

Fifth, science as a human enterprise is practised in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various aspects of the culture in which it is embedded.

Sixth, it follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including 'facts', theories and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible

through advances in technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted from a different perspective.

What Is Scientific Inquiry?

Although closely related to science processes, Scientific Inquiry (SI) extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analysing data. Scientific inquiry includes the traditional science processes, but also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge. From the perspective of the National Science Education Standards (National Research Council 1996), students are expected to be able to develop scientific questions and then design and conduct investigations that will yield the data necessary for arriving at conclusions for the stated questions. The Benchmarks for Science Literacy (American Association for the Advancement of Science 1993) are a bit less ambitious as they do not advocate that all students be able to design and conduct investigations in total. Rather, it is expected that all students at least are able to understand the rationale of an investigation and be able to critically analyse the claims made from the data collected. Scientific inquiry, in short, refers to the systematic approaches used by scientists in an effort to answer their questions of interest. Pre-college students, and the general public for that matter, believe in a distorted view of scientific inquiry that has resulted from schooling, the media and the format of most scientific reports. This distorted view is called 'the scientific method' (i.e. a fixed set of set and sequence of steps that all scientists follow when attempting to answer scientific questions). A more critical description would characterise 'the method' as an algorithm that students are expected to memorise, recite and follow as a recipe for success. The visions of reform, however, provide no single fixed set or sequence of steps that all scientific investigations follow. The contemporary view of SI advocated is that the questions guide the approach and the approaches vary widely within and across scientific disciplines and fields (e.g. descriptive, correlational and experimental).

The perception that a single scientific method exists owes much to the status of classical experimental design. Experimental designs very often conform to what is presented as 'the scientific method' and the examples of scientific investigations presented in science textbooks most often are experimental in nature. The problem, of course, is not that investigations consistent with 'the scientific method' do not exist. The problem is that experimental research is not representative of scientific investigations as a whole. Consequently, a very narrow and distorted view of scientific inquiry is promoted among our K-12 students.

Scientific inquiry has always been ambiguous within science education reforms. In particular, inquiry is perceived in three different ways. It can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation.

It can also be viewed as a cognitive outcome that students are to achieve. In particular, the current visions of reform are very clear (at least in written words) in distinguishing between the performance of SI (i.e. what students will be able to do) and what students know about SI (i.e. what students should know). Unfortunately, the subtle difference in wording noted in the reforms (i.e. 'know' versus 'do') is often missed by everyone except the most careful reader. The third use of 'inquiry' in reform documents relates strictly to pedagogy and further muddies the water. In particular, current wisdom is that students best learn science through an inquiry-oriented teaching approach. It is believed that students best learn scientific concepts by doing science. In this sense, scientific inquiry is viewed as a teaching approach used to communicate scientific knowledge to students (or allow students to construct their own knowledge) as opposed to an educational outcome that students are expected to achieve. With respect to the projects reported here, the primary focus is on knowledge *about* SI, because it is this perspective of SI that is most often ignored in classrooms and in methods of assessments. Specifically, the following understandings about inquiry are most germane to the projects reported here:

1. Scientific investigations all begin with a question, but do not necessarily test a hypothesis.
2. There is no single set and sequence of steps followed in all scientific investigations (i.e. no single scientific method).
3. Inquiry procedures are guided by the question asked.
4. All scientists performing the same procedures might not get the same results.
5. Inquiry procedures can influence the results.
6. Research conclusions must be consistent with the data collected.
7. Scientific data are not the same as scientific evidence.
8. Explanations are developed from a combination of collected data and what is already known.

As with NOS, these understandings about SI are not considered to be definitive or comprehensive. Rather, these understandings are considered to be developmentally appropriate for secondary students and have been shown in empirical studies to be understandable by secondary students.

Why Teach Nature of Science and Scientific Inquiry?

The goal of scientific literacy has been a perennial goal of science education since the 1970s (American Association for the Advancement of Science 1993; National Research Council 1996; Douglas Roberts 2007). In general, the scientifically literate individual has a functional understanding of science concepts and can apply this knowledge to making decisions about personal and societal problems. Two aspects of scientific literacy are an understanding of NOS and an understanding of SI. In addition to the goal of scientific literacy, understanding these two constructs is also

presumed to facilitate understanding of subject matter and increase one's valuing of science as a human endeavour. At this point, there is scant evidence that understanding SI and NOS actually provides the benefits to learners as advertised. However, the emphasis on these two constructs remains as strong as ever, perhaps even stronger. Unfortunately, developing teachers' understandings of NOS and SI is no easy task. It requires a long and continuous programme of professional development. In addition, just because teachers have an adequate understanding of SI and NOS, it is not necessarily the case that they will be able to successfully develop these same understandings in their students. This chapter describes three large-scale professional development projects in Chicago that have been successful in developing teachers' understandings of SI and NOS and enabled teachers to promote the same understandings in their students: (1) Project ICAN (Inquiry, Context and Nature of Science); (2) High School Transformation project (HST); and (3) a programmatic model.

Project ICAN (Inquiry, Context and Nature of Science)

ICAN was a 5-year teacher enhancement project funded by the National Science Foundation. The project ultimately involved 238 teachers in Chicago and 23,500 students. Although the focus of ICAN was on secondary teachers (6–12), there were 12 elementary teachers included in the project. Approximately 50 teachers were recruited each year for participation in ICAN. Engagement with the project involved one full calendar year. During each academic year, Project ICAN was comprised of four stages: Summer Orientation; Academic Year Activities; Summer Institute; and Science Internship.

Summer Orientation

Project ICAN began with a 3-day orientation. The main focus of the orientation was to introduce ICAN teachers to aspects of NOS and SI by engaging them in NOS and SI activities (National Academy of Science 1998), watching relevant videos, and reading NOS- and SI-specific articles. Reflective questions, debriefings and discussions followed these activities to enhance teachers' familiarity with aspects of NOS and SI.

An example of an NOS activity is the tube activity (National Academy of Science 1998). Teachers were shown a mystery tube and its behaviours. They were then asked to infer the internal structure of the tube and design and construct physical models that behaved in the same way as the original tube. The discussion focused on elements of NOS such as how and why inferences differed although observations were the same, how human subjectivity led to different models, and the inconclusive nature of scientific models. This was followed by authentic examples from natural science, such as models of the atom and the centre of the earth.

Academic Year Activities

After the orientation, 10 full-day, monthly workshops took place from September to June. These workshops were centred on further NOS and SI instruction in the context of science subject matter, curriculum revision and assessment. The NOS and SI activities were intended not only for enhancing teachers' understanding of NOS and SI, but also for improving their knowledge of how to teach NOS and SI. An explicit/reflective approach, as described by Fouad Abd-El-Khalick and Norman Lederman (2000) was emphasised.

To help teachers to understand the explicit/reflective approach to teaching NOS and SI, Project ICAN staff presented model lessons. In the mitosis laboratory activity described by Norman Lederman and Judith Lederman (2004), for example, teachers were provided with two different teaching approaches for the same activity. First, teachers were given a brief review of the different stages of mitosis and how to categorise stages from pictures, and then teachers were asked to count the number of onion root tip cells in each stage of mitosis within a given field of view under high power. After the counts were entered as data in a table, they used the relative frequencies of stages to calculate the relative time required for each stage. In the second approach, teachers were given the same brief review, but this time teachers were asked to answer how they decided when one stage ended and the other began and how scientists made the same determination. A striking difference was that the first approach involved teachers in doing an investigation, but without any integration of NOS or SI. Unlike the first approach, the second engaged teachers in NOS and SI discussions involving careful selection and placement of reflective questions, followed by attention to certain aspects of NOS, such as tentativeness, creativity, observation versus inference, subjectivity and empirical basis. Attention to understandings about scientific inquiry was also included, such as the recognition of multiple interpretations of the same data set and the limitations of data analysis. In addition, curriculum evaluation and revision in terms of the teaching of NOS and SI were also emphasised. Under our guidance, teachers brought their own curriculum materials, evaluated them, and revised some topics in order to teach NOS and SI.

Teachers were also encouraged to apply what they learned through ICAN workshops in their classroom, and to bring examples of classroom experiences (verbally or via videotape) to the following ICAN workshop to share and discuss with each other.

Summer Institute

After the academic year, a 10-day summer institute focused on additional examples of curriculum revision and instructional activities focusing on SI and NOS. In addition, a major emphasis was placed on the assessment of students' understandings. Several model lessons integrating NOS and SI were also provided by teachers from previous years of ICAN.

Science Research Internship

During the academic year, teachers also participated in a science research internship with a practising scientist on the Illinois Institute of Technology campus or in surrounding community resources (e.g. zoos, museums). The teachers' primary role was as participant observers. They observed the ongoing investigations in the research settings and discussed specific research content and techniques with the scientists. Teachers kept daily journals, guided by focus questions about connections between the research experiences and the aspects of NOS and SI as presented in the project. In essence, this experience served as a 'reality check' for the perspectives of NOS and scientific inquiry presented in project activities.

Microteaching

During the third year of ICAN, we found that many of the participants' NOS/SI lessons were still characterised by implicit instruction. For this reason, we decided to assign three microteaching lessons to teachers in order to improve their pedagogical skills related to NOS and SI. Microteaching refers to a peer teaching presentation that mimics what teachers plan to do with their students. During the last 2 years of the project, three peer teaching lessons were also required during monthly meetings. These lessons were planned and delivered by teams of teachers. A teacher team consisted of three to four members who were voluntarily changed for each peer teaching assignment. Each lesson lasted for 45 min and afterwards there was a brief discussion of the aspects of NOS and SI addressed as well as ways in which the lesson could be further improved. Additionally, we provided written feedback to all teacher groups in terms of how to better integrate NOS and SI with their lessons.

Data Sources and Analysis

Teachers' Understandings of NOS and SI

Data addressing changes in teachers' views were collected during the summer orientation and the academic year. The summer orientation activities were preceded by pre-tests of teachers' understandings using Norman Lederman's Views of Nature of Science (VNOS) (Norman Lederman et al. 2002) and Views of Scientific Inquiry (VOSI) (Lederman and Ko 2003) questionnaires. These questionnaires were administered twice during the academic year.

The NOS aspects assessed included the idea that science is tentative, subjective, based on empirical observation and a product of human creativity. The distinction between observation and inference was also stressed. Aspects of SI targeted by the

VOSI include (a) multiple methods and purposes of investigations, (b) multiple interpretations of data being possible, (c) distinctions between data and evidence, and (d) data analysis being directed by the questions of interest and involving the development of patterns and explanations that are logically consistent. Additional data sources included journal reflections and revised curricular materials. Development of teachers' views was sought by comparison of profiles for each participant generated from VNOS-D and VOSI responses.

Teachers' Understandings of How to Teach NOS and SI

Teachers were required to provide videotaped lessons and lesson plans to illustrate their attempts to teach SI and NOS to their students. The reader is reminded that, during the last 2 years of the project, peer teaching lessons were also required during monthly meetings. Observation notes of videotapes and for peer teaching lessons were analysed along with instructional plans.

Students' Understandings of NOS and SI

The VNOS is an open-ended questionnaire that assesses views of the various aspects of nature of scientific knowledge. The VOSI is an open-ended instrument that assesses various aspects of scientific inquiry.

The VNOS-D and VOSI were administered to students at the beginning and the end of the academic year. Additionally, ICAN teachers were asked to submit samples of students' work completed during the NOS/SI-focused lessons, as well as test items related to these same topics. These data provided evidence of the impact on ICAN on students' understandings.

Before analysing all data sets, a 5% sample from each data source was used to establish inter-rater agreement. Agreement levels of 80% or higher were reached in all cases.

Results of the Project

Teachers' Understandings of NOS

Overall, over 70% of the participants showed enhancement in their NOS conceptions. The majority held informed views about four or more target aspects. Most significant were the changes in their views of the tentative, empirical, inferential, creative and subjective aspects of NOS.

As compared with 19% prior to instruction, 64% teachers had informed views about the tentative aspect of NOS. Teachers commonly stressed how new technology and discoveries play a role in developing scientific knowledge. For the post-test, 75% of the teacher participants (vs. 36% for the pre-test) exhibited informed views

of the empirical aspect of NOS. For example, one teacher stated that ‘they [scientists] could find evidence that might cause a change in what was previously thought and found’. The distinction between observation and inference was the aspect of NOS for which most participants (i.e. 82% vs. 32% for the pre-test) explicated informed views at the end of the programme.

About 69% of teachers (vs. 20% for the pre-test) demonstrated informed views about the role of imagination and creativity. Initially, around 65% of teachers held a limited understanding of the creative and imaginative aspect of NOS in analysing and interpreting data, stating that ‘scientists use creativity in planning only, but creativity in observation and analysing data is a kind of lying. That is not science’. During the project, such a view was replaced by the notion that scientists involve creativity and imaginations in all the scientific inquiry activities including data analysis and interpretations.

Approximately 74% of teachers (vs. 25% for the pre-test) exhibited informed views of the subjective aspect of NOS. Prior to instruction, most of the teachers believed that scientists reach different conclusions because they have different data. A typical comment was that ‘science is subjective in that each scientist has access to different data and evidence’. These responses changed appreciably during the programme. For example, one teacher believed that scientists disagree about what caused the extinction of dinosaurs even though they all have the same information because ‘different people make different inferences based on their life experiences, education and cultural surroundings’.

Teachers’ Understandings of Scientific Inquiry

ICAN teachers generally showed a significant improvement of their understandings of SI. For example, 40% began the programme with the view that SI consists of a set of steps that should be followed to obtain the correct answer. It was believed that these procedures are followed by objective scientists. They viewed the process as controlled, with the scientist being objective. At the end of the programme, few kept such views (i.e. 3%). They demonstrated major changes in their traditional view of the scientific method: they recognised that there is no universal step-by-step scientific method. Further, they came to recognise multiple methods for conducting scientific investigations and that scientists can have different methods for reaching conclusions. Some of them still described investigations as having steps, but they did not view these steps as a necessary part of doing an investigation.

Teachers improved in their understanding of multiple or alternative interpretations for a given a set of data. Nearly 80% of teachers understood that scientists are able to arrive at different interpretations of the same data because of ‘scientists’ creativity, culture, and differences’ and that scientists often come into the process with prior conceptions, past experiences, beliefs and values that affects how they look, view and interpret things. As one teacher put it, ‘even if scientists are working together, subjectivity can play a strong role in formulating one’s theory and influence how results are looked at’.

Teachers' Understandings of How to Teach NOS and SI

Analysis of microteaching lessons indicated that there was a continuum of pedagogical content knowledge for NOS and SI instruction, from an implicit to a didactic and to an explicit/reflective approach. In the first microteaching session, more than half of the groups demonstrated an implicit lesson in which students were exposed to hands-on activities, but without any attempts to teach NOS and/or SI. Consistent with prior research of Fouad Abd-El-Khalick et al. (1998), Richard Duschl and Emmett Wright (1989) and Julie Gess-Newsome and Norman Lederman (1993), teachers did not consider aspects of NOS and/or SI when planning for microteaching lessons. All lesson plans for those implicit lessons included target aspects of NOS and SI, but most of them did not incorporate how to address those aspects of NOS and SI. Indeed, aspects of NOS were infrequently specified as outcome in their instructional objectives. The objectives pertained to doing science and/or only to science content.

Data analysis indicated that the failure of teachers to use an explicit/reflective approach to teaching of NOS and SI was associated with teachers' assumption that students can learn NOS and SI by *doing science*. In thinking about how to teach NOS, teachers intuitively treated NOS and understandings about SI as doing science.

But, by the final lesson, no implicit teaching was found and about 25% of the lessons were characterised as didactic; 75% of the lessons followed an explicit/reflective approach. The common features detected in explicit/reflective lessons are that the ICAN teachers explicitly addressed target aspects of NOS in the introduction of a lesson and intentionally guided students to situations in which target aspects of NOS were embedded. The explicit and reflective comments and discussions were identified not only at the end of the lesson, but also while students were exposed to the NOS/SI-specific situations. Indeed, in all explicit/reflective lessons, assessment pieces were developed and enacted for monitoring students' understanding of NOS and SI. Teachers provided students with written questions, a quiz, or homework assignments including assessment questions.

Analysis of student work and videotaped lessons indicated many more explicit/reflective attempts to teach NOS/SI in years 4 and 5 of the project than in previous years. About 85% of student work included NOS/SI-related questions to help students reflect on target aspects of NOS/SI and to assess their understandings of NOS/SI in the context of science subject matter, while approximately 75% of videotaped lessons followed an explicit/reflective approach.

It seems to be evident that the three microteaching experiences provided the ICAN teachers in years 4 and 5 of the project with important opportunities to reflect on their understanding of NOS/SI to develop pedagogical knowledge. The ICAN teachers planned and presented their microteaching lessons three times and had the opportunity to observe and discuss 20 peer lessons. The microteaching experiences familiarised the ICAN teachers with teaching NOS/SI and helped them reflect and develop their pedagogical content knowledge related to NOS/SI.

Students' Understandings of NOS and SI

Changing teachers' views is necessary but not sufficient for changing students' views. Teacher intentions and pedagogical skills for integrating NOS and SI into classroom practices are critical. The analyses of students' data indicated increasing success in changing students' views with each year of the project. By years 4 and 5, over 60% of the students (vs. 15% for the pre-test) held adequate views on over 80% of the aspects of NOS and SI that were focused upon.

Pre-test data indicated that overall the students demonstrated naïve views of NOS and SI. The most significant changes in students' views were with respect to the inferential, empirical and subjective aspects of NOS. In terms of SI, 37% (vs. 3% for the pre-test) of the teachers' students came to understand there is no single scientific method', saying that 'they [scientists] follow more than one method. For example, one method is investigating (observing) what birds eat and the shape of their beaks and the other method is doing an experiment involving chemicals'. Students also advanced in their knowledge of multiple interpretations of a set of given data; 46% (vs. 10% for the pre-test) of the students feel that 'if different scientists perform the same experiment, they might not all come out with the same answer. All these scientists have a different way to view things. They might have the same data but a different way in interpreting it'.

Conclusions and Implications

The data analyses indicated that Project ICAN was successful in helping teachers to improve their pedagogical content knowledge related to NOS and SI. Teachers initially tended to adopt an implicit teaching approach in which explicit/reflective questioning and discussion about NOS and SI were not planned. In helping teachers to understand and implement explicit/reflective NOS and SI instruction, the results of this study suggest that there are two critical changes that need to occur. First, teachers need to realise that explicit instruction is better than implicit instruction. Even though several explicit activities and explanations for the difference between explicit and implicit NOS and SI instruction were given to teachers before, in the first microteaching session, 62% of groups adopted implicit instruction. The teachers initially believed that students could learn about NOS only by *doing science*. They confused doing something with knowing something (e.g. Fouad Abd-El-Khalick et al. 1998). Extensive experience is needed for them to realise that they are adopting an implicit approach, which is not generally effective for teaching NOS and SI and to understand that 'doing' something is not necessarily 'knowing' something.

Second, teachers need to be aware that a student-centred approach to explicit/reflective is better than a didactic approach. Most teachers realised their implicit teaching of NOS and SI after the first microteaching session. However, discerning this implicit approach was not sufficient for some teachers for implementing explicit/

reflective NOS and SI instruction. They intended to teach NOS and SI explicitly, but failed to address target aspects of NOS and SI in the explicit/reflective manner advocated by Project ICAN. A short and didactic discussion for NOS was assigned at the end of a lesson rather than a reflective and interactive conversation integrated into the flow of the lesson.

Over the 5 years of the project, peer teaching experiences appeared to be an important professional development experience. In years 4 and 5 of the project, peer teaching became more prominent and provided teachers with opportunities to reflect on their understanding of NOS and SI and pedagogical knowledge related to NOS and SI. ICAN teachers planned and presented their lessons three times and had the opportunity to observe and discuss 20 peer lessons. These opportunities allowed teachers to become more familiar with teaching NOS/SI and helped them to reflect and develop their pedagogical content knowledge related to NOS and SI.

The development of teachers' pedagogical skills related to NOS and SI in years 4 and 5 was consistent with the analyses of student work and videotaped lessons, which showed much more improvement for teachers in years 4 and 5. This result implies that teacher education programmes should provide teachers with opportunities to plan and implement explicit NOS and SI instruction and to observe and discuss peers' lessons. Teachers will more readily adopt what they see that their peers do rather than what is modelled by professional developers.

Developing students' understandings of NOS and SI is not simple. It takes an extended period of time to develop students' understandings, as well as teachers' understandings and relevant instructional skills. It is important to note that short-term professional development activities are likely to meet with less success. It is also important to note that short-term attention to NOS and SI with students, typically through an introductory unit, is also not likely to yield success. NOS and SI are themes that must be developed through extended professional development and integrated throughout science courses and grade levels when dealing with K-12 students.

High School Transformation Project (HST)

The High School Transformation Project is currently a 6-year project (in its third year) funded by the Bill and Melinda Gates Foundation and Chicago Public Schools. Different from Project ICAN, the HST is a high school systemic change effort. For the most part, participating teachers in ICAN are individual teachers from different schools. There are some clusters of teachers from the same school, but this is not the norm. HST eventually engages *all* science teachers in the science department of participating high schools. Although HST includes NOS and SI as unifying themes, there is an equal emphasis on subject matter knowledge. Finally, HST primarily focuses on student outcomes, while Project ICAN focused primarily on teachers. Nevertheless, HST involves extensive professional development for teachers related to NOS, SI and subject matter. It is important to note that the lessons learned from

Project ICAN related to the delivery of professional development and the teaching of NOS and SI significantly informed the structure of HST.

HST has just completed its third year and currently involves all of the biology, chemistry and physics teachers in 20 high schools. There are currently 164 participant teachers and 24,652 students involved in the project. Each year additional high schools are added to the project, with the ultimate goal of having approximately 50 high schools by 2012. Schools are active in the project for a period of 3 years. All 9th grade science teachers in identified schools are involved in year 1; year 2 involves both 9th and 10th grade teachers, and year 3 involves teachers spanning Grades 9–11.

HST consists of three essential elements that are repeated, with some modification, during each of the 3 years of each school's engagement. These phases consist of (1) initial professional development for participating teachers, (2) monthly academic year professional development workshops (divided between the university and an informal education site and (3) on-site academic year support from science coaches. A science coach was assigned to each school to work closely with each of the teachers on a daily basis. Support ranged from observing lessons and providing feedback, co-planning lessons, team teaching or actually modelling instruction for the teacher. In addition, the science coach helped to coordinate science instruction by meeting with the science department as a whole each week. Science teachers in participating schools had a common planning time to facilitate this coordination. Participating schools and teachers received all needed materials, revised and developed new curriculum materials for each course taught, and daily support from a highly qualified science coach. Coaches are either teachers on leave from their school district or PhD students in science education. During professional development workshops, teachers experience a wide variety of 'model' lessons, directly derived from the curriculum content, that exemplify the inquiry-oriented instructional model advocated. Again, the overall focus of instruction is 'traditional' subject matter, scientific inquiry and nature of science by using an inquiry-oriented instructional approach. The primary goals of this systemic initiative are to:

- Enhance high school students' science achievement
- Enhance high school students' understanding of and ability to do scientific inquiry
- Enhance high school students' understandings of nature of science
- Enhance in-service science teachers' understanding of and ability to do scientific inquiry
- Enhance in-service teachers' understandings about nature of science
- Enhance in-service science teachers' ability to teach inquiry, about inquiry, and nature of science
- Enhance in-service teachers' ability to use informal education sites to enhance instruction and student science achievement
- Develop leadership skills in participant teachers so that they subsequently can work with other teachers in their school districts.

The aspects of NOS addressed in this project are that scientific knowledge is tentative, subjective, empirically based, socially embedded, and dependent on human

imagination and creativity. Two additional aspects involve the distinction between observation and inference and the distinction between theories and laws (National Research Council 1996). The aspect of SI that was of particular interest was knowledge *about* scientific inquiry, because this distinguishing aspect of current reforms has been the most difficult to realise in classrooms. Specifically, the aspects of SI that were of interest were that: all scientific investigations begin with a question, but do not necessarily test a hypothesis; there is no single set and sequence of steps followed in all scientific investigations; inquiry procedures are guided by the question asked; all scientists performing the same procedures might not get the same results; inquiry procedures can influence the results; research conclusions must be consistent with the data collected; scientific data are not the same as scientific evidence; and explanations are developed from a combination of collected data and what is already known (National Research Council 2000).

Data Sources

Achievement scores were derived from standardised instruments developed for the project by the American Institute for Research (AIR). These instruments went through strict content validation procedures using multiple groups of subject-matter experts and educators. A level of agreement of 80% or higher was achieved for each item on each of the resulting instruments. Kuder-Richardson (21) reliability estimates exceeded 0.80 for each subject-matter test (0.82 for biology, 0.86 for chemistry, 0.83 for physics). As for previously described ICAN project, we used the VNOS and VOSI to assess students' views of nature of science and scientific inquiry respectively.

Results of Project's First 3 Years

Science Achievement

During each of the first 3 years of the project, pre-test and post-test data were collected on students' achievement. For Biology, 3 years of data exist because it is focused on the first year of school engagement and then continued in the subsequent 2 years; 2 years of data exist for chemistry and only 1 year for physics, at this time. For each subject area, correlated *t*-tests ($\alpha = 0.05$) were used to verify that students exhibited significant gains in achievement. Because instruction was provided to intact classes, the number of classes was used as the unit of analysis for each statistical test. Significant improvement in test scores ($p < 0.05$) was exhibited in each of the 3 years for biology, each of the 2 years in chemistry, and for the 1 year in physics. Although it is expected that significant gains would be exhibited across a year of instruction, these students on average were achieving at relatively high levels by the end of the academic year. That is, biology achievement reached 75% for the first

year, 76% for year 2 and 78% for year 3. For chemistry, the average achievement score was 84% for year 1 and 85% for year 2. The physics achievement level was 85%. It is important to note that, for the chemistry and biology scores, the different years represent different sets of students.

Understandings of Scientific Inquiry

Both students and teachers were pre- and post-tested on understandings of scientific inquiry during each year of the project. If a student or teacher was part of the project for 3 years, he/she was assessed on understandings for each of those years. In short, teachers and students were assessed each year in which they participated in the project. Chi-square analyses ($\alpha = 0.05$) indicated significant improvements in each aspect of scientific inquiry addressed. Within the group of teachers, the greatest gains were shown with respect to understandings that there is no single scientific method and that scientists viewing the same data could arrive at different interpretations. As expected, teachers assessed in multiple years showed consistent improvement from year to year. The largest changes in students' views were related to an understanding that there is no single scientific method and that all science investigations must begin with a question. As with subject-matter understandings, the final understandings exhibited by students and teachers are more impressive than the fact that significant changes occurred from pre-tests to post-tests. That is, the 'final' understandings noted here are not commonly observed in student and teacher populations.

Understandings of Nature of Science

Teachers and students were assessed with respect to their understandings of nature of science as they were with scientific inquiry. Chi-square analyses ($\alpha = 0.05$) were again used to identify any changes in understandings from pre-test to post-test. Significant changes were found for all aspects of nature of science assessed within the group of teachers. Students did not show any change with respect to their understanding that scientific knowledge is partly a function of human creativity and imagination. As with subject matter knowledge and understandings of scientific inquiry, the 'final' understandings are more important than the significant changes from pre-test to post-test.

Comparisons Across Years of Engagement

Because HST is a multiple-year systemic change effort (with unifying subject matter themes such as inquiry and nature of science), it was logically assumed that both teachers and students would become more proficient in knowledge and skills with additional years of engagement in the project (i.e. students in the project for 3 years

would become more proficient in science than students participating in the project for only 1 year). With respect to teachers, it was assumed that they would become more proficient in both knowledge and teaching ability with increased years of involvement. Although students involved for more than 1 year were taking different subject-matter courses (e.g. biology, then chemistry, then physics) comparisons of subject-matter improvement across years indicated that students' achievement levels increased from year to year. That is, students in the project for 3 years tended to achieve at a higher level in their physics course than in their chemistry course, and higher in their chemistry course than in their biology course. Students participating for 2 years consistently showed a greater level of achievement in chemistry than in biology. However, these data should be viewed with caution because the achievement levels are being compared across different subject matters. Still, the trend of increasing achievement levels from biology to chemistry to physics runs counter to students' typical performance in these different areas of science. That is, students usually do better in biology than chemistry. As was noted earlier, students consistently showed improvement in their understandings of scientific inquiry and nature of science from year to year.

Analysis of co-variance (ANCOVA) was used to assess student performance in the same subject matter area for teachers who participated in the project for more than 1 year. For example, for biology teachers who participated in the project for 3 years, their students' performance in biology was compared across the 3 years. The same analyses were undertaken for teachers involved in the project for 2 years. The ANCOVA tests ($\alpha = 0.05$), using the class as the unit of statistical analysis, indicated significant differences across years, with student achievement increasing with each additional years of teachers' experience. For example, if a teacher had participated in the project for 3 years, his/her students performed best in the third year relative to the second year or first year of involvement.

Conclusions and Implications

HST is a multi-year systemic change initiative that focuses on improving students' science achievement on standardised tests and knowledge of NOS and scientific inquiry. The design of the instruction and professional development for NOS and SI were directly derived from our work on Project ICAN. The project has completed its third year and so far has involved a total 20 high schools with instruction in biology, chemistry and physics. Furthermore, the project has involved 164 teachers and 24,652 students. Teachers are provided with extensive on-site and off-site instructional support. To date, it appears that the project has been quite successful with respect to improvement in students' subject-matter achievement and knowledge about scientific inquiry and nature of science. Single-year or short-term professional development efforts are often criticised for their inability to promote systemic change (Loucks-Horsley et al. 1998). Because systemic change requires intensive, frequent and long-term interaction with schools, teachers and students, there is an

accumulated effect over time. The results of HST support this contention. The longer that students or teachers were involved in the project, the greater were the gains in their knowledge (for students) and knowledge and teaching ability (for teachers). With respect to teachers, it seems that the longer that they are involved with the project the more proficient they become in successfully enacting instructional materials and activities. Anecdotal data collected from the science coaches corroborate this assertion. Students improved because they benefited from the accumulated knowledge and perspectives provided by curriculum themes, as well as from the change in academic culture in a school that was very focused on systemic change. However, there is also another possibility at play. The formative assessments used within each instructional unit were designed to model the kinds of questions that students would encounter on the standardised summative assessments. Hence, it is quite possible that the students became more comfortable, with time, about answering such questions. This is not the same as learning test-taking skills or a case of teachers teaching to the test. Rather, students often do not do well on high-stakes tests because of their inexperience with the question types and formats as opposed to lack of knowledge. This issue needs further investigation and will be tracked in future years of the project.

Linking Knowledge of Nature of Science and Scientific Inquiry to Classroom Practice: A Programmatic Model

The previously described large-scale systemic professional development efforts clearly benefitted from external financial support. In addition, each of the projects had the luxury of engagement with teachers over multiple years. However, within the semester-to-semester reality of university in-service programmes, long-term and intensive professional development is not possible. The impact that one hopes to have on teachers' knowledge and practices must occur within approximately 450 hours of class contact and, with respect to NOS and SI, the impact might be limited to the content of just several courses. Thus, the desire to have teachers' classroom practice sustain itself after finishing a degree programme is a much more serious concern than with a funded project lasting for as much as 6 years.

Although previous investigations have attempted to develop teachers' understandings of NOS and SI, and the ability to teach these constructs (Randy Bell et al. 2000; Renee Schwartz and Norman Lederman 2002), there has only been limited success in getting teachers to continue attending to NOS and SI in an explicit manner during instruction. Various reasons have been cited by teachers for their lack of follow-through (e.g. time constraints, curriculum constraints, perceptions of what students can learn). Nevertheless, science classrooms are still not characterised by any concerted instructional focus on SI or NOS. At the Illinois Institute of Technology, we have been experimenting with the sequence of two courses (i.e. a course focusing on NOS and SI and a course focusing on advanced teaching strategies) within our in-service Masters Degree programme. In this investigation, a course on NOS and SI was taught concurrently with a course on

advanced teaching strategies in an attempt to track the relationship between the development of teachers' understandings of NOS and SI and how this development was related to their ability to teach NOS and SI in an explicit manner within the context of a science lesson. The aspects of NOS and SI addressed in this investigation were the same as those addressed in Project ICAN and the HST.

Programmatic Design

The sample for this investigation comprised the 15 high school science teachers (9 females, 6 males) who were part of a Masters Degree leadership cohort for secondary mathematics and science teachers. Seven teachers were biology teachers, three were chemistry, and two were physics. These teachers ranged in experience from 3 years to 28 years, with an average of 8 years. The teachers were simultaneously enrolled in a course on NOS/SI and a course in Advanced Teaching Strategies. The teachers had previously completed courses in curriculum, assessment and evaluation, clinical supervision and action research, and they were currently completing an action research study that they had designed during a previous course. The course on NOS/SI was a discussion-oriented seminar focused around the reading of various books and classroom activities designed to develop teachers' understandings of the various aspects of NOS and SI. The course assumed no prior knowledge for the teachers and the instructional approach consistently expected teachers to reflect on both readings and activities with respect to how science was characterised. Instead of the teachers being provided with a list to memorise, the aspects evolved from class discussions. This course was taught by one of the researchers.

The Advanced Teaching Strategies course provided teachers with reform-based model lessons and the chance to practice instructional models that focus on student thinking (three 40-min peer-teaching lessons). The particular models stressed were the General Inductive Model, Concept Attainment Model and Inquiry Model described by Paul Eggen and Donald Kauchak (2006). During each of the three peer-teaching lessons, teachers were expected to follow the instructional model stressed and to include attention to at least one aspect of NOS and one aspect of SI. Teachers were free to choose the subject-matter focus of the peer-teaching lessons. All lessons were videotaped and followed by a 10–15 min debriefing class discussion. Teachers were also expected to watch their own videotapes and write self-critiques of the lessons. This course was team taught by two additional researchers.

Data Sources and Analysis

Multiple data sources were used in this investigation. Data collected during the NOS/SI course included pre-test and post-test administrations of the VOSI survey and the VNOS survey. In addition, teachers' book reports related to books read and

reaction papers related to short readings were analysed. A total of two book reports and five reaction papers constituted the data set from the course. The data collected during the Advanced Teaching Strategies course included videotapes of lessons, teachers' lesson plans for their lessons, and teachers' self-critiques. Again, pre-test and post-test administrations of the VNOS and VOSI were used to assess changes in teachers' knowledge during the NOS/SI course, while the reaction papers and book reports provided a measure of the development of teachers' knowledge during the course. The data from the Advanced Teaching Strategies course also allowed documentation of the development of teachers' knowledge of SI and NOS, but were primarily used to correlate teachers' instructional development relative to their growth in knowledge during the course. Finally, a random sample of five teachers was interviewed to ascertain what facilitated or compromised their ability to explicitly address NOS and SI in their lessons.

The VNOS and VOSI were independently scored by two of the researchers. For each aspect of NOS and SI, each teacher was rated as 0 (unclear), 1 (naïve), 2 (transitional/mixed) or 3 (informed). The level of agreement for the VNOS was 0.88 and 0.92 for the pre-test and post-test, respectively. Levels of agreement for the VOSI were 0.91 (pre-test) and 0.94 (post-test). All disagreements were discussed and a consensus score was reached for all teachers. Data from the book reports and reaction papers were individually scored by one of the researchers and a chronological profile was created for each teacher's development of NOS and SI knowledge during the semester. All three researchers analysed the relationship between responses to the pre-test and post-test surveys relative to changes noted in the reports and reaction papers. With no exceptions, the views expressed in the surveys mirrored what was noted in the reports and reaction papers, lending confidence to the validity of the assessment of teachers' understandings.

The lesson plans and peer-teaching lessons from the Advanced Teaching Strategies course were analysed with respect to explicit references to aspects of NOS and SI. The two researchers who team taught this course analysed the data. Only explicit references were noted because the emerging research has indicated that students' views of NOS and SI are significantly impacted primarily through explicit instruction, not implicit instruction. Specific attention was paid to what aspects of NOS and SI were targeted by the teachers, how well these aspects were addressed explicitly, and how the teachers' instructional development was related to the chronological profile of their knowledge development.

Results

As mentioned before, teachers' views were categorised as unclear, naïve, transitional and informed for both NOS and SI. These categorisations were based on analyses of VNOS and VOSI surveys, as well as other artefacts from the Advanced Teaching Strategies course and NOS/SI course.

Nature of Science

Teachers showed significant changes (pre-test to post-test) on all aspects of NOS using chi-square tests ($p < 0.05$). The largest changes occurred with respect to the creative and subjective aspects of scientific knowledge, with the smallest changes occurring with respect to teacher's understandings of the cultural embeddedness of scientific knowledge and the relationship between theory and law. By the end of the NOS/SI course, 73% (11/15) of the teachers exhibited informed views of all aspects of NOS.

Scientific Inquiry

As with NOS, teachers showed significant improvement on all eight aspects of SI investigated (chi-square tests, $p < 0.05$). The largest changes occurred with respect to the ideas that all scientific investigations begin with a question, but do not necessarily test a hypothesis, that there is no single set and sequence of steps followed in all scientific investigations (i.e. no single scientific method) and that scientific data are not the same as scientific evidence. The smallest changes occurred for the ideas that all scientists performing the same procedures might not get the same results, that inquiry procedures can influence the results, and that research conclusions must be consistent with the data collected. Overall, 80% (12/15) of the teachers exhibited informed views for each of the eight aspects of SI.

A clear relationship between the development of teachers' understandings of SI and NOS was evident when data from the Advanced Teaching Strategies course and the NOS/SI course (i.e. teachers' knowledge profiles) were analysed. In particular, during the first peer teaching lesson, teachers tended to teach NOS and SI implicitly, as opposed to explicitly as intended in both the NOS/SI course and Advanced Teaching Strategies course. That is, the teachers demonstrated a strong ability to design lessons that engaged students in investigations of scientific phenomena, but there was virtually no explicit attention to the NOS and SI objectives included in their lesson plans. This tendency was related to teachers' relatively superficial (i.e. transitional) knowledge of the various aspects of NOS and SI. As lessons from the second and third peer teaching lessons were analysed, which corresponded to teachers' possessing more informed views of NOS and SI, it was clear that teachers became more proficient at explicitly addressing NOS and SI (during instruction) as the courses progressed. In addition, teachers tended to include in their lessons those aspects of NOS and SI for which they had the most well-developed knowledge. In general, it appeared that, for most aspects of NOS and SI, teachers became more proficient at teaching each aspect of NOS and SI as their knowledge became more well-developed. Interviews with randomly selected teachers also indicated that they also selected for teaching those aspects of NOS and SI that seemed to fit most seamlessly with the topic of instruction.

There were some trends, however, that did not fit with what was noted overall.

Although teachers showed large changes with respect to their understandings that all scientific knowledge involves some level of human creativity and human imagination, the way in which this knowledge was manifested in lessons was distorted in an interesting way. Initially, it appeared that teachers were teaching ‘creativity’ in an implicit manner. However, as the Advanced Teaching Strategies course proceeded, it became clear that teachers instructionally interpreted ‘creativity’ to mean that students should be allowed to use their creativity during an investigation. Again, teachers approached instruction in this manner even though they had demonstrated through their survey responses and other artefacts that they understood ‘creativity’ to mean that all scientific knowledge is partly composed of human creativity and imagination. The five randomly selected teachers who were interviewed explained their instructional approach by stating that students could not understand that creativity was involved in scientific knowledge unless they were allowed to be creative. Interestingly, the teachers did not have this difficulty in translating knowledge into instructional practice when it came to addressing subjectivity in scientific knowledge.

Conclusions and Implications

Research over the past 2 decades has made it clear that the most effective way to teach students about NOS and SI is through an explicit/reflective instructional approach (Abd-El-Khalick and Lederman 2000; Lederman 2007). Although numerous studies have shown success in enriching teachers’ knowledge about NOS and SI, teachers continue to struggle in their attempts to translate their knowledge into effective classroom instruction. This investigation attempted to enhance the relationship between teachers’ understandings and their instructional practice in the relatively short time span of a professional Masters Degree programme. The results indicated a strong relationship between the progression of teachers’ understandings and their instructional practice. On the one hand, this finding is intuitive because a teacher cannot be expected to teach what he/she does not know. But, the relationship is not a simple one because teaching practice does not immediately follow the development of knowledge of NOS/SI and knowledge of how to teach both. It was clear that the progressive development of classroom practice lagged behind the progressive development of knowledge.

Prior to this investigation, researchers have been content to study teachers’ and students’ conceptions of NOS and SI using an ‘input–output’ model in which the primary focus has been monitoring pre-test–post-test changes during a carefully designed intervention. With respect to research on teachers, this approach to research has left us with the knowledge that we can enhance teachers’ knowledge about NOS and SI, but with little knowledge of how teachers’ knowledge progressively moves from naïve views to views that are consistent with current reforms. Other research efforts have clearly indicated that, although teachers might possess the desired views of NOS and SI and knowledge of how to teach NOS and SI, this knowledge

is not automatically and necessary translated into classroom practice (Lederman 1999, 2007). This investigation has provided insights into the relationship between the progression of teachers' knowledge about NOS and SI and the progression of their instructional abilities related to these two constructs. It is clear that teachers' knowledge precedes their instructional ability. Our findings here are consistent with what was noted in the previously described projects. The teachers in these projects were not immediately successful at teaching NOS and SI as soon as their knowledge of the constructs developed. It seems that having the courses offered concurrently is not as effective as having the courses run consecutively. In addition, the relationship between knowledge and action is much more complex than simply meaning that teachers must know what they are expected to teach. Rather, after teachers develop in-depth understandings of NOS and SI and knowledge of how to teach it, there is a period of 'negotiation' during which the teacher needs to carefully consider how and where to best integrate NOS and SI into the existing curriculum. Consequently, recommendations for the integration of NOS and SI throughout the curriculum should be carefully considered in the light of the subject matter at hand (which provides an important context) and teachers' knowledge and instructional approach. Thus far, researchers have not considered the interaction between subject matter and the ability, or willingness, of teachers to address NOS and SI.

Professional Development and Teachers' Knowledge of Nature of Science and Scientific Inquiry: Lessons Learned

The previously described projects varied widely in terms of scope and logistical format. Project ICAN and the HST project were two large-scale professional development efforts that involved hundreds of teachers and thousands of students in the Chicago Public Schools. The third project is actually the in-service programme at Illinois Institute of Technology. Although the projects differ, they all focus on helping teachers to develop their understandings of NOS and SI and then translating this knowledge into effective instructional approaches. Consequently, the various projects do have some commonalities. That is, the views of NOS and SI promoted are consistent and the instructional approach, within the professional development activities and the approaches that the teachers are expected to use with their students, are all based on the research-supported explicit, reflective teaching approach (Lederman 2007). With respect to the focus of this chapter on professional development, we have learned several lessons through our work.

In each of the aforementioned efforts, we found that professional development needs to be long term, frequent and intensive (Susan Loucks-Horsley et al. 1998). In particular, in the large projects, we found that it was critical to meet with teachers throughout the academic year on at least a monthly basis. In addition, Project ICAN and the HST both included 'up front' intensive (i.e. 2 weeks or more) work during the summer and intensive capstone experiences during the summer following the academic year. These professional development activities involved knowledge

development first, followed by attention to the development of instructional approaches. Teaching teachers about NOS and SI concurrently with teaching them how to teach NOS and SI simply did not work well. The cognitive demand seemed to be too great. In the organisation of the in-service programmes at the Illinois Institute of Technology, we found that courses addressing NOS and SI are best situated sequentially as opposed to concurrently with courses on the teaching of NOS and SI.

Microteaching opportunities have been shown to be crucial for success in all three of our efforts, regardless of scope. That is, our teachers benefitted significantly from opportunities to teach NOS and SI to their peers, as well as observe their peers, followed by 'friendly' but productively critical feedback. In each of the long-term efforts, it was obvious that the effectiveness of microteaching opportunities increased as trust developed among the teachers and our staff. It is also important to note that, in our in-service programme, this trusting environment was also critical and it was just developed prior to the two critical courses discussed here.

In terms of the decades of research on teaching and learning NOS, and more recently on the learning of SI, the overwhelming majority has focused on descriptions of teachers' and students' knowledge and on the development of isolated instructional approaches for developing teachers' and students' knowledge. The only long-term efforts focused on the development of science curriculum, but such efforts have not met with much success. The work reported here leads us to believe that the nature of the professional development efforts is more critical than the particular instructional materials. In addition, it appears that the intensive and prolonged work with teachers in two of the three reported projects is also successful in generating teachers' enthusiasm for teaching NOS and SI. This enthusiasm is critical if teachers are to continue addressing NOS and SI in their classroom practice after the completion of grants and professional development efforts.

References

- Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, 82, 417–437.
- Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22, 665–701.
- Alters, B. J. (1997). Whose nature of science? *Journal of Research in Science Teaching*, 34, 39–55.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching*, 37, 563–581.
- Duschl, R. A., & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. *Journal of Research in Science Teaching*, 26, 467–501.
- Eggen, P. D., & Kauchak, D. P. (2006). *Strategies and models for teachers* (5th ed.). Boston: Pearson Education, Inc.

- Gess-Newsome, J., & Lederman, N. G. (1993). Preservice biology teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Education*, 77, 25–45.
- Hipkins, R., Barker, M., & Bolstad, R. (2005). Teaching the 'nature of science': Modest adaptations or radical reconceptions? *International Journal of Science Education*, 27, 243–254.
- Lederman, N. G. (1992). Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331–359.
- Lederman, N. G. (1998). The state of science education: Subject matter without context. *Electronic Journal of Science Education [On-Line]*, 3(2), December. Available: <http://unr.edu/homepage/jcannon/ejse/ejse.html>
- Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, 36, 916–929.
- Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Mahwah, NJ: Lawrence Erlbaum Associates.
- Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39, 497–521.
- Lederman, J. S., & Ko, E. K. (2003). *Views of scientific*. Unpublished paper, Illinois Institute of Technology, Chicago.
- Lederman, N. G., & Lederman, J. S. (2004). Revising instruction to teach nature of science. *The Science Teacher*, 71(9), 36–39.
- Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press, Inc.
- National Academy of Sciences. (1998). *Teaching about evolution and nature of science*. Washington, DC: National Academy Press.
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
- National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.
- Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum Associates.
- Scharmann, L. C., & Smith, M. U. (2001). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education*, 85, 493–509.
- Schwartz, R. S., & Lederman, N. G. (2002). It's the nature of the beast: The influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching*, 39, 205–236.
- Smith, M. U., Lederman, N. G., Bell, R. L., McComas, W. F., & Clough, M. P. (1997). How great is the disagreement about the nature of science: A response to Alters. *Journal of Research in Science Teaching*, 34, 1101–1103.