Project ICAN: A Multi-layered Model of Professional Development

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Abstract

Effective nature of science (NOS) and scientific inquiry (SI) instruction require teachers to develop a knowledge base as well as purposeful intentions to address NOS and SI within classroom instruction. Project ICAN: Inquiry, Context, and Nature of Science, an NSF-funded teacher enhancement project, aims to enhance teachers' abilities to improve students' understanding of NOS and students' understanding of, and ability to perform SI, within a context of standards-based instruction. In its second year, 50 teacher-participants participated in the project that comprised three phases with the following sequence: monthly workshops during the academic year, a three-week summer institute, and a follow-up. Questionnaires, video-taped lessons, lesson plans, instructional materials/assessments, and classroom observations, as well as student data comprised the data for examining the teaching and learning of NOS and SI. Participants demonstrated major enhancements in their understandings and their classroom applications of NOS as demonstrated in gains in their students’ views.
INTRODUCTION

Students' understandings of science and its processes beyond knowledge of scientific concepts have been emphasized in the current reform efforts in science education (AAAS, 1993; NRC, 1996; NSTA, 1989). In particular, the National Science Education Standards (1996) state that students should understand and be able to conduct a scientific investigation. The Benchmarks for Science Literacy (AAAS, 1993) advocates an in-depth understanding of scientific inquiry (SI) and the assumptions inherent to the process. Both reform documents consistently support the importance of students' possessing adequate understandings of nature of science (NOS). Research, however, has shown that teachers do not possess adequate views of NOS and SI that are consistent with those advocated in reforms. Moreover, it is difficult for teachers to create classroom environments that help students develop adequate understandings of NOS and SI (Lederman, 1992; McComas, 1998; Minstrell & van Zee, 2000) without explicit instruction and assessment.

Nature of Science

NOS refers to the values and beliefs of how scientific knowledge develops (Lederman, 1992). The disagreements among philosophers of science, historians of science, scientists, and science educators regarding a universal definition for NOS are irrelevant to K-12 students (Abd-El-Khalick, Bell, & Lederman, 2000). The latter argue that there are seven general aspects of NOS that are accessible to and relevant to K-12 students’ everyday lives. These involve understanding that scientific knowledge is tentative, subjective, empirically based, socially embedded, and depends on human imagination and creativity. Two additional aspects involve the distinction between observation and inference and the distinction between theories and laws.
Scientific Inquiry

The NSES, (NRC, 1996) state that “Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.” (p. 23) In addition to being able to conduct inquiries of various types, the NSES also promote students’ understanding about scientific inquiry (NRC, 2000). This understanding includes

- knowledge about various methods of investigation (there is no single "scientific method"),
- understanding of the placement, design and interpretation of investigations within research agendas (current knowledge and direction guide investigations),
- recognition of assumptions involved in formulating and conducting scientific inquiries,
- recognition of limitations of data collection and analysis in addressing research questions,
- recognition and analysis of alternative explanations and models,
- understanding of the reasons behind the use of controls and variables in experiments,
- understanding of distinctions between data and evidence,
- understanding of relationships between evidence and explanations and the reliance on logically consistent arguments (based on historical and current scientific knowledge) to connect the two,
- understanding of the role of communication in the development and acceptance of scientific information
Research has shown that through explicit/reflective instruction of NOS aspects and connections of aspects within the context of science activities, students are able to understand aspects of NOS (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Smith, Maclin, Houghton, & Hennessey, 2000). An explicit/reflective approach draws learners’ attention to relevant aspects of NOS and SI in the context of inquiry-based activities or historical examples. These considerations of effective teacher development and classroom guided the design of Project ICAN.

**Project ICAN**

Project ICAN (Inquiry, Context, and Nature of Science) is an NSF Teacher Enhancement grant that focuses on the development and implementation of a professional development model to enhance middle and high school science teachers’ disciplinary and pedagogical knowledge related to unifying concepts, SI and NOS. The goal of the Project was to enhance teachers' abilities to improve students' understanding of NOS and students' understanding of, and ability to perform SI, within a context of a standards-based science curriculum. Previous efforts have focused on either teacher knowledge or student achievement relative to SI and NOS. Project ICAN represents a first attempt to couple teachers’ professional development relative to NOS and SI with an extended focus on teachers’ classroom practice and student achievement.

The second year of the project, described in this paper, was conducted with 50 teacher-participants. Five out of the seven NOS aspects that are accessible to and relevant to K-12 students’ everyday lives (Abd-El-Khalick, Bell, and Lederman, 1998) were emphasized in the study. These include understanding that scientific knowledge is tentative, empirically based, subjective, depends on human inference, imagination and
creativity. An additional important aspect is the distinction between observation and inference.

METHOD

Project ICAN comprised three phases: monthly workshops during the academic year, a two-week summer institute, and a follow-up during the year.

Phase One: Academic Year Activities

During the academic year, 50 teachers participated in 10 full-day monthly workshops. These workshops included NOS and SI instruction, reflective review of participants’ instructional experiences videos, and curriculum revision. Teachers actively engaged in SI activities and NOS activities, sample activities include “tricky tracks,” “fossils,” “mystery bones,” “tube,” and others. Detailed descriptions of some of these NOS activities can be found elsewhere (Abd-El-Khalick et al., 1998). Teachers videotaped at least one lesson for the project staff to review and provide feedback prior to the workshops. A selection of videotaped lessons were chosen to view as a group at the monthly workshops. This approach provided the group opportunities to discuss each others' teaching and teaching contexts, offer peer support and feedback, and see growth in their own and others' teaching. Monthly workshops also addressed NOS and SI instruction in the context of science subject matter, curriculum revision, and viewing/debriefing teachers' videotaped lessons. Teachers shared lessons and reported outcomes during the workshops.
Teachers focused on revising lessons to teach about NOS and SI in an explicit manner within the context of traditional science subject matter. All lessons were followed by group debriefs to discuss successes, challenges, and extensions to the activities.

Prior to the summer institute activities, the 50 teachers engaged in research experiences the purpose of which was to incorporate information from their research experiences into their classrooms. Some teachers engaged in a science research internship with practicing scientists, others engaged in a research field experience in informal settings such as natural history museums and zoos. The aim of that research experience was to enhance teachers' understanding of inquiry and NOS within an authentic context.

**Phase Two: Summer Institute Activities**

During the two summer weeks, teachers participated in 10, six-hour sessions that focused on NOS, SI, and unified concepts through a series of explicit/reflective activities, readings, and discussions. NOS and SI were contextualized within standards-based science subject matter. These sessions targeted a variety of areas. Focus questions and journal responses served to guide group discussions for reflection, comparison among research experiences, and sharing of ideas to establish connections between the research settings, aspects of NOS, SI, and classroom applications. Again, teachers engaged in revising lessons to teach about NOS and SI in an explicit manner within the context of traditional science subject matter. The main focus of the two summer weeks was on the development of performance-based assessments for scientific inquiry and the nature of science.
Phase Three: A Follow-Up

After the summer, the teachers returned to their schools and applied in their classrooms what they had learned during the previous academic year and summer. They were asked to videotape at least one lesson per month for the project staff to review and provide feedback. Accompanying the videos were lesson plans, reflections, and student work. Staff conducted on-site classroom observations and provided feedback and support. Student data were also collected during this phase.

DATA SOURCES AND ANALYSIS

Data addressing the change in teachers’ views were collected during the first phase. The academic year activities were preceded by collecting teacher responses to two questionnaires: Views of Nature of Science (VNOS-D) and Views of Scientific Inquiry (VOSI). These questionnaires were administered twice during the project year; at the beginning of the academic year and at the end of the summer institute.

The NOS aspects assessed include that science is: tentative, subjective, based on empirical observation, the product of human creativity, as well as the distinction between observation and inference. Aspects of SI targeted on the VOSI include a) multiple methods and purposes of investigations, b) importance of consistency between evidence and conclusions, c) multiple interpretations of data are possible, d) distinctions between data and evidence, and e) data analysis is directed by the questions of interest, involves the development of patterns and explanations that are logically consistent. A representative sample of ten teachers, based on their views of NOS and SI, was interviewed regarding their responses on the VNOS-D and VOSI. Profiles of teachers' views of NOS and SI aspects were generated based on their two VNOS and VOSI responses. Additional data sources
included journal reflections and revised existing curricular materials, which were collected during the second phase. Developments in teachers’ views were sought by comparison of profiles for each participant generated from VNOS and VOSI responses. Other data were examined for similar progress throughout the program to further inform the effectiveness of Project ICAN.

Video-taped lessons, lesson plans, instructional materials/assessments, and classroom observations comprised the data for examining the teaching of NOS and SI. Students' views of NOS and SI were assessed during the third phase by the administration of the Views of Nature of Science (VNOS-D) and the Views of Scientific Inquiry (VOSI) questionnaires (around 1500 students, grades 2-12) to students. Additional teacher developed classroom assessments that specifically addressed NOS or SI were examined to enrich the description of student outcomes. All of these data were collected during the third phase after the summer.

Data were reviewed for explicit reference to NOS and SI. Data for each student were analyzed to provide details of students' views of the targeted aspects of NOS and SI. Class data were pooled to describe project outcomes.

**PRELIMINARY RESULTS**

Participants demonstrated major enhancements in their understandings and their classroom applications of NOS and SI.

**Change in Teachers’ Views of Nature of Science and Scientific Inquiry**

Overall, a large majority of participants showed enhancement in their NOS conceptions. About 80% of them held informed views of at least three target aspects.
Most significant were the changes in their views of the tentative, creative, and subjective aspects of NOS. Inquiry-based activities and the group discussions explicitly dealt with these aspects and helped teachers gain examples as well as discuss their integration of these aspects into their classroom instruction.

Forty two percent of teachers, as compared with 19% in pre-instruction, had informed views of the tentative aspect of NOS. Following are some quotations from the VNOS post-questionnaire:

Their models [computer models of the weather patterns] are the best representation they can make at the time of what they understood.

What may have been thought of as true in the past becomes subject to debate and sometimes is even tossed out.

It [atomic theory] is accepted as true until disproved by other scientists (atomic theory)

Half the participants (vs. 32% from the pretest) held informed views of the distinction between observation and inference. As one teacher-participant had put it, “without directly observing what happened, scientists can only infer what happened.” Another teacher-participant believed that “we can only infer these dimensions of the dinosaur.”

Forty-five percent (vs. 26% in pretest) of the teacher participants exhibited informed views of the empirical aspect of NOS in their responses to the posttests. For example, one teacher-participant stated that “they [scientists] may find evidence that may cause a change in what was previously thought and found.”

Forty percent of teachers (vs. 10% in pretest) demonstrated informed views in their views of the role of imagination and creativity. However, some teachers still did not
understand the creative and imaginative aspect in observation and data analysis,
“scientists use creativity in planning only, but creativity in observation and analyzing
data is a kind of lying. That is not science.”

Thirty-five percent (vs. 19% in pretest) 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 “science is subjective in that each scientists has access to different data and evidence.” These responses changed drastically during the program. For example, a teacher-participant believed that scientists disagree about what caused 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.” Other responses were as follows:

Scientists interpret the same information differently. They have different perspectives by which they understand or view the same information.

They [scientists] draw conclusions based on their prior knowledge and collected data.

Based on what scientists know about how animals today look, they have used this information to guide in the reconstruction of dinosaur skeleton.

At first, most of the teachers made the activities that they experienced in the program, as.. Gradually, they started integrating NOS & SI into their regular activities and lessons.

With regard to scientific inquiry, the teachers began the program with the view that it involves a linear step-by-step process that, if followed, leads to the correct answer. These procedures are interpreted by objective scientists. They viewed the process as controlled, where the scientist is objective. They demonstrated major changes in their traditional view of "The Scientific Method"; they recognized that there is no universal step-by-step scientific method. Further, they came to recognize multiple methods to conduct 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. In their classrooms, these teachers conducted many of the inquiry-based activities that reinforced multiple methods of investigations. They tried to suggest to their students that there is no single universal scientific method. Many of their students showed enhanced understandings of multiple methods of investigations.

Teachers advanced in their knowledge of multiple or alternative interpretations given a set of data. They came to understand that scientists can have different inferences due to “scientists’ creativity, culture, and differences;” and that the scientists often come into the process with prior conceptions, past experiences, beliefs and values that affects how he/she looks, views, and interpret things. As one teacher had put it “even if scientists are working together, subjectivity may play a strong role in formulating one’s theory and influence how results are looked at.” However, only some teachers explicitly addressed this aspect in their classroom practices. Some teachers reported that they had difficulty in recognizing opportunities to teach about this aspect within daily instruction. They reported difficulties in communicating the subjective aspect of NOS due to lack of examples relevant to classroom investigations.

Teachers advanced in their understanding of the importance of supporting conclusions with evidence, which corresponds to the empirical aspect of NOS. Many of the inquiry-based activities as well as experiences in the science research settings reinforced the importance of basing conclusions on data. Most of the student participants exhibited more informed views of this aspect.
All teachers demonstrated more informed understandings of the role of evidence in supporting conclusions, and the majority explicitly emphasized this aspect in their classroom practices. Emphasis, however, was context-dependent. Some of their students demonstrated more informed views of this aspect.

**Teachers’ Instructional Practices**

During the academic year, most of these teachers explicitly discussed the inferential, empirical, and creative aspects of NOS. Most of these teachers' students showed more informed views of these three aspects of NOS. Teachers, however, reported difficulties in fitting the subjective and tentative aspects into their regular classroom investigations.

The instructional approaches included post-discussions within the context of demonstrations and inquiry-oriented activities. The following are three case studies of how teachers’ instructional practices changed as a result of their experience in the ICAN project. The first teacher, Christine, is in her second year as a middle school general science teacher. Prior to the project, she had already been using inquiry-based teaching in her science classes. However, she had never been introduced to the Nature of Science as content that needed to be explicitly taught in the science classroom.

Not only did the ICAN workshop teach Christine more about NOS and how to integrate it into her classroom practice, but it also provided her with the resources needed to begin implementing NOS into her curriculum. At every ICAN workshop, teachers would be introduced to both NOS and Inquiry activities that could be incorporated into their curriculum and were then given the opportunity to try the activities for themselves. Participants also received activity descriptions and any handouts or other materials that would be needed to begin incorporating the activities into their own classrooms.
One activity that participants did during the ICAN workshop was tube activity. Christine decided to add this to a curriculum she had taught the previous year called *Struggle for Survival*. This curriculum gives students actual data that scientists collected while studying the island Daphne Major in the Galapagos Islands. Students are told that half of the finches on the island died and are asked to explain why half the finches died and why half of them managed to survive. Students must work in groups to analyze the data they are given and come up with plausible answers to the problem that are supported by data. The instructor used the inquiry tube activity as an introductory lesson.

The teacher presented the students with a completed tube and had them observe the behavior of the various strings as she pulled them individually. She then provided student groups with their own cardboard tubes as well as a variety of other supplies that they could use to create an inquiry tube that would behave the same as the model that was presented to them. They could not see how the teacher’s model was made and so had to use what they did know to create their own inquiry tube. The instructor thought this lesson served as a good introduction to the curriculum because it was a short activity that gave the students a chance to begin using the skills they would be using during the long term *Struggle for Survival* project. That is, students got to practice working as a group to solve a problem using a limited amount of information.

When student groups completed their inquiry tubes, they presented their solution to the class. Most of the groups made successful tubes in that they behaved in the same way as the teacher’s original model. However, the students noticed that even though different group’s tubes behaved in the same way, they were not all constructed in the same way. The instructor used this outcome to introduce students to several aspects of NOS that they
would be learning about and using during the upcoming project. These aspects were
tentativeness, creativity, and the distinction between observation and inference.

Students understood subjectivity when the teacher asked them to compare their final
inquiry tube to that of the other student groups, and then explicitly discuss that. Even
though they all observed the same model, the inferences as to what the inside of the tube
looked like that each group made from their observations were different based on the
ideas and creativity of the students in that particular group.

Using the inquiry tube activity as an introduction to the Struggle for Survival unit
provided a timely introduction to the aspects of the nature of science that the students
would need to understand and use during their Struggle for Survival project. Adding this
to the curriculum better prepared the students for the task they had ahead of them.
Students knew that their conclusions they reached were right, even if different from those
of another group, as long as they had the data to support them. Students also came to
realize that science is not just memorizing facts, and that their individual ideas and
experiences could help them when interpreting and analyzing their data.

Taking the ICAN workshop had a marked effect on Christine and the teaching
strategies that she chose to use in the classroom. Prior to ICAN, her focus had been on
inquiry-based teaching of science content. After the workshop, the teacher also began to
include teaching of the nature of science, in addition to science content. NOS was used
as a way to introduce lessons and tie content together into more cohesive lessons. In
addition, she began implementing new teaching strategies including asking students
questions that would help them draw the connection between nature of science and the
particular science content and skills they were learning and using, conducting more in-
depth discussions at the end of a lab to discuss the similarities and differences in data gathered and analyses made, and assigning homework and assessing nature of science topics taught in class.

The second case study is of a first year science teacher, Gina. This teacher taught 7th and 10th grade science and began the workshop during her first trimester of instruction. Prior to ICAN the teacher valued and implemented the use of inquiry, but was unclear about NOS. She participated in the ICAN grant in effort to be a more effective teacher.

Two of the activities that she incorporated into her science instruction were the inquiry tube and the bird activity. The inquiry tube was incorporated into a 10th grade astro-biology class during a unit on evolution of life. Students were studying characteristics of living things; specifically they were reviewing research done to determine the role of DNA in cells. The tube was incorporated into the curriculum in order to emphasize the use of models in science. The following aspects of NOS were discussed explicitly: observation/inference, subjectivity, creativity, and tentativeness.

The bird activity was added into a 7th grade problem-based curriculum focusing on the concept of natural selection. The bird activity was used to reinforce the concept of structure and function. The aspects of NOS that were explicitly discussed were observation/inference and creativity. This activity was used as an assessment piece. The activity requires students to randomly pick a characteristic from 5 different categories. Students use these characteristics to create a bird. Students were required to illustrate and describe the relationship of structure and function of an organism within its environment.

After the project, Gena stated that “being a part of the I-CAN grant shaped my teaching. It challenged me to approach teaching and learning with a different lens. It
made me analyze and reflect on my instruction and student learning. I used the activities to make small changes in the existing curriculum. The activities I added were a meaningful fit into the existing curriculum. The activities sparked student curiosity, and required students to think, reason, and problem solve. Additionally, the strategies taught during the I-CAN grant were versatile across age groups and subject areas.”

This third case study is of a teacher, Elizabeth, with 5 years of teaching experience; specifically biology, physical science and earth science. The teacher came into the ICAN during her 5th year of teaching.

Prior to the project, the teacher used probe ware technology in the classroom on a regular basis. She participated in the ICAN grant as part of a school wide initiative to improve the school science curriculum. At first, the teacher was confused about the idea of inquiry and the teaching of it explicitly. She felt that it would be hard to incorporate NOS and inquiry as part of an already busy and overloaded year.

Through the series of workshops and collaboration with the team of teachers from her school, she was able to initially try out activities offered in the workshop in her classroom. She thought that it was beneficial to be able to meet with other teachers in the workshop and discuss the success, failure or confusion in using the activities with the other teachers in the grant. The teacher felt that she took her biggest leap of faith in taking her own classroom activities and modifying them to contain NOS and inquiry. The hardest part for her was to begin to allow the students to do labs that were open ended. What would happen if they all did not come up the same ‘result’? As she began to modify her technology activities she found that she was able to use less direct instruction time with her students and more guided instruction. Students were participating in the lab
work more actively, and as the year went on, stopped asking her the constant lab question “is this right?” Students often repeated results on their own without being prompted by the teacher. About her experience in the project, Elizabeth stated that “most classroom technology curriculum that I have encountered as a teacher seems ‘cookbook’ and lacks inquiry and NOS components. Such as the books that you can order to correlate with the TI and Vernier probe ware. The ICAN workshop gave me the knowledge necessary to take these labs and modify them to be inquiry base.

**Change in Students’ Views of Nature of Science and Scientific Inquiry**

Pretest data indicate that overall the students demonstrated naïve views of NOS and SI. During the academic year, most of the teachers explicitly discussed the inferential, empirical, tentative, and creative aspects of NOS. About 40% of these teachers' students showed more informed views of these four aspects of NOS. About 60% of the students showed more informed views of at least two NOS aspects. The most significant changes in students' views were with respect to the inferential, empirical, and creative aspects of NOS. All of the teachers who held informed views of these aspects were able to explicitly integrate them more frequently than other aspects. Instructional approaches included whole-group discussions within the context of a demonstration or an inquiry-based laboratory activity.

The two teachers who maintained naïve views themselves were unsuccessful in implementing explicit NOS or SI instruction, and their students maintained naïve views. Seventy percent of teacher participants, as compared with 35% of their students, demonstrated major changes in their views of SI. During the project, 55% of teachers acknowledged that there are multiple methods of scientific investigations. These teachers
conducted many inquiry-based activities that were followed by explicit discussions of inquiry and NOS. About 40% of their students showed enhanced understandings of multiple methods of investigations. Again, grade level and subject varied.

All teachers had more informed views of the multiple interpretations of a given set of data. However, only 60% of these teachers explicitly addressed this aspect in their classroom practices, although inconsistently. About 30% of student participants exhibited more informed views. To their credit, these teachers recognized their instructional inadequacies. They attributed their difficulties to lack of examples relevant to classroom investigations. This result is evident of simplistic inquiries where one general conclusion is likely. Lesson observations were thusly consistent.

CONCLUSIONS AND IMPLICATIONS

All of the teachers showed improvement in their views and their abilities to explicitly teach NOS and SI within the context of their subject matter. Changing teachers’ views is necessary but not sufficient to change their students’ views. Teacher intentions to integrate and fit NOS and SI into their classroom practices are a key. Peer group support and interaction in the monthly workshops proved to be an integral factor in teachers’ development of PCK for NOS and SI.

Teachers’ views of the inferential, empirical, tentative, creative, and subjective aspects of NOS improved tremendously. These aspects, with the exception of the tentativeness of science, appeared to be more easily integrated into teachers' classroom practices, as they can match with a wide range of contexts. These results indicate that the content/context might have a critical influence in teaching NOS and SI. Moreover, the
results from grade 2 through grade 11 suggest that grade level might also determine the ease of integrating NOS and SI into the regular science lessons.

The results of this project clearly indicate that explicit instruction and continuing teachers’ support can develop the knowledge and instructional skills required to enhance students' understanding of nature of science and scientific inquiry. It should be recognized, however, that such professional development takes an extended and continuous period of time.
REFERENCES


