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Epistemological undercurrents in scientists' reporting of research to teachers

George E. Glasson and Michael L. Bentley
Department of Teaching and Learning
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0313

Abstract

Our investigation focused upon how scientists, from both a practical and epistemological perspective, communicated the nature and relevance of their research to classroom teachers. Six scientists were observed during presentations of "cutting edge" research at a conference for science teachers. Following the conference, these scientists were interviewed to discern how each perceived the nature of science, technology, and society in relation to his particular research. Data were analyzed to determine the congruence and/or dissimilarity in how scientists described their research to teachers and how they viewed their research epistemologically. We found that a wide array of scientific methodologies and research protocols were presented and that all the scientists expressed links between their research and science-technology-society issues. When describing their research during interviews, the scientists from traditional content disciplines reflected a strong commitment to empiricism and experimental design, while engineers from applied sciences were more focused on problem solving. Implicit in the data was a commitment to objectivity and the tacit assumption that science may be free of values and ethical assumptions. More dialogue is recommended between the scientific community, science educators, and historians/philosophers of science about the nature-of-science, STS, and curriculum issues.

Introduction

Epistemological undercurrents in scientists' reporting of research to teachers
Our interest is in the relevance of contemporary scientific research to the elementary and secondary school science curriculum. Specifically, we investigated aspects of what may have been communicated by scientists and engineers to teachers at a conference intended to enhance instruction in science, mathematics, and technology. The conference is part of a project in a southeastern state designed to connect the principles, laboratory protocols, and results of scientific research to the K-12 classroom curriculum. An audience of K-12 educators from across the state attended a two-day conference in order to interact with a diverse group of practicing research scientists and engineers, who presented and discussed their work and what

they perceived to be classroom connections. Because previous research has indicated that many teachers hold misconceptions about the nature of science and technology, and their interrelations with society (Gallagher, 1991; King, 1991; Pomeroy, 1993; Rubba and Harkness, 1993), we saw the conference as an opportunity to examine how scientists communicate the nature and relevance of their own research to classroom teachers.

Here we discuss how the prevailing perspective on the nature of science, technology and society, as presented in contemporary science education curriculum documents and research, represents a significant change from the view of science which dominated only a half century ago. We will review what is known about teachers' understanding of the nature of science and what teachers might learn about the nature of science from contact with "science-in-the-making." Finally, we will share the results of our investigation into how scientists at the conference communicated the nature of their own research to an audience of K-12 classroom teachers and how they reflected on their work from an epistemological perspective. These results, reflecting scientists' viewpoints, will be compared with contemporary views on the nature of science, technology and society that have been advocated in science education literature.

The Nature of Science

The most influential current curriculum documents in science education consider the nature of science as basic content for the K-12 curriculum for *all* students.¹ For example, the National Council on Science and Technology Education, in formulating the American Association for the Advancement of Science's Project 2061, considered the nature of science to be a category of knowledge, skills, and attitudes essential for all citizens. Project 2061's *Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993) have been the basis for many state curriculum guides and a major resource for the National Research Council's *National Science Education Standards* (NRC, 1996). The National Council on Science and Technology Education specified three principal components of the nature of science:

- *the scientific world view* (e.g., the world is understandable, scientific ideas can change but also are durable, science cannot answer all questions);
- *scientific methods of inquiry* (e.g. science demands evidence, is a blend of logic and imagination, explains and predicts, is not authoritarian, scientists try to identify and avoid bias);

- *the nature of the scientific enterprise* (e.g. science is a complex social activity, is organized into content disciplines and conducted in various institutions, ethical principles operate in the conduct of science, scientists participate in public life both as specialists and as citizens). (Rubba & Anderson, 1978, p. 25-31, italics added)

The *National Science Education Standards* (NRC, 1996) states that, “science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism.” (p. 201) In addition, the NRC included both “Science as a Human Endeavor” and “Historical Perspectives” as part of the “Nature of Science” content standard. As explained in the guide to this standard, “Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separated from society but rather science is a part of society.” (p. 201).

The nature of science is characterized among scholars in the philosophy of science as a theory-driven and empirical enterprise in which the historical development of science is characterized by periods of consensus and dissensus (Kuhn, 1970; Duschl, 1990). Science is also ongoing and dynamic, a complex activity in which both comprehensiveness and simplification/parsimony are aims (Kimball, 1968). Such qualities of science as openness, tentativeness/uncertainty, testability, multiple methods of investigation, naturalism, peer review, and community authority are aspects of the current, post-positivist view of science (Kimball, 1968; Fleury & Bentley, 1991, Bentley & Fleury, 1998). From a socio-cultural perspective, both the political and contextual nature of scientific research becomes more salient in the construction of scientific knowledge (Kelly, Carlsen, & Cunningham, 1993).

A contemporary understanding of the learning process in the science classroom, in which knowledge construction requires active participation on the part of both the learner and the teacher, parallels and reflects the contemporary perspective on the nature of science (Glasson & Lalik, 1993). According to Lederman (1986, p. 98), “...the ‘nature of science’ is more akin to a values system which is to be adopted by students.” As opposed to briskly covering material and testing students throughout the year, this value system is associated with learning scientific theories in depth, as teachers help students “actively and meaningfully link knowledge claims” (Duschl, 1990). Further, understanding how children learn from a constructivist perspective may enrich teachers’ beliefs about the nature of science (Pomeroy, 1993).

Science, Technology, and Society Connections

Since the early 1980s, science-technology-society (STS) content (of which ‘nature-of-science’ content is part) has risen to the status of “a common science curriculum component.” (Rubba & Harkness, 1993, p. 407) Standards related to STS now are conspicuous in both national and state documents.

According to Dennis Cheek (1992) there are two distinct educational goals to STS education:

- (1) teaching students about the nature and culture of science and technology as experienced by practitioners and understood through the conceptual lenses of sociology, history, psychology, anthropology, and philosophy, and,
- (2) introducing students to personal, local, national, and/or global issues at the interface between science, technology and society...(which) entails personal decision-making and informed, premeditated action. (p. 199)

The first goal is the nature-of-science part of STS while the second goal is about the interrelationship between science, technology, and society as revealed through the study of social issues. Numerous issues may be relevant to students’ lives and to the communities in which they live, such as land use, standards for and maintenance of water and air quality, climate change, birth control, genetic engineering, weapons research and production, and so on.

As an example of the second aspect of STS content being advocated for the science curriculum, Joseph D. McInerney (1989), Director of the Biological Sciences Curriculum Study, lists the following as basic principles students should understand about technology as a force for change:

- Technology exists within the context of nature, that is, no technology can contravene biological or physical principles.
- All technologies have unintended consequences.
- Just as proposed explanations about the natural world are tentative and incomplete, proposed technological solutions to problems are incomplete and tentative.
- Because they are incomplete and tentative, all technologies carry some risk; a society that is heavily dependent on technology cannot be risk free. (pp. 6-7)

A number of features of an STS enriched curriculum have also been identified in a position statement by the National Science Teachers Association (NSTA, 1990). Such a curriculum: (1) engages students in identifying problems with local interest and impact; (2) focuses on the impact of science and technology on students' lives; and (3) provides opportunities for students to experience citizenship roles as they resolve issues (pp. 47-48).

The STS link to the nature of science was explicated by Duschl (1990) in advocating Laudan's triadic network of justification as a model for connecting scientific theories, methods, and aims in science teaching. Specifically, the aims of science include a connection to science, technology, and society issues:

The activities of science, technology, and society do not take place in a vacuum. Social pressures affect the formulation of standards that scientific communities apply to research efforts and research funding. Present day examples of socially relevant scientific problems include global warming of the atmosphere, AIDS, secondary and tertiary recovery of oil reserves, solid-waste disposal, and superconductivity (Duschl, 1990, p. 89)

According to Duschl (1990) the relationship between basic science and applied science is fundamental to the growth of scientific knowledge.

Teachers' Understanding of the Nature of Science, Technology and Society

An understanding of science as a human endeavor that is embedded in and interdependent upon the larger society is supported by scholarship from the fields of the philosophy, history and sociology of science. However, these are fields that few teachers regularly follow, as the fields of science education and the philosophy of science have developed exclusive of each other for many decades (Duschl, 1985). Beginning and practicing teachers typically have little knowledge of, or background coursework in the history and/or philosophy of science (Gallagher, 1991; King, 1991). As Lederman (1992) discussed, this is an unfortunate situation, because science teachers' choices in enacting the curriculum are significantly influenced by their understanding of the nature of science. Indeed, the nature-of-science is a

global conception that frames teachers' understanding and teaching of science (Bohm & Peat, 1987). Recommendations being offered for curriculum reform in current standards and frameworks are evidence that science educators have become more aware that the social studies of science should inform K-12 curriculum content and pedagogy (NRC, 1996, American Association for the Advancement of Science, 1989, 1993). Gallagher (1991) further explains:

Moreover, secondary science teachers have a distorted understanding of the nature of science because their scientific education has focused on the body of knowledge in science, and it has given very little emphasis to the processes by which scientific knowledge is developed and validated. . . . Applications of scientific knowledge to the experiential realm outside of classrooms and laboratories is another area of deficiency of knowledge of both prospective and practicing secondary science teachers. (p. 132)

What has been overlooked by many K-12 teachers of science is the understanding that science is a socially constructed, human enterprise, a stance supported by most contemporary scholars (see, for example, Bateson, 1979; Aicken, 1991; Chalmers, 1990; Giere, 1988, Laudan, 1984 ; Segal, 1986; Richards, 1987, and Reiss, 1993). Examples of misconceptions about the nature of science held by many teachers include, “conceptualizing science as a sequence of steps commonly referred to as ‘the scientific method’; visualizing scientific hypotheses, theories, and laws in a developmental sequence; and not distinguishing between science and technology” (Rubba and Harkness, 1993, p. 426). Further, instead of conceptualizing the practice of science as value-laden throughout (Garrison & Bentley, 1990), preservice science teachers were found to perceive science in a positivist frame, as objective and linear, an exclusively logical-empirical enterprise (Palmquist & Finley, 1997). Although Abd-El-Khalick, Bell, & Lederman (1998) reported that preservice science teachers may understand the empirical and tentative nature of science, they were unable to distinguish between theories and laws and overlooked the social and cultural aspects of science. Further, teachers lacked explicit reference to nature of science when planning instruction (Abd-El-Khalick, Bell, & Lederman, 1998).

Despite the currently widespread recognition that STS content is an important component of science in the curriculum, many K-12 teachers are poorly prepared to teach in this area. In

discussing the results of their study of pre-service and in-service secondary science teachers' beliefs about science-technology-society interactions, Rubba and Harkness (1993) conclude:

Where the integration of STS into science instruction is concerned, science teachers need to understand the nature of science and technology and their interactions within society. The findings presented herein, however, show that science teachers may not, in fact, hold adequate understandings of the nature of science and technology and their interactions. (p. 429)

In addition, "while they generally recognized the existence of interactions among science, technology, and society, neither the preservice nor in-service science teachers were able to explicate those relationships" (p 427).

The southeastern state's conference planners, in an effort to enhance teachers' understandings of the nature of scientific research, recruited scientists to present their "cutting-edge" research to K-12 teachers. This study examined how these scientists communicated their research protocols to the teachers and the epistemological positions they assumed in discussing their own research.

Cutting-edge Research: Science-in-the-Making

Latour (1987) and others distinguish between different forms of scientific knowledge, for example, between what Latour calls "ready-made science" and "science-in-the-making." Ready-made science is uncontroversial knowledge, taken for granted, and similar to "final form science" (Duschl, 1990); it is the science of textbooks, the content which is widely agreed upon by scientists in the particular field. While all scientific knowledge is tentative, scientists generally consider it unproductive to challenge this variety of scientific knowledge. In contrast, claims made in contemporary scientific research viewed as contestable and subject to revision represent science-in-the-making. "When uncertain knowledge associated with science-in-the-making is a part of a social issue, a socioscientific dispute results because there is no consensus as to the scientific facts" (Bingle & Gaskell, 1994, p. 187).

It is reasonable to expect that teachers and students, by learning 'first hand' about the science-in-the-making kind of research, the cutting-edge of science, will construct a more sociocultural view of the nature of science. Considering the recommendation that science teacher

preparation programs include opportunities for the teachers to study the social studies of science (McComas & Almazroa, 1998), it could be argued that STS connections should be studied in the context of exploring the assumptions underlying scientific research. Perhaps the “ready-made science” of the textbook may be supplemented or even replaced by “science-in-the making.”

Scientists’ Perspectives on Research

Although many scientists engage in cutting-edge research with links to societal issues, scientists may be more inclined to view their research from a positivist perspective. In a survey of scientists and teachers, Pomeroy (1993) found that scientists were significantly more likely to adhere to traditional logico-empiricist views of science than secondary science or elementary school teachers. Pomeroy speculated that scientists may not have the acceptable public vocabulary to discuss the nature of their research from an epistemological perspective. Scientists in Pomeroy’s sample also ascribed to more traditional, non-constructivist views of science teaching than did secondary or elementary teachers. These results are important to consider if “science-in-the-making” is being promoted to enhance teachers’ understandings of the nature of scientific research. In light of the growing consensus on the importance of improving teachers’ understanding of nature of science, (McComas & Almazroa, 1998), teachers’ exposure to scientists and scientific research may be helpful in promoting the social studies of science. However, further research on scientists’ epistemological understandings of the nature of their own scientific research is essential if scientists are involved in presenting their research to teachers.

Methodology

In this study, we were interested in how scientists described their “cutting edge” research from both a practical and epistemological perspective. Our research involved a statewide project designed to connect cutting-edge scientific research to K-12 curriculum, in part by means of an annual two-day conference for educators. The conference, which attracted approximately 250 attendees, featured one and two-hour presentations and workshops led by practicing research scientists who discussed their research and what they perceived to be K-12 classroom connections.

In order to determine what views of science were being communicated to the teacher-participants by the scientists, we collected and examined data from two primary sources. First,

we observed a sample of six key scientist-presenters whose sessions primarily were intended to communicate scientific research. During the presentations, the authors remained unobtrusive and did not attempt to intervene or seek clarification or more depth of explanation related to the research. We recorded through field notes the essential aspects of the scientists' presentations and collected documents and handouts for later analysis. In taking field notes, we compiled and organized our observations by focusing on significant aspects or categories of the nature of science as defined by the National Research Council's *National Science Education Standards* (NRC, 1996) and as documented in studies in the nature of science, technology, and society (e.g. Rubba & Anderson, 1978; Duschl, 1990; Kelly, Carlsen & Cunningham, 1993; Rubba & Harkness, 1993). These categories included: (1) methods of inquiry (e.g. empiricism, experimentalism, respect for logic and rational thinking); (2) socio-political connections; (3) technological connections; (4) historical connections; (5) underlying values and assumptions. We documented the scientists' research protocols which "fit" into these categories to provide data which indicates the extent of compliance with the national standards and the nature-of-science/STS research. For example, in presenting his research to teachers, a chemist focused on research protocols involved with bioassay testing techniques that fit into the category of "methods of inquiry." However, we also collected data that were not consistent with the national standards and research documents and perhaps more reflective of the personal views of the scientists' in describing their research or novel methods of investigation. As an example of a novel bit of information that did not neatly fit into a category, an engineer used the model of "spaghetti" to discuss the mobility of polyethylene molecules. These data were categorized and synthesized through an iterative process of searching for recursive themes by reviewing the field notes (Ely, Ansul, Friedman, & Garner, 1991) to develop a descriptive profile for each session in which the nature of the scientific research and the connections with technology and society were explicated.

Second, we conducted interviews of the same six scientist-presenters in order to discern how each perceived the nature of science, technology, and society in relation to his particular scientific work.² We asked the scientist to describe how his own work reflected the nature of science, as he understood it, and we asked each to identify the aspects or characteristics of the nature of science that were communicated to conference participants in his presentation or workshop. We also asked each to identify aspects or connections among science, technology,

and society that were communicated to teacher-participants when the scientific research was described and explained. Each interview was audiotaped and transcribed for analysis.

In the interview analysis, data from the interviews were categorized and organized by themes (Ely, Ansul, Friedman, & Garner, 1991). Following an interpretive design (Erickson, 1986), we considered the scientists' viewpoints in relation to their actions (presentations to teachers) and the meanings of their actions (interviews). For example, in discussing research with tropical plants at the conference, a chemist shared how he negotiated with tribal chiefs and shamans to identify botanical specimens for collection and assaying. During an interview following the conference, this same chemist described his scientific research as searching for "objective truth."

During data analysis, the two researchers collaborated to extensively review the observations of the conference and the interview transcripts to create an overall portrayal of each scientist's philosophical stance in relation to his scientific research. We were specifically looking for congruence and/or dissimilarity in how the scientists described their research in the conference sessions and how they reflected on their research from an epistemological perspective. Finally, the scientists' views were interpreted in relation to contemporary literature on the nature of science, technology, and society.

Results

In this report, we will narrow our focus to two of the six scientist-presenters who were subjects in the study. We selected these two cases because they represent examples of contrasting research protocols and also contrasting perspectives on the nature of science, technology and society. We will also summarize our findings regarding the views of the scientists in the whole sample.

A Chemist Investigating Plant Biology

One scientist-presenter, a chemist, described his research on tropical plant species with potential use as drugs. He has mainly collected plant materials in a South America country. In his presentation, he used examples like taxol and digitalis to illustrate the potential significance of his research. He described features of the South American country and its peoples, and explained how he negotiated with tribal leaders for access to the plant materials of the forests.

He showed slides, which illustrated the collection process and bioassay testing techniques, and explained how he tested potentially useful plants for pharmaceutical applications.

In the presentation, the value of plants as resources for pharmaceuticals was emphasized, as was the process for researching plant products. Concurrently, the scientist-presenter described the problem presented by accelerating deforestation in the tropics, emphasizing the potential loss of useful species due to habitat destruction. Relevant aspects of the history of the country were interwoven throughout the presentation, and the researcher pointed out specific social, political and ecological issues. The scientist expressed his view that those who govern biologically rich areas need to be provided an incentive to preserve natural habitat. He talked about ways of negotiating with the government for access to the forest's biological resources. His research project demonstrates the international nature of contemporary science and shows how science can become a collaborative process involving coping with local situations and negotiation.

Interview with Chemist. When interviewed about his work, this chemist, who specializes in finding pharmaceutically valuable plants, characterized his research as empirical and grounded in objectivity:

My research is very much an empirical approach. There are different ways of looking at science, sometimes you have a hypothesis, a theory or idea to see if a compound will have some effect, a physical or biological property and you set out to make that compound to see if it has that effect.

When asked what public school students should know about how science works, this scientist focused on the consistency and reproducibility of nature:

I think one of the key things they need to know about nature, in a sense, is the idea of consistency, the reproducibility of nature, the fact (that) if you are given an experiment (and) you do it the same way on ten different occasions, it should give you the same result on ten different occasions. In real life, we know there are obviously. . . .you can't reproduce these exactly so there are little differences from time to time.

This researcher also believed that K-12 students should learn that science investigations can lead to “objective truth.”

One of the things I would like to see people come away with is the idea of truth. Students have in a sense put their minds in different compartments, in some areas, they say there is such a thing as objective truth, and in some other areas they say there is no objective truth. If you believe it’s right, it’s right. I repudiate that notion strongly. I think there is such thing as objective truth in the ethical area as well as the scientific area.

This scientist further stated that, “the ultimate way, in the scientific way, is by experimentation. Chemistry is an experimental science to validate the truth of the science and to obviously learn about the properties of compounds and so on.”

When discussing STS connections, this scientist-presenter identified strong connections between his research and how science addresses societal problems:

My research has obviously directed toward the discovery of drugs, so it has direct benefits to society if it were successful What we have done is discovered a lot of reactions, a lot of chemistry of taxol that other people may use, or in some cases have used to develop other analogs of taxol, and maybe we will not be the ones to come up with the next generation of taxol but maybe someone else will come up with it using some of our chemistry and some of their own chemistry, so in a sense I will have contributed to society through that discovery.

When asked what K-12 students should know about science-technology-society, this scientist spoke of the need to improve the image of chemistry:

It’s unfortunate, I think, that chemistry has taken a bad rap in the public at large. When a lot of people think about chemistry they think of polluting industrial plants, they think of toxic compounds, the word *chemicals* almost has a bad name, the word *drugs* or *pharmaceuticals* has a good name. So chemistry is very much the foundation of all pharmaceutical science. . . . So I would like for high school students to understand. . . .

chemistry as a discipline and the fact that, yes, there are bad chemicals, but there are also good chemicals.

Further, this researcher discussed the importance of science to everyday life:

I would like students to appreciate something of the importance of science to life, without science we can't live. We wouldn't have the standard of living we have without all the benefits that come to us through science and engineering.

The views expressed by this scientist, and communicated in his conference presentation, reflect strong connections of science to society. Further, many of the scientific concepts and principles that the scientist identified as being related to K-12 instruction also were contextualized within the overall picture of benefits to humans:

I want them to learn that plants are important components of the ecosystem, if you will. Plants are there, they are important to us, they are beneficial to us, and I would like the students to learn and understand that. So that whether or not they become biologists, or botanists, at least they can say plants are important to us, we need to treat them well. We don't want to cut down the forest or whatever.

These statements reflect the influential role of values in connecting science research to STS issues.

An Engineer Working in Materials Science

In his conference session, this engineer-presenter highlighted the interdisciplinary nature of materials science and related examples of his field's influence in everyday life. The researcher suggested ways teachers could integrate materials science into the curriculum. For example, in explaining how the mobility of a polyethylene molecule is essential to understanding the chemical properties of plastic grocery bags and bulletproof vests, the engineer compared the mobility of this molecule to "spaghetti." He suggested students could learn about stress-strain curves through investigations using plastic wrap and another involving stretching a two-liter plastic bottle. He demonstrated the concept of surface tension using various substances in a petri dish.

This engineer-presenter connected STS issues to his field in relation to recycling. Consumer concern over choosing plastic vs. paper was discussed from a “scientific” point of view: since landfills are anaerobic, he explained, paper does not decompose and plastic takes up less volume. The consumer calculation, he pointed out, also should take into consideration energy consumption. He discussed other issues related to recycling glass, metal, and plastic. The researcher stated that students should consider scientific information when discussing recycling issues.

Interview of Materials Scientist.

The materials science engineer discussed the scientific method utilized in his own research: “I would do things like gathering information, organizing the information, categorize, cross reference the information - you check external resources, the steps you would go through to solve a problem from a mechanical point of view.” To this scientist, the research process is similar to solving everyday problems, with the exception that scientists focus more on the analysis of problems:

A lot of difference between science and regular problem solving is that we focus heavily on analysis after the problem is solved, recording what you did and why you did it, publishing that information so that other people can get hold of it so they don’t have to solve the same thing over again.

To the researcher, peer review and community authority are important aspects of contemporary science practice.

Further, this materials science engineer related the nature of science to cognitive psychology and the discovery process:

So I have a real strong interest in the discovery process, what are the mechanisms, from a cognitive psychology point of view, the scientists use when they come up with a creative idea. . . . You can improve a person’s creativity just like you can improve memory, by teaching them tools. So a lot of what I’ve done after we’ve worked on projects is spend

time thinking about what were the things we did along the way that lead to the creative acts.

This engineer-presenter has talked with school groups about the cognitive steps involved with solving problems. He discussed how he perceives the thinking processes involved:

But I also talk them through incubation in your brain and what happens when you incubate on problems versus the mnemonics part, remembering the information you have stored and . . . the different methods that you think about problems, like the proximity method of going toward a solution.

The researcher's consideration of the role of metacognition in the practice of science reflects a view of science as a creative human endeavor.

When asked about the STS connections to his research, this materials science engineer mentioned the issues of recycling and reuse of materials:

That's a classic example, recycle/reuse, and they're not all obvious issues. I think the problem with society and these issues is that a lot of people without the technical understanding of them have to make decisions, (and make) faulty decisions without the appropriate technical input. A good example is the McDonald's containers. When you and I were kids, they were Styrofoam, and now they're paper. Everyone feels it's time to save the environment. It's clear to show that after calculation to calculation (sic), and (after) study, study and study, that the paper containers are much more damaging to the environment than the Styrofoam containers.

This researcher reiterated that in a landfill neither paper nor plastic is biodegradable and it takes more energy to recycle paper than plastic. Students learn about this "everyday stuff," he stated, by investigating specific properties when studying materials (e.g. mechanical properties, elasticity, and conductivity). In his view, future citizens would make more informed decisions about environmental issues if today's students learned about the properties of materials and engaged in cost/benefit analyses in terms of, for example, energy use and pollution. STS

connections such as these, identified by the materials engineer, reflect a view of science as an enterprise involved in societal issues by assisting citizens in decision-making based on the examination and analysis of empirical evidence.

Analysis of Six Scientists' Research Protocols and Viewpoints

In studying a conference designed to connect scientific research to the K-12 curriculum, we examined the communication of a sample of scientists and engineers about their own research to an audience of elementary and secondary teachers. This result was then compared to the presenters' discussions of the nature of their own scientific research. Our interpretations should be considered within the context of the methodologies that were used by the authors during the scientists' presentations and during the interviews of the scientists. During the presentations, we collected observational data through field notes to learn how scientists describe their research protocols in a public forum without an attempt to intervene or probe for further elaboration. The scientists were subsequently interviewed to discern more about the epistemological undercurrents underlying the scientific research that was described in the presentations.

The type of research of the six scientists/engineers who presented at the conference represents a wide array of scientific methodologies and research protocols (see Table 1). These protocols represent mostly applied research (e.g. using satellite systems for wildlife conservation or developing "smart road" technology), though one scientist described research that is primarily theoretical but potentially has practical applications (i.e. microgravity and embryological development). All scientists, however, discussed collecting empirical data as fundamental to their research. Three scientists (the chemist, botanist, and biologist) used experimental design in their research while the ecologist employed statistical analysis. The two engineers were involved in "problem-solving" and developing and testing materials or electronic components.

During the presentations, each of the scientists also discussed connections between their research and societal issues. These issues included such topics as developing drugs to fight cancer, increasing agricultural production, or recycling. One scientist, the chemist, discussed the negotiation of research contracts with other stakeholders, thus reflecting the political and contextual nature of scientific research. However, it is important to note that all of the scientists were promoting an agenda that supported the viability and vitality of their own research.

While these scientists were able to discuss research protocols and connections between their research and societal issues with teachers, we also found that they held a multiplicity of views in discussing the nature of the science of their own research during the interviews. Most prevalent among the scientists from traditional disciplines (e.g. chemistry, biology, botany), was the commitment to empiricism and experimental design. The focus of the engineers, who represent the applied sciences, was more on problem-solving and searching for multiple solutions. All of the scientists discussed connections to public policy decisions and societal issues, especially those decisions/issues that lend support of their research agendas. Inasmuch as the scientists discussed science as an empirical endeavor yet contextualized and connected to political and societal issues, we were able to ascribe their views as reflective of a contemporary “post-positivist” framework. We also found it difficult to label a scientist as positivist or post-positivist based on their perceptions of their own research. For example, scientific research was described by the chemist as exclusively an empirical endeavor, searching for “objective truth,” and science as an enterprise free from ethical assumptions. Such views may be interpreted as representative of a positivist view of the nature of science and inconsistent with the discussion of the pharmaceutical research in which the chemist negotiated with drug companies and tribal chiefs. However, a closer analysis must interpret how this scientist is using the term “objective.” For this chemist, objectivity appears to be compartmentalized, considered as part of empirical and experimental research that is separate from the process of negotiating for funding and access to rain forests. Further, in the scientific community, objectivity may be defined as related to “trials of strengths,” or the extent to which a scientist has support in the scientific community for his or her knowledge claims and research protocols (Latour, 1987). Clearly, this chemist's research was well regarded by his peers, as he was successful in obtaining funding and publishing his results. Perhaps, as a scientist, he did not hesitate in describing his research as searching for objective truth because his work is validated by the community authority in his field.

Nevertheless, our data require us to ask whether these scientists view their research as free from underlying epistemological assumptions. Notably, none of the scientists talked explicitly about their own biases in their research and how objectivity may be achieved, or about any controversies regarding research methodologies and knowledge claims in their fields. To the scientists, epistemological assumptions may require no explication because theory, methods, and

aims in their fields are closely interrelated and developed within the context of the scientific community. From the epistemological perspective of an outsider, however, these assumptions may be considered subjective and value-laden.

Discussion

Overall, related to the conference's stated mission to enhance instruction in science and technology, we found that the K-12 teacher-participants were presented with a range of current scientific and engineering work; examples of different research protocols; a variety of connections between science, technology and society; and some relevant links between cutting edge research and the classroom curriculum. For these reasons, we believe the conference was a worthwhile professional development experience for many participants. Although the scientist-presenters did not explicitly discuss their views of the nature of science in the conference sessions, in the interviews they expressed a commitment to empiricism and they were able to articulate significant science, technology, and society connections to their work.

Our investigation focused on what views of the nature of science were implied in the presentations that were given at a state conference designed to connect scientific research to the K-12 classroom. Of course, the teacher-participants at the conference experienced each presentation through the lenses of their own conceptions of the nature of science. Although not the focus of this study, we did survey the participants regarding the value of the scientists' presentations in helping them understand the nature of science, the history of science, and connections to science, technology and society. The participants reported that they learned about the nature of science and connections to science, technology and society but learned less about the history of science. We might wonder if the participants experienced *affirmation*, or, in contrast, *dissonance* between their understandings and the views of science implicit in the research presented. Future research should investigate if and how teachers develop *epistemologically* when exposed to "science-in-the-making." It should also be noted that all six scientists in the sample were male; future investigations may find gender differences in the epistemological assumptions of the scientists.

Science-in-the-Making, STS, and the Classroom

In our view, while the STS content of the conference presentations enabled participants to learn of new science-society connections, this should not be judged apart from the nature-of-

science messages that were concurrently, if implicitly, presented. This STS/nature-of-science link is so important because all scientific research proceeds from epistemological assumptions. For participants at a conference intended to connect science research to the classroom, cognizance of such assumptions, and of epistemological issues in research, is essential to appreciating, critiquing, and applying any science research to the K-12 curriculum. If those who comprised the audience at this conference were representative of teachers in general, most attended the sessions on “science-in-the-making” having never studied or otherwise considered current thought in the fields of philosophy, history, and sociology of science. Many may have been unaware of the philosophical assumptions and issues involved in the work presented in the conference sessions because the substance of scientific research was presented with little or no consideration of these assumptions.

In classroom practice, there have been two main ways of approaching STS content. One has been to focus on social issues, and the other to focus on the social studies of science. The former is the most common practice, which mainly involves fostering students’ awareness of the roles science and technology play in creating and solving social problems. However, this approach to STS “reinforces science teachers’ views of scientific knowledge as being uncontroversial, dealing with subject matter that is certain and that can be marked right and wrong” (Bingle & Gaskell, 1994, p. 196). On the other hand, by focusing STS in the curriculum on the social studies of science, students have the opportunity to consider the nature of scientific research within the context of examining underlying values and decisions that influence research protocols.

To some degree, the conference participants were exposed to aspects of the social studies of science, for example, as scientist-presenters discussed some socio-political influence on their research. However, in our view, before the shift of STS curriculum focus that Bingle and Gaskell recommend can take place, many teachers will need to assess and address their professional development needs in the areas of philosophy, history, and sociology of science. Michael Matthews (1997) reminds us that, “... there has been increased stress on metacognitive awareness and epistemological development as important outcomes of science instruction.” (p. 324). By recognizing the underlying values and assumptions of scientific research, our students become more aware of their own learning as they conduct investigations in the classroom and field. Moreover, as Dougal MacDonald (1996), points out,

Current curriculum materials tend to provide little guidance to teachers who want to consciously convey messages about the nature of science while they teach science subject matter. Teachers who do develop lessons with such dual intents are basically on their own in this regard. . . (T)he addition of an explicit nature of science intent can make science lessons richer and give teachers ‘more to work with.’ (p. 195)

And as Driver (1994, p. 219) has pointed out, “Science learning, viewed from a constructivist perspective, involves epistemological as well as conceptual development.”

Finally, the responses of these six scientists raises the question: How can the basic tenets of scientific investigation, as understood by ‘bench’ scientists (e.g. empiricism, experimental design), be reconciled as viable vis a vis the post-positivist paradigm of scholars in the social studies of science? Kelly, Carlsen, and Cunningham (1993) provide a framework for conceptualizing scientific research by discussing how some hallmark principles of science (e.g. replicability, falsifiability, objectivity) have been negotiated through a social process that includes the socio-political and cultural contexts in which the research is conducted. However, acknowledging the role of social consensus in science does not negate the importance of empiricism in scientific research or in classroom science investigations.

The overriding view among practicing scientists is that science is essentially experimental and empirical; however, the important role of theory, the multiplicity and complexity of science methods, and the value-ladenness of science require that scientists examine the assumptions underlying their own research and what goes into the decision-making that affects research design, funding, and public acceptance of results. As Bohm and Peat (1987) note,

The image of the ‘hard-nosed’ scientist is yet another example of the subliminal influence that is exerted upon scientists by the tacit infrastructure of ideas of the community at large. Possibly it would be better to regard scientists, in the case of interpretations, as being somewhat like artists who produce quite different paintings of the same sitter....Some interpretations may show creative originality while others may be mediocre. Yet none give the *final* ‘truth’ about the subject. (p. 102)

Thus, as we see it, opportunities for dialogue between the scientific community and science educators about the nature-of-science, STS, and related curriculum issues, might further enhance understanding all around, as well as justify the relevance of projects devoted to connecting scientific research to the classroom. These concerns might also be addressed by future conference planners by incorporating sessions in which philosophers, historians, and sociologists of science present their work, or otherwise help teachers interpret empirical research in order to recognize the underlying assumptions. In other words, conference organizers need to recognize they will need to facilitate the epistemological development of teachers if teachers are going to know how to think about what they hear about cutting edge scientific research.

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Footnotes

1 Here we will focus on science education in the U.S., but contemporary science curriculum work elsewhere also could be cited to support this claim, for example Ministry of Education (1993), Curriculum Corporation (1994), and Northwest Territories Department of Education (1991).

2All the scientists in this study were men.

Appendix

Table 1: Scientists' Research Protocols and Viewpoints

Field/Research focus Presentations to Teachers: Research Protocols/STS Connections Scientists' Views During Interviews: Nature of Science

Chemist: Plant Chemistry bioassay techniques of plants to identify potential drugs;
collaboration with drug companies and negotiation with tribal chiefs in rain forest
"objective truth" in scientific and ethical areas, achieved through experimentation
Botanist: Agricultural Research measurement of photosynthesis, respiration, and plant
growth by treating plants with hormone and growth regulators; referred to global warming
experimental method as key to scientific research; increasing agricultural production
important rationale for research; public understanding/financial support for research necessary
Ecologist: Wildlife Management

developing wildlife information systems; habitat maintenance and wildlife conservation;
using advanced technologies (satellite systems, cybernetics)

using observation data and statistical analysis to make inferences and policy decisions
related to wildlife management

Biologist: Microgravity and Embryological Development

investigating the embryological development of salamanders in microgravity;
collaboration with Japanese scientists on-board space shuttle

use of experimental design; science as teamwork; analysis of failures; necessity of public
support

Engineer: Transportation

Research “smart road” technology; developing safer transportation
research as problem-solving

Engineer: Materials Science chemical and physical properties of common materials;
costs/benefits of recycling paper versus plastics

research as chaotic, non-linear process, involving multiple solutions

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