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ABSTRACT

This case study of learning explores the relationship between a chemistry teacher's instrumentalist perspective on the nature of science, the classroom culture that flourished through curriculum enactment during the course of a school year, and development of perspectives on science by his students. An ethnographic methodology was employed, with participant observer field notes, interviews, and text analysis as major sources of data. From the outset, the teacher explicitly interjected his views on the nature of science into class lectures and discussions with the intent of alleviating student fears of higher-level science courses. In addition, students implicitly learned about the process of scientific inquiry through participation in lab work and science projects. Data from exit interviews exploring students' views on the nature of science confirmed that most students were instrumentalist in their perspectives. Six of the teacher's instructional techniques were identified as contributing to a classroom culture that fostered this viewpoint: modeling scientific inquiry and attitudes; interjecting anecdotes related to the development of scientific concepts; using explicit language; employing high level questioning; providing a supportive classroom atmosphere for the exploration of science; and involving students in independent science projects. (Contains 16 references.) (Author)

Fostering Instrumentalist Conceptions of the Nature of Science: A Classroom Study

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Fostering Instrumentalist Conceptions of the Nature of Science: A Classroom Study

Background and Objectives

Research in classrooms has demonstrated that a preponderance of science students sit in classrooms where science is presented as a noun, i.e., a compendium of 'true' facts collected over time, embedded in esoteric vocabulary. More appropriate, however, is the view of science as a verb. Instruction from this perspective engages students 'doing' science, studying its development as a process of disciplined inquiry, demonstrating the creative, tentative features of the discipline. For the better part of the century, understanding of the nature of science has been an objective of science curricula (Lederman, 1992), translated into the goal of scientific literacy for all students (National Research Council, 1996).

Lederman's (1992) analysis of research on the nature of science chronicles a gradual change in focus from simple assessment of student conceptions to analysis of the interactions between teachers' understandings of the nature of science, their classroom practice, curriculum enactment and student understandings. Similarly, this investigation of a chemistry classroom culture asked: Does the teacher's conception of the nature of science influence his classroom behavior and the classroom environment? Does the teacher's conception of the nature of science directly influence the perspectives of his students? What influence do other contextual factors have upon students' perspectives?

Theoretical Underpinnings

Generally defined as "the values and assumptions inherent to the development of scientific knowledge" (Lederman & Zeidler, 1987), the term 'nature of science' has been characterized in various forms. Shulman and Tamir's (1973) list of five common science learning objectives includes understanding the nature of science. Subdivisions of this category are: "the scientific enterprise, scientists and how they work, the existence of multiplicity of scientific methods, the interrelationship between science and technology and among the various disciplines of science" (p. 1119). Meichtry (1993) describes nature of science and of scientific knowledge as two facets of scientific literacy. In her definition, nature of science is the broader term, incorporating "not only the nature of scientific knowledge, but the nature of the scientific enterprise and nature of scientists as well" (p. 430). From a seven-part definition of scientific literacy developed by Showalter (1974), Rubba and Andersen (1978) created the Nature of Science Knowledge Scale (NSKS) to represent the first dimension of scientific literacy - understanding the nature of scientific knowledge. Their model of scientific knowledge includes six factors: Amoral (moral judgment can be passed only on man's application of scientific knowledge, not on the knowledge itself.);Creative (scientific knowledge is a product of the human intellect.); Developmental (scientific knowledge is never 'proven' in an absolute and final sense. It changes over time.): Parsimonious (scientific knowledge tends toward simplicity, but not to the exclusion of complexity. It is comprehensive as opposed to specific.); Testable (scientific knowledge is capable of empirical test.); Unified (scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contributes to a network of laws, theories, and concepts.) (Rubba & Andersen, 1978, p. 456).

The orientations from which ideas about the nature of science are communicated have been distinguished as realist or instrumentalist (Meichtry, 1993; Zeidler & Lederman, 1989). In the realist perspective, scientific knowledge is portrayed as real and true, existing independently of human existence. On the other hand, an instrumentalist view depicts scientific knowledge as a product of human creativity, tentative and inferential - the components of scientific literacy. In their operational definition of variables related to teachers' language (Zeidler & Lederman, 1989), for example, a realist viewpoint is expressed about constructs and models through the opinion that models are equivalent to the objects and events they depict, whereas an instrumentalist position is apparent in statements that depict scientific models as arbitrary, employed to predict the behavior of objects or events and suggest how they may be viewed.

Correspondingly, the theory of curriculum modulation envisions curriculum naturally changing form and emphasis as it progresses from its intended version, through enactment to learning by students in the classroom environment. Curriculum materials, teacher and students become major participants in, and determinants of, the curriculum. Accordingly, each classroom culture, as a unique blend of individuals and materials, produces a complex set of factors that influences learning. Thus, a comprehensive study of any educational process must consider all these aspects of the curriculum.

As a significant goal of science education, the development of students' views of the nature of science requires attention. Tracing this development through the intended, enacted and learned curriculum allows the researcher to construct a case study of learning that highlights the roles of all classroom factors in the process, and illuminates their influence upon construction of learners' notions of science.

Design and Procedure

An ethnographic methodology was chosen for this investigation. Data collection was accomplished primarily through participant observation by the researcher in a high school chemistry class for an entire school year. Additional data sources included an analysis of the textbook and related curricular materials, the researcher's personal journal, formal and informal interviews with the teacher Mr. London (a pseudonym), interviews of six students representing high, middle and low achievement levels, and artifacts such as tests, labs, and student Learning Logs.

An American school on an overseas United States military base served as the setting. The enrollment of Victory High School was approximately 700 students in grades 7 through 12. Three chemistry classes with an average of 20 students each were taught daily. Most chemistry students were juniors concurrently enrolled in advanced mathematics. Mr. London, with sixteen years of experience, volunteered for the study in which he would be using a newly adopted commercial chemistry curriculum. As a participant observer, I took part in daily activities of the seventh period class, recording copious field notes, working in cooperative groups to complete assignments, conducting labs and taking tests. Daily transcription of notes allowed me to continuously develop questions for subsequent observations and interpretation, according to methods outlined by Erickson (1986).

An exit interview conducted with six students consisted of three sections. The first included twelve questions on the interviewees' thoughts and experiences associated with learning science. The second section related to attitudes about the chemistry class. The third explored students' views of the nature of science, which were subsequently analyzed for realist/instrumentalist orientation, providing rich data for this study.

This case study of learning begins with a vignette in which Mr. London reveals his orientation to the nature of science as he introduces the chemistry class to the process of scientific inquiry. Next, the chemistry curriculum's orientation to, and presentation of, the nature of science is compared to Mr. London's philosophy and classroom practice. Research on teaching the nature of science is then related to events in the chemistry class. The study concludes with a report on teacher and student conceptions of science that were revealed in their end-of-year interviews.

"Science Doesn't Look for Absolutes"

We are reviewing Chapter 1 today. Led by Mr. London, the class has discussed graphing, the difference between accuracy and precision, and significant figures in a lively fashion, despite this being the end of a long day. Next, Mr. London says, "The scientific method. Make you think here - it's a little hard here." He puts a 10-cm long blue plastic 'rod', tapered at each end, on the overhead projector. He taps one end. "Observe. A little thingie." The blue object spins quickly on the screen at the front of the room. "Give me an observation about it." Junior states that the harder you spin it, the longer it spins. "Let's make a hypothesis about this. According to what you say, if you spin it with more force, it will spin longer." He tries this on the overhead. The object whirls faster with a stronger tap. "Have we tested it? Yes. If we only observed it once, what do we want to do?" Mr. London spins it again and everyone watches it turn, a bright blue flash. "Can I now make a conclusion? We had a hypothesis. We tested it. Should we only test once? No." He spins again. "Can we make a conclusion? Yes, the hypothesis is supported. In order to do an experiment and have it become acceptable, how long do we test it until the hypothesis becomes a theory? As soon as everyone's repeated it enough, it becomes a theory." Again, Mr. London spins the blue object, but it suddenly pauses, then begins to spin in the opposite direction! "Wait! We just had a law. Does that mean everything's wrong?" Celeste calls out, "There's an exception!" Mr. London asks for a new hypothesis, and Fatima volunteers, "If you spin it clockwise, it goes backwards." He spins the object clockwise, and it does begin to turn in the opposite direction. "What happened to the theory? It gets modified or revised; it must be changed. That is different from religion, what you believe or don't believe. Science doesn't look for absolutes. Is evolution a theory? A theory doesn't mean it's all right or all wrong. This thing, by the way, is called a rattleback."

After class, Mr. London asks for my reaction to his demonstration with the rattleback he had purchased in a museum last summer. I feel the lesson was well planned and organized, perfect for demonstrating how theories have to be modified to fit new observations. Mr. London closes the conversation with a summary of his beliefs and intentions. "If there's one thing that bugs me it's this mixing up of beliefs and theories. I can't understand how people can say that science is right or wrong when they are talking about beliefs. I try to get that across to my classes - that beliefs say what is right or wrong, but scientific theories don't work that way."

Developing Conceptions of the Nature of Science

In the vignette Mr. London demonstrates an instrumentalist view of science as amoral, developmental, creative and testable. Is he typical of all science teachers? Is his conception of science translated into his teaching? Do his views influence his students to establish an instrumentalist position on the understanding of science? What was the effect of the textbook on students' conceptions of science and the scientific enterprise? The following sections examine curricular and instructional influences within the chemistry classroom. Next, research findings on teaching the nature of science serve as guides for the analysis of the chemistry class' understanding of the processes of science.

The Curriculum's Orientation to the Nature of Science

Considering the prominent status of the nature of science as a goal of science curricula, Gallagher's (1991) analysis of science textbooks offers striking evidence that the presentation of the history and development of scientific ideas is rare, as is discussion of the application of science to students' daily lives. In addition, Meichtry (1993) summarizes research that highlights the tendency of instructional materials to portray a realist, rather than an instrumentalist, view of the nature of science. Thus, it is not surprising to see the absence of an instrumentalist orientation, and of in-depth discussions of the nature of science, in *Chemistry: The Study of Matter* (Dorin, Demmin & Gabel, 1992).

The philosophy of the chemistry course presents its major goals for students' learning and understanding the "facts, formulas and principles" of chemistry, and developing critical thinking and problem solving skills. The nature of science is briefly mentioned in only one of the goals of laboratory work: "The lack of absolute certainty in scientific results is underscored" (p. TG-18). The authors emphasize that through post-laboratory discussions students come to realize the inevitability of uncertainty in measurements and conclusions, a feature of scientific knowledge. No further link is established to the nature of science or to the scientific enterprise.

In the Planning Guide for Chapter 1, Introduction to Chemistry, the overview promises a discussion of the nature of science "both pure and applied," as well as the six steps of the scientific method. The Chapter Objectives expect that students distinguish between pure and applied science and explain the scientific method. The teacher is advised, in addition, to ensure that students do not develop the "erroneous idea" that all scientists follow the steps of the scientific method in the manner "implied by the stepwise presentation of the scientific method." Teachers are given the responsibility to "Tell students that some theoretical scientists approach the solving of a problem from a mathematical point of view, while others make scientific discoveries by chance" (p. TG-60).

In Chapter 1, students are introduced to science in the following paragraph:

> **Science.** Scientists search for facts about the world around them. They try to find logical explanations for what they observe. Scientists believe in the principle of cause and effect. According to this principle, everything that happens is related in a definite way to something that preceded it. ...By discovering what causes certain changes to take place, scientists enable us to understand past events and to predict and control future events (Dorin, Demmin & Gabel, 1992, p. 1).

Subsequent paragraphs distinguish pure and applied science by their goals - discovery or practical application. No further explanation of the nature of scientific knowledge is presented to the reader. The scientific method discussed in the next section of the chapter has six steps: stating a problem, collecting observations, searching for scientific laws, forming hypotheses, forming theories, and modifying theories. The only statements that allude to the developmental character of scientific knowledge include: "Scientific laws describe natural events but do not explain them" (p. 3) and "A theory can never be established beyond all doubt" (p. 4). In the chapter summary, students read, "The scientific method is the way scientists go about solving a problem" (p. 11), with no qualifying statements recommended in the chapter planning guide. Thus, the chemistry curriculum's treatment of the nature of science does not explicitly address the components of scientific knowledge that are common to many science curriculum objectives. In addition, a realist orientation is prominent in text discussions, and students are not guided to develop ideas of science as creative, developmental, tentative, or testable.

Mr. London's "Demystification" of the Nature of Science

Mr. London never mentioned teaching the nature of science as one of his objectives in our interviews, similar to the teachers in Duschl and Wright's (1989) study. However, as a participant observer in the chemistry class, I became aware of Mr. London's frequent efforts toward what I termed the "demystification of science." For instance, when discussing Crookes Tube, he explained to the class that Crookes "had no idea what he had," that all scientific inventions and discoveries are "made up by man - all this has taken time - it was not done overnight." Fahrenheit was described as a "German guy who takes a piece of glass that has mercury to make a mercury thermometer. He takes a marker and starts marking. He puts numbers on it. He puts it in water and when it freezes, it stops at 32." Celsius, on the other hand, "froze water and that was zero. Then he heated it to boiling and that was 100. You could make up your own scale." When asked about this in an interview, Mr. London explained that he was attempting to relieve students' fear of science by assuring them that "it's man-made-up."

> They understand that it's just - they made it up....I think, too many times before chemistry was all this magic stuff. You had this magical periodic chart that suddenly appeared, and then people had to figure out how to use it. To put it together was like magical kind of stuff. But now it's like they know that it was just...it's just people, as they discovered things, trying to put them together (LII,15).

His explicit emphasis on the creative, developmental and testable character of science was a major component of classroom instruction. However, in my observations, the demystification of science accomplished more than Mr. London's objective of allaying students' fear of the subject matter. It also taught students about the nature of science and of the scientific enterprise in both explicit and implicit terms. Further, demystification was accomplished through six techniques that emerged in the daily life of the chemistry class - modeling science, interjecting anecdotes, using explicit language, employing high level questioning, providing a supportive classroom atmosphere for the exploration of science, and involving students in original independent projects. The following vignette reveals some of these methods, and all of the techniques are discussed in the section that follows:

The Saga of the Cobalt Chloride Paper
or
"What Doesn't Happen is as Important as What's Supposed to Happen"

In the first chemistry lab of the year, Qualitative Observations of a Chemical Reaction, students observed a candle, recording appearance, odor and feel. Next, they were instructed to light, observe, and describe changes in the candle after several minutes of burning. A series of steps concluded with students inverting a beaker over the lighted candle, noting the substance (water) that collected inside the beaker, and testing it with cobalt chloride paper. The teacher's guide explained that the water would turn the blue cobalt chloride paper to pink. (When Mr. London did not find cobalt chloride paper in the chemical supply room, he made some by swabbing a cobalt chloride solution on paper and drying it in an oven.)

A test with cobalt chloride paper produced no results. Tammy turned around from her table. Because her group was ahead of ours, Carla asked her what happened to the cobalt chloride paper. Tammy confidently said nothing was supposed to happen.

During clean up, Mr. London carried a flask containing a clear liquid in one hand and a beaker in the other past the lab stations. "Before you go, the cobalt chloride paper didn't work because it's so humid here. That's the trouble with these labs - things don't always work like they're supposed to work. When I tried this lab, the paper turned <u>blue</u> in the smoke. It was supposed to be blue and then turn <u>pink</u> in water. Also, cobalt chloride dissolves in alcohol - it doesn't like to dissolve in water. I put water into the cobalt chloride solution (Demonstrates by pouring water from the beaker into the flask) and it changes to pink. It gives you some idea of the paper. What was the paper hoping to show about what happened? What were you looking for? What was the paper supposed to be showing? What didn't show? Why? These are things you might want to think about."

The next day, during Lab 2, Mr. London discussed the cobalt chloride paper again. He explained, "I had to find out what happened. That's the trouble with these labs. They are set up for ideal conditions where there is no humidity - like Texas. I had to look it up in a book because the paper never turned blue when I made it."

As the groups began to write up the lab, Tammy complained to Mr. London that he was "going too fast" and "This is not chemistry. Things are supposed to work in chemistry." Mr. London was encouraging - "Hang in there; You'll be all right, you'll be fine." Knowing some students had not understood his hints about the reasons for the use of the cobalt chloride paper in the lab, he became more explicit. The paper didn't turn color - even though it is an indicator for water, as he showed us last week - because there was too much humidity in the air. He returned to Tammy's group and said in a purposeful voice, "What doesn't happen is as important as what's supposed to happen! In the experiments we have things that work and things that don't work. On the cobalt paper, it was supposed to show moisture in the jar. Part of science is inferring - I may not give you a direct answer. In the cobalt chloride demo last week, I said that no water, only alcohol, was added. What color should the paper be in the jar when it's dried out? Blue. In science you have to be aware when things don't work. Science is not an absolute thing. Get past that seventh and eighth grade thing. If something is wrong, it's not you. Don't say, 'I made a mistake - Did I do it wrong?'" He reminds the class that the cobalt chloride was blue in his demonstration of the liquid in the beaker and that water turned the solution pink. However, the paper he gave them was whitish. "If you want perfection, take math. No absolutes in science. Nothing is something in this class. Begin to question in the lab, question, observe, do research, ask questions, start analyzing. We'll do that in this class. Learn to use your brain. How did I know about the paper in the smoke? I played - it's called explorative play. Why did it turn blue in the smoke? Why was the paper not blue? A student calls out, "Humidity." "Yes. Water in the air - for the cobalt chloride paper there was too much water in the air, so it doesn't work. You did some analyzing."

Teaching the Nature of Science

Participant observation in the chemistry classroom allowed me to experience Mr. London's instruction on the nature of science. From field notes and excerpts of interviews, I identified six instructional techniques which appeared to directly affect students' conceptions of science and the scientific enterprise by directly addressing the nature of science, involving students in thinking about or participating in scientific inquiry. Each is discussed in more detail below.

Modeling the Scientific Enterprise

The Saga of the Cobalt Chloride Paper vignette was included for its portrayal of Mr. London as a scientist. When the paper did not provide students with the expected results, Mr. London was confused and curious. Although the students would have been content with Tammy's explanation that nothing was supposed to happen, or with the rationalization that "it didn't work," Mr. London conducted an investigation into the problem. He checked reference books, made a solution and demonstrated it to the class, and tenaciously pursued the issue until he was satisfied that the high humidity in the room had caused the cobalt chloride to give unexpected results. Later he identified his actions as "explorative play," the result of questioning and analyzing to solve the problem. He had modeled problem solving and explicitly described his views of the nature of science, and even though the students did not themselves become involved in the investigation of the failure of the cobalt chloride paper, they apparently understood the implicit messages about scientific knowledge and scientific investigation, as indicated in their interview responses at the end of the year.

Employing Explicit Language

The vignette is replete with Mr. London's comments on the nature of science, from the sarcastic "That's the trouble with these labs. They are set up for ideal conditions" to definitions of science as "inferring" and "not absolute." Perhaps the most valuable statement for the students was his advice for them to avoid blaming themselves for inconclusive results in the lab, and to "question, observe, do research, ask questions, start analyzing." He indicates that students' thinking and analyzing are encouraged and supported in his chemistry classroom.

Asking High Level Questions

Mr. London always had a ready supply of questions to stimulate thinking. Generally, the questions were asked in quick succession, not addressed to a specific student, but as a menu of avenues of investigation. In addition, rather than give a direct answer to the cobalt chloride question, he used questions to guide students to an understanding. He clarified this technique in terms of science: "Part of science is inferring - I may not give you a direct answer." The first step toward an answer in the vignette was a demonstration of cobalt chloride solution and water, followed by questions the students "might want to think about." As students worked through the lab, Mr. London's explanations became more direct in response to students' needs for more concrete understanding of the cobalt chloride paper's intended use and its subsequent failure.

Providing a Supportive Environment

Tammy was frustrated when she recognized that the planned results of the cobalt chloride had not been accomplished, and she voiced her frustration, "This is not chemistry." Mr. London responded with words of encouragement - "Hang in there. You'll be fine." Later he explained to students that science is not absolute. Therefore, events in the lab should not be construed as right or wrong, but as starting points for further investigation. He admonished the class to avoid the "seventh and eighth grade thing" of blaming themselves when something is wrong. Mr. London always met students' expressions of confusion or frustration with encouraging comments.

Two additional methods of demystifying science that were not obvious in the vignette, but that surfaced throughout the school year, are Mr. London's use of anecdotes, and his assignment of student projects that involved the class in original research. At the end of each quarter students were expected to report results and conclusions of projects they designed. The oral reports were opportunities for Mr. London to ask a multitude of questions about the design and execution of the project, to elicit suggestions for further research, and to discuss related content. Often he added information he had gained from personal experience in the form of anecdotes.

Interjecting Anecdotes

An excerpt from field notes provides an example:

> Tammy volunteers to do her report first. It is on leather tanning. She goes through the steps and lists the chemicals, "easily found materials," needed to tan the leather. When asked, she lists the three most important things as having the skin clean and dry to start and to wash the chemicals off at the end. Mr. London begins a story about his two pet rabbits. "They weren't doing well, so we decided to eat them. We killed them and then I decided to tan the hides. I cleaned the fur and skin and used nuts and berries and leaves to soak it. Those have the alum Tammy mentioned. I still have their fur somewhere. I also tried a cow hide. Don't ever try that one - it was rough. Get leaves and berries and tan you own hide" (FN5,2).

In another story about his youth, Mr. London told the class how his interest in gunpowder led him to research and then purchase the ingredients, experiment with different mixtures and successfully create an explosion. Later, he mentioned how he "redesigned fireworks so they would work better when I was a little kid." These anecdotes served two ends in demystifying science. First, they personified Mr. London as a scientist who understood the nature of the scientific enterprise. Second, they demonstrated that "science" can be an activity of ordinary folk whose curiosity and problem solving skills take them to experimentation.

Including Student Projects

The quarterly projects provided students with authentic experiences in the process of science. They participated in the creative and testable aspects of science research, and learned that challenges can be ovecome with creative, cooperative problem solving. For example, the requirement for the second project was collection and analysis of data. Students were encouraged to select topics that interested them. Mr. London advised students on selecting projects, helped them locate appropriate references, and lent equipment. Descriptions of projects attest to the students' creativity and wide spectrum of interests:

> Before presentations begin, Mr. London tells how a group took a question from the last lab about heating a crucible before measuring its mass. For the project, the students used an electronic balance and did three trials of measuring mass after heating. They found that there was a change of .08 gram within 20 seconds of heating - that the mass increased as the crucible cooled. They also tried a smaller crucible to see if it made a difference in the numbers. Again, he states, "Experiments don't have to be complicated." We begin the reports. First, Katrina does hers on Do Cats Have a Preferred Paw? She has devised three tests - a well-designed project. Monty was next with a report on protecting cars from acid rain. He used different waxes to test their protectiveness on the surfaces of old cars. Benjamin presents a poster on a 'liquid race' in which he tested how the angle of inclination and the type of surface affect the speed of a liquid on an inclined plane. His variables were nail polish, water, and oil on Saran Wrap or wax paper, at angles of 30, 60 and 90 degrees. Of course, the speed increased with the angle. Mr. London added how this was related to the viscosity of different weights of oil - 10W, 20, 20 and 40 - and temperature changes. Tammy presented her project to discover which laundry soap works best on stains. Her poster had many 3 inch square swatches of white cotton that she had stained with blueberry jam, lipstick, coffee and grape juice. She varied the temperature from cold (45 degrees) to hot (104 degrees), and used five different soaps. This project must have taken a lot of time, and I was glad to see she spent so much time, as her interest in chemistry so far this semester has been low (FN9,21).

The revisionary nature of science was emphasized when Abe was questioned about the kite he built for the project on a toy that demonstrated a scientific concept:

> Abe showed his large kite made from a green garbage bag on a wooden frame. With questioning from Mr. London, he explained how he experimented to make it fly, finding first that it could not be perfectly flat, and that it needed 'streamers', to fly correctly. He said he flew the kite this morning and "almost lost it." (FN4A,8).

In summary, the six techniques employed by Mr. London enabled the class to experience the ways and means of instrumentalist science. Theories on the tentative and developmental nature of science permeated classroom interactions and instilled in students a basis for scientific literacy.

Research on Teaching the Nature of Science

Studies whose findings are related to this case study focus on specific classroom practices that appear to foster improvement in students' views of science. Lederman and Druger (1985) studied the influence of 44 teacher behaviors and/or classroom climate variables on specific changes in student understandings of science. They reported:

> In general the classes of the most effective teachers were typified by frequent inquiry-oriented questioning, active participation by students in problem-solving activities, frequent teacher-student interactions, infrequent use of independent seat work, and little emphasis on rote memory/recall. With respect to classroom climate, classes of the more effective teachers were more supportive, pleasant, and "risk free," with students expected to think analytically about the subject matter presented.
>
> (Lederman, 1992, p. 348).

The importance of language in teacher-student interaction was emphasized in the findings of Zeidler and Lederman (1989). Relationships between teachers' instrumentalist or realist orientations and changes in their students' NSKS scores were correlated to the type of classroom language employed by the teachers. The use of commonsense everyday language without specific comments about, for example, the arbitrary nature of models or tentativeness in scientific knowledge, fostered students' realist orientations of science. The authors conclude:

> Without precise language on the teacher's behalf, without *forethought* about the manner in which teachers present subject matter to their students, it is quite possible that the "common" perceptions that students envision may at best lead to a misunderstanding of physical laws, theories, or phenomena, or at worst a distorted caricature of the theoretical foundations of all scientific endeavors (Zeidler & Lederman, 1989, p. 777).

In addition, Meichtry (1993) reports on her investigation of a BSCS middle school science program in which neither the curriculum nor the teacher directly related experimental activities to the developmental and testable nature of scientific enterprise and knowledge. It is reasonable to expect, she concludes, that students will not make such connections intuitively. A later study of teachers' translation of ideas on the nature of science into classroom practice (Lederman, 1999) underscores the importance of explicitly addressing the nature of science in instruction to aid in students' development of adequate understandings.

In his analysis of the research on conceptions of the nature of science, Lederman (1992) concludes that "the individual science teacher must make a difference" (p. 350) through "unspecific instructional behaviors, activities, and decisions implemented within the context of a lesson" (p. 351). Classroom environment factors which appear to enhance appropriate student conceptions of the nature of science include frequent higher level questions that stress high level thinking skills in problem solving, supportive, risk free contexts. However, Lederman emphasizes, "translation of these understandings (of the nature of science) into classroom practice is mediated by a complex set of situational variables" (p. 351) which extend to curriculum constraints, administrative policies, teachers' knowledge, intentions, and attitudes.

Fostering Instrumentalist Conceptions of the Nature of Science

The two assumptions which guided the early nature of science research now resurface as questions in relation to the chemistry classroom culture: Can we assume that the teacher's conception of the nature of science influences his classroom behavior and the classroom environment? Does the teacher's understanding of the nature of science directly influence those of his students? By relating Mr. London's theory and practice to research conclusions, we reveal close associations between his beliefs and the developing conceptions of his students.

In the classroom environment, it is obvious that an instrumentalist conception of the nature of science became an integral component of the chemistry curriculum enactment despite its absence from the text. Mr. London's strong beliefs about the nature of science, and his commitment to have students understand them, permeated the activities and discussions which he and the class shared. Opportunities to clarify the nature of science arose often as the students participated in labs, watched demonstrations, practiced science in projects, and learned content from textbook activities. In a supportive, risk-free environment that encouraged the exchange of ideas and discouraged competition, students gained confidence as they learned that science is not a matter of right and wrong answers. In her exit interview, Shelly was asked about the strategies she used to learn chemistry.

> As far as labs go, writing up a lab or doing chapter homework or whatever, I learned that whenever you do a lab, you don't need to worry about having the lab write up right then - you need to just get all the data and realize any things that can make your data vary from the data that anybody else ever had. I also realized that we can do the same experiment, but everyone is going to get their own data - it's not all going to be the same. So just because my data is different doesn't mean I'm wrong! (SC,1).

Thus, the environment created by Mr. London's explicit language about the nature of science matched his personal philosophy and appears to have created a classroom ecology that influenced Shelly's understanding of learning chemistry.

Student Conceptions of the Nature of Science

Research points to the inadequacy of student views of the nature of science (Griffiths & Barman, 1995; Lederman, 1995; Meichtry, 1993; Edmondson & Novak, 1993; Lederman, 1992). Measures by the Test on Understanding Science (Klopfer and Cooley, 1961) and the Nature of Scientific Knowledge Scale (Rubba & Andersen, 1978) demonstrate the strength of realist orientations in students. Later studies have employed interview protocols to assess conceptions of the nature of science (Lederman & O'Malley, 1990, Roth & Roychoudhury, 1994, Griffiths & Barman, 1995) and have revealed that students' apparent realist/absolutist views of the nature of science are ameliorated when they can express their ideas directly to an interviewer. Nevertheless, the conception of science as the unchanging, absolute truth, as uncreative, more complex than other subjects and "almost dehumanized" was expressed by significant percentages of the American sample in a recent international interview protocol (Griffiths & Barman, 1995).

Although the chemistry students' conceptions of the nature of science were not assessed at the beginning of the year, many of the students expressed their beliefs in, and expectations for, the process of science during class. For example, Tammy was perplexed by the lack of a clear cobalt chloride test, and protested that "This is not chemistry" because she expected everything to work. Students in the lab often asked each other, "What's supposed to happen?" In the interview, Shelly's description of her learning the scientific process of collecting data indicates that the revisionary and tentative aspects of science were new insights for her.

The final section of the exit interview for Mr. London and six selected students included questions to disclose their conceptions of the nature of science and of the scientific enterprise. A comparison of teacher and student responses reveals the similarity between the views of Mr.

London and his students, although it does not identify the source of their views. A selection of questions and representative answers is presented below.

Realist vs. Instrumentalist Orientations

The two statements in the following question are presented separately in the Nature of Scientific Knowledge Scale. Later they were employed in Roth and Roychoudhury's (1994) study of student conceptions. An average of 60% of their subjects disagreed with the first statement and agreed with the second statement, indicating a majority of students held objectivist/realist views. In interviews to clarify their answers, 75 to 81 per cent of the students voiced realist opinions on the nature of scientific knowledge.

Which of these two statements do you feel better describes your idea of science: Scientific knowledge is artificial and does not show nature as is it really is. Or, Scientific knowledge more and more approximates the truth?

> Mr. London: I'd say scientific knowledge approximates the truth. What is the truth? I would say whatever, quote, "the truth" is. So it, sort of like we're looking at shadows and we're trying to predict what's really there. I think we're trying to understand what the world is working like. I think the other one is too negative. True, it's artificial, but I don't think to say "it doesn't show nature as it really is." That's what you're doing - you're studying nature as it is, and trying to understand it (LE,17).

Roth and Roychoudhury (1994) categorize this answer as constructivist-relativist because it states the belief that scientific theories are constructed for the purpose of understanding nature. The negative connotation of "artificial" mentioned by Mr. London appears to have caused a hesitation in all respondents. Nevertheless, four of the six students' answers mentioned 'truth' a realist conception, and were rated as intermediary between realist and instrumentalist orientations. For example:

> Celeste: So I think science is just trying to always...trying to figure things out. Like when you do the scientific method, you always just try to find the truest answer. I don't know, there really isn't no answer to life, but...Because things change anyway.

> Shelly: It's what's really actually there, I think. Because the more you know...then you come to make your own understanding of what's true and what's not true. So it's up to yourself. I get to make my own understanding.

> Brian James: Number two..because I think of science as a tool of explaining things. If no one believes what it is, then I don't know if it can be called "truth" or whatever. But if it can be proven, then I think it could be counted as a fact, it can sort of explain what's going on.

> Linda: Probably number one...because! I mean, they don't really know exactly...because, like, where people came from, ...I have archaeology, and we watched this video about evolution. Well, I don't believe in that. I don't.

Notably, students emphasized the autonomy of the individual's decision about the "truth" and qualified their statements to admit a more instrumentalist position. Only Monty, the high achieving male, and Abe, the low achieving male, expressed realist conceptions of science.

> Monty: It's not artificial; it may <u>look</u> artificial, because of all the mathematics involved with it, but it's really not, because they take the concept from their surroundings. They don't just make up stuff. The stuff they show you is actually happening, you just can't see it, because it's on a real small scale, like cell biology. And it <u>does</u> show nature. It's like the study <u>of</u> nature and the surroundings.

> Abe: I think more and more approximates the truth. Because if..the more you receive science, the more...I don't know. I don't know how to explain it. That's the way it is.

With only one-third of the interviewed students expressing realist conceptions of the nature of science, the chemistry class' basic orientation intermediate between realist and instrumentalist is atypical of those reported in previous studies.

True or false: Scientific laws and theories exist independent of human existence.

> Mr. London: No, because laws and theories are based upon what humans look at things. And sure, the sun will burn and continue if humans don't exist, but the laws and the theories are based upon what we understand is going to happen. So you have to have the humans. Laws and theories are based on humans. Humans make it up (LE,17).

> Monty: False. Because human existence is really related to it. The laws were there - we just didn't understand why it happened. That was it. We tried to explain what happened.

> Celeste: I think we're trying to find out what they are, kind of. Yeah.

> Shelly: Un-uh, false. I think the people who do the research make up the laws and the theories.

> Brian James: Well, everything is going to happen whether we're here or not. We call them scientific laws and theories, but we might not have the whole truth, and we might be counting separate things as one..subject or whatever. So everything is going to happen, it's just what we title it.

> Linda: False. How are they going to know..I don't know, I just think it's false.

> Abe: That's false, because...Because a lot of laws of science is not based on man. It's ...I mean, it's...I don't know. Because a lot of stuff, you know, is natural, like.

Every student except Celeste expressed an instrumentalist view of science identical to that of Mr. London. In Roth and Roychoudhury's (1994) study, 69% of students agreed with the statement and 25% disagreed. Mr. London's students represent a significant turn toward instrumentalist conceptions.

Social Influences on Scientific Knowledge

Two statements from the Nature of Science Knowledge Scale assessed students' opinions about the presuppositions of, and social influences on, scientific knowledge. Similar to Roth and Roychoudhury's (1994) results, about one-third agreed and two-thirds disagreed with these statements. Mr. London's conception is presented with a typical positive and negative answer for each statement.

True or false: Science, like law, art, and religion, is based on presuppositions.

> Mr. London: Yeah, it is. It's based on things as you understand it to be. Models. As you understand it. You have to make assumptions.
>
> Monty: No, I think it's false. We may be able to prove what's happening. You prove it, you test it again and again -- it always works. We don't think it's happening, we know it's happening. There's (a small portion) of science that can't be explained because we don't have the technology to explain them. It's like we can't see an atom, we're just guessing that's how electrons are. We can't prove it. That's where it can get into argument and presupposition.
>
> Celeste: Yeah, I think so. I think that's why people do things in science. Because if you have an idea...then you're going to see if it's right or wrong.

Even Monty, who tries to convince the interviewer that science is proof of "what's happening," adjusts to an instrumentalist position when he realizes that the atom itself is a presupposition. None of the students presented a purely realist perspective on this question.

True or false: The social environment of the scientist influences the content of knowledge he or she proposes.

> Mr. London: Yes, I would say there is - very much so. There's the Western philosophy and then there's the Eastern philosophy, looking at science. So both may come to the same kind of conclusions at the end, but the approach is different, philosophies are different. So yes.
>
> Monty: I think it's kind of true. Well, like, wherever a scientist is, it's going to influence how he thinks about it. See, the people he's around will affect what he believes, and what he believes will affect what he researches. Yeah, what he says and what he's going to do will be influenced by who he's around.
>
> Abe: That's false. A true scientist will have an idea, his idea, stick to it, no matter what anybody else says to him or about him or anything like that. A true scientist will stick to his theory, what he thinks.

Both Abe and Shelly believe in the strength of the individual scientist to formulate ideas and test them in isolation, but the other four students expressed agreement that scientists' work is affected by social forces.

The Developmental, Tentative Nature of Science

The interview protocol included three questions also used by Lederman and O'Malley (1990) in an open-ended questionnaire and follow-up interviews to investigate student conceptions of common science dichotomies such as conclusive/tentative, realist/instrumentalist, and subjectivist/objectivist. The following question categorizes respondents into conclusive or tentative positions on the nature of science.

True or False: After scientists develop a theory, it never changes.

> Mr. London: (giggle, snort). That's wrong!

So then why do we bother to learn theories if they change?

> Mr. London: Ah! Because they're useful. They're useful and they work again, so we can predict what's going to happen, and understand what's going to happen. But if they don't work, then you have to change them, look for new reasons. Most of the theories are true to a minimum degree. The only reason they have to be changed is because we find out more, and they have to be modified, but not just totally thrown out. Most theories are modified, not junked completely. We didn't have enough knowledge to go ahead and seek the furtherness -- it just kind of grows.

Mr. London again demonstrates his belief in the tentative nature of science, as did 74.5% of Lederman and O'Malley's (1990) subjects on a pre test and 92.8% on a post test at the end of a year of science instruction. All of the chemistry students responded a fashion identical to that of Mr. London. If the assumption is made that classroom teaching affects students' conceptions, the students' agreement with an instrumentalist view is not surprising, considering Mr. London's emphasis placed upon this idea throughout the school year.

Subjectivist/Objectivist Views of Science

As a part of Lederman and O'Malley's (1990) study on student perceptions of science, the next question had the highest frequency of "No Response." In contrast, the question elicited lengthy responses from Mr. London and each of the chemistry students. Monty and Abe represented objectivist positions, and the remainder of the students expressed subjectivist views identical to that of Mr. London.

Some astrophysicists believe the universe is expanding, and others believe that it's shrinking, and then others believe the universe is in a static state, without any expansion or shrinkage. How are these different conclusions possible if all these scientists are looking at the same experiments and data?

Mr. London: Different interpretations of data, different calculations. When you're dealing with something as immense as the universe and trying to understand what's going on,...one equals a thousand. So you have such a large error in trying to predict..With astronomy you're getting into the world of philosophy and Big Guesses... and the calculations they make are so imperfect...So they're trying to see what's going on. Some don't even know which way we're looking.

Brian James: Because it can be interpreted in different ways. Something unexplained can probably be explained in more than one way. Like you can do a math equation in five different ways.

Abe: (laughs) I have no idea. I don't know. Because they are all looking at the same thing. Well, someone has to be wrong, and some have to be right.

Another facet of the subjectivist/objectivist dichotomy concerns the role of creativity in scientific enterprise. Lederman (1999) found that students in their study "believed that only certain types of scientific knowledge were tentative (i.e., theories) and that creativity, imagination, and subjectivity had limited, if any, place in the development of scientific knowledge" (p. 16). Mr. London and his chemistry students were asked to state the relationship between two statements that distinguished between creativity (subjectivity) and objectivity. Unlike Lederman's students, every chemistry student expressed beliefs in the creative nature of scientific investigation. Mr. London's answer and representative student responses are included.

State the relationship between these two statements: Investigating questions of a scientific nature requires creativity. The scientific method cannot allow for creativity because it's objective.

Mr. London: No. (chuckles) The observation should be objective. The creativity comes in designing an experiment or designing what observation you're going to make, and designing a method to go about and make those observations. The objectivity has to come in when you collect the data, that you do not allow yourself to become emotionally attached. So you have to be objective in collecting the data and analyzing the data, but you have to be very artistic in designing your experiment.

Shelly: The scientific method..there is creativity in there.

Brian James: So you have to be creative. You can't make up data, or ...make something up. You can't use your creativity in that way. But you can use creativity to think of new experiments or think of explanations.

In summary, Mr. London's chemistry students displayed a higher percentage of instrumentalist conceptions of the nature of science than students in any of the cited studies. Like the subjects in previous research (Roth & Roychoudhury, 1994; Lederman and & O'Malley, 1990), most did not demonstrate uniform conceptions; rather, their viewpoints varied according to the aspect of science under investigation, a phenomenon, according to Lederman & O'Malley

(1990), possibly indicating "a state of transition" (p. 229). Although the data is correlational, some credence must be given to the assumption that Mr. London's perspective influenced both his classroom practice and the classroom environment, which, in turn, had a direct and positive influence upon the students' conceptions about the nature of science. Research has tentatively identified certain elements of classrooms judged successful in developing appropriate notions about the nature of science. Among them are explicit emphasis on characteristics of science (Lederman, 1995; Edmondson & Novak, 1993; Meichtry, 1993; Zeidler & Lederman, 1989), inclusion of laboratory activities and group work (Roth & Roychoudhury, 1994), as well as stress on problem solving activities and higher order thinking skills in a supportive, risk free environment (Lederman, 1992). In Mr. London's classroom, the presence of these elements appeared to contribute to an unusually high percentage of students with appropriate notions of science and the scientific enterprise.

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