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ABSTRACT

This study examined teachers' content knowledge about the nature of science and how this knowledge was expressed in their classrooms. Understandings about science influence not only explicit lessons about the nature of science, but also shape an implicit curriculum concerning scientific knowledge. Consideration was also given to ways in which teachers' understandings about how students learn science in school influence teachers' beliefs and lessons about science. Seven precollege science teachers were interviewed to probe their knowledge about the nature of science. Three were asked to participate in the study based on their diversity of orientations. The teachers' knowledge about the nature of science, their roles as teachers, and their students' roles as learners were probed in a series of at least four hour-long, audiotaped interviews. Their classrooms were observed and audiotaped for at least 35 hours each over a 4-month period. During the interviews and the classroom observations the researcher was continuously involved in building, validating, and altering hypotheses concerning the teachers' content knowledge about the nature of science. The data from this study illustrates how teachers' views of science may be expressed in their classroom instruction. (MVL)

Teachers' Content Knowledge about the Nature of Science and its Relationship to Classroom Practice

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Purpose

This study examines teachers' content knowledge about the nature of science and how this knowledge is expressed in their classrooms. Understandings about science influence not only explicit lessons about the nature of science, but also shape an implicit curriculum concerning scientific knowledge. Consideration is also given to ways in which teachers' understandings about how students learn science in school influence teachers' beliefs and lessons about science.

Theoretical perspective

Questions concerning the nature and growth of science relate to issues of epistemology, i. e. "how do we come to know?" Piaget's work focused on the development of knowledge in the child (Piaget, 1972). Piaget asserted that knowledge is actively constructed in the mind of the child. Similarly, Kuhn (1970) described the development of science as knowledge actively created by scientists to explain natural phenomena and to generate new research. Cobb (1987) writes about the relationship between this view of learning and the philosophy of science.

> This radical theory of knowledge is compatible with the view that scientists impose structure on and give meaning to phenomena rather than extract information from them and read off nature's secrets.

Von Gasersfeld (1984) describes the correspondence of knowledge and reality as being analogous to the way in which a key fits a lock. Knowledge "fits" reality, rather than matches it. Knowledge fits reality if it helps learners meet their goals of making sense of observations and predicting future events. Furthermore, the knowledge created is influenced by prior knowledge and epistemological commitments.

This study adopts the perspective that teachers' actions are goal-directed. Teachers have created knowledge about science and about their students and schools that serve to meet their goals for themselves and for their students. This study explores the knowledge three teachers have created about the nature of science and relates this knowledge to the events in their classrooms.

Teachers' content knowledge in science and mathematics

Considerable work has been recently undertaken in the area of teachers' content knowledge. Much of this work has been discussed in terms of Shulman's (1986) framework that divides content knowledge into three areas: (1) subject matter knowledge, which includes not only an understanding of facts and concepts of a discipline, but also why it is deemed warranted, why it is useful, and how it relates to other propositions; (2) pedagogical content knowledge, which includes understandings of what makes certain topics difficult to learn and the influence of prior knowledge on students' learning; and (3) curricular knowledge, which is knowledge of curricular alternatives and the possible connections with topics students may be studying in other classes. I will limit my discussion to subject matter knowledge. Schwab has described the structure of a subject to include both substantive knowledge and syntactical knowledge. Substantive knowledge refers to the body of interrelated concepts of a discipline. Syntactical knowledge is the set of ways in which claims are made and argued.

Substantive knowledge in science and mathematics

Researchers working with novice secondary math teachers found that teachers with strong subject matter knowledge focused on mathematical concepts, explained why procedures do or do not work, and emphasized problem solving (Steinberg, Haymore, & Marks, 1985). Teachers with weaker content knowledge taught mathematics as a rule-based discipline and did not make explicit connections between concepts. Ball (1988) found that subject matter knowledge was important for elementary mathematics teachers in making judgments about which student questions to pursue, developing tasks to encourage certain types of exploration, and conducting class discussions.

Work with novice science teachers (Baxter, Richert, & Saylor, 1985) indicates that those who were most knowledgeable emphasized inquiry and planned to teach from more general concepts to more specific information. Less knowledgeable teachers viewed inquiry as a set of prescribed procedures and focused on specific information when teaching.

The nature of discourse in a science class may also be influenced by teachers' subject matter knowledge. For example, Carlsen (1987) found that novice teachers with weak subject matter knowledge limited students' verbal participation in class to avoid questions they could not answer. Hollon & Anderson

(1987) found that teachers weak in their content area tended to emphasize acquiring facts.

Researchers at Stanford University have also directed their attention to teachers who have been "misassigned," ie., are teaching courses for which they are not credentialed. In one study (Ringstaff & Haymore, 1987), an English teacher and a science teacher were observed teaching Cannery Row. Without prior knowledge, it would have been difficult to tell from the classroom observations which teacher was credentialed to teach English. The science teacher was an excellent biology teacher, loved literature, volunteered to take this assignment, and viewed it as a personal learning experience for himself. When the same two teachers taught remedial mathematics, the English teacher had considerably more difficulty than the science teacher (Ringstaff, 1987). These studies make the important point that credentials cannot be equated with subject matter knowledge.

Teachers sometimes know more about their content than they reveal in their teaching. Ball (1988) describes how teachers' understandings about their roles as teachers and the learning potential of their students may influence teachers with strong subject matter knowledge to instruct with algorithms and procedures rather than understanding. McNeil (1988) believes that teachers do not share much of their personal knowledge with students because of the stifling effects of mandated curricula and standardized testing.

Teachers also have understandings about the origin of knowledge, how it changes and how it is supported. This knowledge has also been found to be influential on classroom instruction.

Syntactic knowledge in science and mathematics

Duschl (1983) found that the science teachers he studied held understandings that were congruent with logical positivism. Examples include the usefulness of a step-wise scientific method, the objectivity of propositional knowledge, and the superiority of observational data over theoretical data. Teachers' conceptions of science were found to influence word usage, laboratory designs, and the selection of science curricula.

Lantz and Kass (1987) studied the relationship between the implementation of new chemistry curriculum materials and the teachers' understandings and values concerning high school chemistry, teaching, students, and the school setting. They found that the three teachers who used the same basic chemistry curriculum taught very different lessons about the nature of science as a result of differences in their understandings of the nature of chemistry.

Thompson (1984) found that teachers' understandings about the nature of mathematics and teaching mathematics affect the way they teach. A teacher who considered math to be primarily a tool of the scientist emphasized applications of mathematical concepts. Another who viewed mathematics as a continuously expanding and changing discipline created a more open classroom atmosphere and encouraged students to guess and conjecture when solving problems. One teacher who believed the content of mathematics to be "cut and dried," with little opportunity for creative work, focused on teacher demonstration of mathematical procedures, followed by student repetition of these procedures.

Ball (1988) has described two prospective elementary teachers who believe mathematics is a collection of rules that are not supposed to make sense. These rules should be memorized, because there is no sense that can be created from them. Similarly, their views on teaching focused on procedures without attempts for understanding. Although they expressed a desire to increase their understanding of the substance of mathematics, they saw no need to change their beliefs about the nature of mathematics. Teachers' knowledge about mathematics also depended on what they believe they should know to teach it. If they believe that all they must know about mathematics of a set of rules, then they did not develop a rich, conceptual understanding of mathematics. Teachers' beliefs about the content, their role as teachers, how students learn, and the context of school are part of a complex web of beliefs that influence one another.

Thus far research in science education suggests that teachers' syntactical knowledge plays a role in their classroom instruction. This study examines that role more closely and considers the possible link between teachers' views of the growth of scientific knowledge and how their students should learn science.

Methodology and data sources

Seven precollege science teachers were interviewed to probe their knowledge about the nature of science. Three were asked to participate in the study based on their diversity of orientations. Such purposive sampling of extreme cases is often used by qualitative researchers because it allows us to examine particularly troublesome or enlightening cases (Lincoln & Guba, 1985) and helps us to better understand more moderate cases (Goetz & LeCompte, 1984).

The teachers' knowledge about the nature of science, their roles as teachers, and their students' roles as learners were probed in a series of at least four hour-long, audiotaped interviews, and their classrooms were observed and audiotaped for at least 35 hours each over a four month period. During the interviews and the classroom observations the researcher was continuously involved in building, validating, and altering hypotheses concerning the teachers' content knowledge about the nature of science. In a manner described by Skemp (1982), as hypotheses were formed, the researcher looked for contradictory and supporting evidence for the hypotheses.

Towards the end of the study, the teachers were given a copy of the case study written about them and their classrooms and asked to check it for accuracy and to comment on any ideas that they believed to be misrepresented or incomplete. The teachers had few disagreements with the case studies and two compared them to photographs.

In addition to field notes and audiotaped observations and interviews, other data were collected. These included textbooks and teachers' documents on discipline, tests, quizzes, worksheets, and lab activity sheets. I kept a reflexive journal containing a record of the schedule and logistics of the study, a personal diary for reflection and speculation, and a log concerning methodological decisions and rationales.

Description of teachers

McGee is a 44 year-old man teaching seventh grade life science, physical science for gifted students, and health in a middle school in a large town in the midwest serving students from diverse socioeconomic backgrounds. This is his second year as a teacher, and his first in this school using the Silver-Burdett-Ginn textbook series. Prior to returning to college in his late 30s, McGee worked with the Boy Scouts of America and held various jobs in the coal mine construction industry. His teacher preparation was completed at a large research institution and credentialed him for middle school science with a primary area of earth science and secondary area of math.

Cathcart, a man in his late 40s, has a master's degree in science education and has been teaching middle school science in the midwest for 26 years. Most of his students come from blue-collar families who work in a large nearby town and live on the outskirts. Cathcart has a single preparation, general science for seventh graders, and covers two textbooks each year, Silver

Burdett Ginn's Earth Science and the Intermediate Science Curriculum Study (ISCS) physical science text.

Lawson is in her late thirties and has been teaching high school physics for fifteen years, of which the last thirteen have been in a midwestern, university-town high school. She has a master's degree in physics in addition to her teacher certification and is very active professionally. She teaches first-year physics for non-majors using Paul Hewitt's Conceptual Physics text and second year advanced placement (AP) physics using University Physics by Sears and Zemansky.

Findings

Scientific Processes

Much attention has been given to teaching the processes and methods of science. In the first chapter of most science textbooks is a description of the "scientific method," which consists of such "process skills" as observation, forming hypotheses, designing and conducting experiments, and drawing conclusions. Do teachers believe that scientific knowledge is based on theory-neutral observation (Finley, 1983)? Do they ask their students to make observations without using their prior knowledge? Or perhaps the scientific method is vaguely viewed as following procedures (Aikenhead, 1987a).

Cathcart

As Cathcart expressed in his interviews, the scientific method requires the use of rational, step-wise procedures. Procedures are predetermined and reproducibility is of prime importance. Psychology, according to his beliefs, is not a science because "it's very difficult to go in with a set of procedures as scientists use and get the same results again and again." Following exact procedures enables scientists to discover the truth.

> The things that have been discovered, have been discovered through very exact, precise experiments ... and I think that ... one of the reasons science has grown so much is because of this.

The students in Cathcart's class do all of the activities in the text. Cathcart likes the text because it is activity-based and encourages students to become scientific discoverers. The focus of the activities is on following the directions and getting the right answers. When students had difficulty or came up with wrong answers, Cathcart's response was that they had failed to follow the directions.

> Cathcart: You need four balancing two. You don't have that.
> Student: I do. I have four of them.
> Cathcart: ... Top of page 80. You move the clip on the balance, it moves in, the four moves in ...
>
> All experiments in chapter five are with four sinkers balancing two sinkers. If you're doing anything else, you're getting wrong answers. You're wasting your time.

Science activities require following directions to get correct answers. Any deviation from the predetermined procedures is discouraged because it results in wrong answers. Students record their answers, which usually consist of a word or a number, on worksheets and take them to Cathcart so he can tell them if their answers are correct. If the students answers do not match his, he tells them to repeat the procedure until they get the right answer.

The laboratory instruction in Cathcart's classroom consists of information about procedures. When the students were working on a textbook chapter on machines, Cathcart's initial instructions for an activity were "If you did five questions yesterday, the first thing you do is balance four against two" A recurring phrase throughout these lessons was "4 balancing 2." It was only from reading the text that I was able to discern that the lab activity was intended to demonstrate principles of work and levers. As was typical of all pre-lab instruction, Cathcart's emphasis was procedural rather than conceptual. Similarly, in class, Cathcart described a case of a scientist persistently carrying out procedures without a conceptual framework to guide his observations.

> Scientists often, if not always, go back and check their answers. Remember Brother Edison? How many times did he try on a light bulb filament before he found the one that worked? Does anyone recall? 900 and something.

Cathcart's understanding of science considered scientific processes, such as observation, as separate from facts and theories.

McGee

McGee believes in a step-wise scientific method and teaches it by asking students to read about historical experiments from their texts and to identify the steps of the scientific method in them. He also asks the students to design an experiment to determine the density of Mendelevium using the scientific method as an outline.

Even though McGee explicitly teaches the scientific method, some of the stories he tells in class about scientists do not depict them acting in a predetermined fashion. The following story (of dubious accuracy) about the discovery of the double helix is an example:

> He said that the way he figured that out was he was sick in bed and he was drawing this thing out on a piece of paper. And while he was drawing, he got to fiddling with the paper and twisted it accidentally and noticed that when he twisted it a certain way that it repeated itself all the way around. And that's how he got the idea ... It was just by accident.

At other times in interviews, McGee's description of scientific endeavors is rather anarchistic.

> You let your mind take off and you didn't have these axioms and stuff to tell it what to do, it just did it.

> [In] mathematics, two and two is always four. And there's never any chance that it will be anything else. But in science, there's a chance that if I sneak off into a room and if I thought hard enough, I might make it five and a half.

Given this discourse, it is surprising that he also says that he believes in a step-wise scientific method.

McGee, as is especially common for beginning teachers, is very reliant on the textbook. The text is the authority in the classroom and the textbook espouses the existence and importance of the scientific method. The text described it as follows:

> Scientists search for answers to many questions in nature. There is a certain method used by all scientists as they seek these answers. The special way

> in which a scientist gathers information and tests ideas is called the scientific method.

McGee does not question the textbook on this or any other issue.

A second reason McGee teaches the scientific method is because he believes the students must be given structure to learn and that the scientific method provides the needed structure.

> We're trying to get the student to understand that problems can, at least scientifically-oriented problems can, be put into a matrix ... So this is one way of instilling into them that there are methods, that there are rules and regulations that can be followed that will help you ...

Lawson

Lawson's beliefs were radically different than Cathcart's. The underlying theme in her classroom and in her discourse was the importance of the interplay between theory and observation.

> Einstein's general relativity, one of his predictions was that the star would be displaced during the eclipse ... When he got word that in fact it was displaced he said, "I knew it would! I knew it would be!" ... That interplay between the theoretician and the experimentalist, that's science.

In Lawson's classroom, observations were discussed in light of scientific theories, and theories were strengthened by observations. Prediction of classroom demonstrations or lab activities were a central aspect of Lawson's teaching. She would commonly introduce a concept, discuss it for a while, describe a demonstration she was going to do, and ask the students, based on the theory discussed, what will happen? Similarly, following laboratory activities, she would often ask the students if the results they obtained were what they expected. If they were unsure of their results, she would encourage them to repeat the experiment.

Although the scientific method is also presented in Lawson's chosen text for non-majors physics, Lawson did not spend much time on this topic. This was not because she disagreed with it, but because she believed the students had seen it enough and it was not particularly valuable.

Theories as truth vs theories as tools

Traditional philosophies of science have asserted that science is the search for truth and that as scientific theories progress, we come closer to knowing that truth. This view may be contrasted with more recent philosophies (Kuhn, 1970; Lakatos, 1977; Feyerabend, 1975) that contend that science consists of solving problems and that scientific theories are tools to be used in solving problems and generating new research. Educational goals of these two views may also be quite different.

One of the most striking aspects arising from this study was the extent to which Lawson and Cathcart diverged in their views of theories. Lawson thought of theories as tools to solve problems whereas Cathcart viewed theories as truths that had been uncovered through rigorous experimentation.

Lawson

The utility of theories is a recurring theme in Lawson's classroom. Lawson's students use theories to explain observations and to solve problems.

Lawson's view of the role of scientific theories is very utilitarian. Theories are useful if they predict the results of experiments. Lawson explicitly states her beliefs about this in the following way:

> I think ... you use the theory ... to make predictions and then ... the experimentalist sets about trying to test the predictions. And if all the predictions that you can make with the theory come to pass, then it's a workable theory and we'll go with it for a while until another comes along that shows that one was just an approximation ...

As mentioned earlier, a commonly used instructional method of Lawson's was to introduce a concept, discuss it for a while, describe a demonstration she was going to do, and ask the students, based on the theory discussed, what will happen? For example, consider a discussion about el- ~ic and inelastic collisions that took place in Conceptual Physics. Lawson had demonstrated an elastic collision between a cart and a dart while a student marked the distance the cart moved on the table t' p. While Lawson was put masking tape on the cart and dart to demonstrate an inelastic collision the following discussion took place:

L: What will that do?
S1: It will cushion it and it won't go as far.
L: If that doesn't stick nothing will. (Lawson raises the dart and drops it so it collides with the cart.) Did you notice the difference in how far the car went?
S2: No. I didn't. (Student helper failed to mark the spot.)
L: So measure the difference. Do you want to do it again? (They repeat the demonstration. This time the student marks the distance moved on the table top. This seems to satisfy the students that there is a difference.)

One day after solving a problem using Gauss' Law in her AP physics class, Lawson pointed out in the textbook where the authors had solved the same problem using Coulomb's Law.

> Look at 25-8. They took a whole page to arrive at the same conclusion using Coulomb's Law. So [Gauss' Law] can be very powerful once you know how to use it.

In Lawson's classroom, the goal of the instruction is to solve qualitative and quantitative problems using scientific theories. Theories are tools and there is no value in knowing what they are without knowing how to use them.

Cathcart

In Cathcart's classroom, theories are truth and the goal of the instruction is for the students to learn the truth. Furthermore, Cathcart doubts that students are capable of applying their knowledge; any case in which a student applied a theory to solve a new problem would be beyond normal expectations.

Students are told what they are to memorize for tests by review sheets and self-evaluations. They have difficulty answering questions on tests that are worded differently than the self-evaluations. Cathcart describes how he chooses what the students should memorize in an interview and describes the problem associated with the tests to his class.

> But I think in determining, [I] always have a question of what I should cause, require students to memorize. And I think those things that are going to be held true for at least the foreseeable future are important.

> Number one many people did not answer. You know it because you memorized it. But it wasn't word-for-word like it was on self-evaluation.

Cathcart writes tests to evaluate whether the students have memorized what they were supposed to learn. His expectations are limited by what he believes the students are capable of doing. He believes they should be able to memorize what they are told to memorize and this is what he tests.

The view that science is truth takes on interesting implications when that truth is believed to contradict religious truths. Since Cathcart believes that the theory of evolution contradicts his religious values, he avoids teaching those chapters in earth science that focus on evolution.

This difficulty first became apparent to me when Cathcart was going over the answers to a worksheet on the origin of the solar system and pointed out to the students that the explanations being given for the origin of the universe were just hypotheses, not theories. There were characteristics of the solar system that the hypotheses could not explain. This struck a dissonant chord in my thinking because I had not heard any other theories or hypotheses questioned in his classroom. Cathcart explained to me the difference between a hypothesis and a theory in an interview:

> A hypothesis is to a large part a guess based on experimental data ... but I have a lot more experimenting to do ... A theory is one that has been tested and retested in many different laboratories. Right now it appears that there's no room to say it doesn't work. Everybody's tested, came up with right, same answer ... now it may be adjusted and modified, but the basic heart of this particular theory is

> accepted by the science community based on experiments that everyone's gonna know. That's the whole secret of science.

Similarly, when Cathcart showed a filmstrip from Carl Sagan's Cosmos series that included the Big Bang Theory, he commented that not everything that was shown in the filmstrip was accurate. This year Cathcart did not teach those chapters in the text that dealt with evolution nor does he intend to teach these chapters next year. I asked him how he thought the theory of evolution differed from other theories. His response was as follows:

> My opinion is the theory of evolution is the biggest bunch of hogwash that's ever been presented to mankind. It has more holes in it than it has facts. If we were to use our yardstick of models, we'd throw that thing out. (laughs) It doesn't fit. We've only made it fit and designed our theories on the false assumption that it's correct. It's totally wrong. That's my personal opinion.

Science as Accumulated Knowledge

Recent views of the nature of scientific knowledge (Kuhn, 1970; Lakatos, 1977) have suggested that science progresses through changes in knowledge. Strike and Posner (1982) assert that similar changes in knowledge occur in the individual when learning new concepts.

McGee

McGee's view of science as the accumulation of knowledge was apparent in his discussion concerning the development of the atomic theory. In describing the various models, McGee portrayed the models as building on one another. Each scientist mentioned gave more detail or more insight into the previous model of the atom. Two examples of this follows:

> Then Thompson came along and took it one step farther. He got more specific about what is happening in this atom. He's trying to give it a little more identity.
>
> Dalton ... accepted Democrites - that there were these things called atoms.

McGee also talked about this idea in an interview.

> I see [science] changing a lot in the addition, better understanding of fundamental truths.
>
> I really think that possibly ... you've gotta accept what the guy has done before you. I mean, you've gotta start somewhere. Where else do you start your own experiment? Now you can either say, I don't agree with [or] I'm gonna change that experiment. But still that's just taking what they've done and then adding yourself to it ... So then either way you wind up having to start out accepting what the other guy before you'd done.

This description is similar to Kuhn's view of normal science (Kuhn, 1970). During this time, scientists work within the accepted paradigm, fine-tuning current theories. However, McGee's view does not include the idea of scientific revolutions. During revolutions, scientists may be changing the paradigm rather than working within the current paradigm.

The idea of accumulated knowledge is consistent with McGee's questioning strategies. McGee began a class discussion of compounds and mixtures by asking "What is the difference between a compound and a mixture?" One student answered that a mixture can be physically separated but a compound cannot. Another student said that in mixtures you can see the different elements in it, whereas in compounds you cannot. McGee's response to this was to say that this student "has added some comments to the situation. Does anyone want to clarify that any farther?" Another student said that when you mix two things together to make a compound, it comes out different from either one of them. McGee's response was "now she's adding a third." This discussion is similar in nature to the discussion of the evolution of atomic theory.

Cathcart

Cathcart also believed science was a building process and that the use of mathematics and exact and reproducible experimentation provided an unshakable foundation on which to expand scientific knowledge.

> We can read what's been done before and we don't have to go back and repeat that, once it's been repeated enough to be proven, obviously. Then we build upon that knowledge.

Cathcart also viewed the science he taught as an accumulation of knowledge. He told his students:

> Every experiment from this page on proves the rest of the chapter, each and every one of them.

Cathcart was aware that many theories have been rejected over time. He believed that these rejected theories are incorrect because early scientists were fooled by their observations.

> ... for example, we teach the heat substance model, although it's been proven since late 1700s it's not valid. We teach it as a form of teaching them how scientists can be fooled because of the observations they were doing. ... Then we show them what's wrong with the theory and we shoot it down ...

Cathcart described observation as limited by available technology, but did not acknowledge the role of scientists' beliefs in deciding what should be observed. Cathcart expressed this idea in class when the students were going over the answers to a worksheet.

> Number one says "what early evidence was there that the earth was not flat?" ... That's dumb, isn't it, to think that the world was flat. How could they be so stupid? ... Because the ordinary man had only his senses. And he looked and he saw what he saw. And he didn't have the advantage of watching jet planes curve, orbit the earth with satellites.

Lawson

An aspect of learning physics that Lawson continually emphasized was that learning new concepts often requires that they already understand other more fundamental concepts. She described this learning as one of building a pyramid, with the most fundamental concepts forming the base of the pyramid.

> Now you notice we keep on with the stuff right at the beginning. Remember that pyramid. We laid the foundations of the pyramid in the first five chapters. Now we're going up the next level. And we're going to be combining stuff in that lower level. So it's real important that you keep going back and try to tie this all together. Otherwise there's a missing chunk. You're going to walk in here one day and we're not going to be able to communicate anymore.

> See how a lot of these problems are combining the mechanics from the first semester?

In order to help with the construction of this pyramid, Lawson often introduced new concepts by deriving them from previous equations or by extending previous concepts to special cases. However, the real responsibility for making the connection between previously covered concepts and new ones rests on the students.

> You need to keep reviewing this stuff at night so that when you come in here you're not still trying to figure out how I'm getting momentum while I'm going on to other things.

Lawson believes that science changes, not just because new observations are made, but also because the same observations may be made but interpreted differently. She expresses this belief to the class.

> Aristotle said constant force is required for constant speed and it is if you don't accept friction as a force. But if you think of friction as a force, then once you get going...

Lawson does not see student learning of physics to be merely a gradual accumulation of facts and concepts. Sometimes a concept in physics will suddenly make sense, and from then on any accumulated facts that you may learn about that concept are easy. Lawson expressed this thought one day in AP physics class:

> Do I need to remind you what Einstein said about physics? He said "all of physics is either impossible or trivial." That's really true. Sometimes it's really hard to understand. But once you've got it, you've got it. It's trivial.

The belief that students sometimes make giant leaps in their understanding of physics is analogous to Kuhn's (1970) description of revolutionary science or Piaget's (1972) idea of accommodation. Kuhn argued that in the history of science there have been changes that are revolutionary rather than simply evolutionary. These changes are drastic rather than gradual.

Similarly, Piaget asserted that children also make large intuitive leaps in their private understandings of the world.

Science-technology-society (STS) Instruction

Although conventional instruction implicitly addresses epistemological issues, STS instruction includes them as explicit goals. However, McGee was the only teacher in this study who included many STS topics in his instruction. Lawson said that she includes these issues later in the year because they fit better within the regular physics content. The only STS issue mentioned in Cathcart's class was his talks about his personal concerns on pollution. All of the teachers must find their own instructional material to teach these topics because their textbooks either exclude these issues or the treatment is shallow.

McGee

McGee's philosophy of science was quite influential during a lesson he taught on directed-energy weapons (D.E.W.) in space. McGee describes a scientist as "a guy who is trying to find out what makes nature tick" and considers himself to be a scientist. He considers the pursuit of knowledge to be subjective.

> I would say that true science is subjective.
>
> There are some basic things you have to do in studying science to guarantee that you're duplicating what was done before ... But at a point ... your experiment takes over, where you are able to put yourself into it ... That's just you taking something they've done and then adding yourself to it.

Since science is a personal endeavor, it is subjective. McGee views goal-oriented tasks such as industrial research as objective and impersonal, but does not believe this is true science because it is interested in the application of knowledge rather than the pure pursuit of knowledge.

> If I was working for Eli Lilly, I would definitely probably be objective ... I would be working toward these goal-oriented things ... rather than searching for knowledge. There are other guys like Leakey ... they were just trying to find out why. They didn't care what somebody had done with it.

McGee believes that much of modern science is not really science. It is concerned with profit and is therefore technology. McGee explains the difference:

> I just say technology is science with a price tag on it, profit motive ... I see science as trying to explain why things are so they can perpetuate mankind and the whole world as we know and love it and I think of technology as someone taking that scientific knowledge and simply merchandising it.

McGee asked the students to read a paper from a popular, yet technical magazine, (Scientific American, 257, Vol. 3, 39-45), so they could have a debate on directed-energy weapons (D. E. W.) in space. Before students read the paper, McGee led a discussion to create a list of points to be debated two days later. He wanted the nature of the debate to be different from what would be expected in a social studies class.

> In social studies they're more concerned about the political result. And I was trying to get them to see that on the other side ... Who cares about the politics?

So, McGee told the class that they would not discuss political arguments.

> What we need to decide, what is it about directed-energy weapons that we should know? I am going to arbitrarily say that I am the monitor and I will not allow things that I deem to be political unless you can convince me otherwise.

McGee led the discussion by asking the students what nonpolitical concerns they should have? He later added that their considerations should not be economic either.

In an interview following the class discussion on directed-energy weapons, I asked him about the purpose of the debate. McGee responded that he really wanted them to consider the problem of tying up scientists for working on D. E. W. when they could be doing other things.

> But when there are the ... guys who are designing and thinking and working to develop a whole new world of instruments of science ... There aren't very many of them around. And when you tie them up to come up with some defense system the politicians want, then that means we won't land on Mars for another 100 years. That means we won't understand the human cell. That means we have no ideas what's going on with interferon.

It was not apparent to me while observing the class that he was trying to steer them in this direction. However, it is clear in retrospect that this belief was influential in McGee's instruction. At one point, he explicitly brought up the question, but attempted to do so in a way that it would be construed as nonpolitical.

> If we spent all the money on AIDS that we've spent for D. E. W., then you do have an economic concern that is not profit-motivated, right? So this is beginning to be a nonpolitical or noneconomic problem. It's

slightly economic but not political ... Would D. E. W. benefit society more than a cure for AIDS?

McGee sees D. E. W. as a technological issue. As he told the students "Directed-energy weapons is a result of technological applications of what they've been finding out in science." To his students he distinguished science and technology as follows:

> A scientist takes the information he can and expands it, find out as much as he knows. It's the technological people that are giving it a profit motive and assigning it a task.

In other words, scientists seek knowledge and technologists exploit the knowledge for a profit. The quote is laden with values concerning the purity of science as opposed to the greed of technology.

Constraints

The issue of institutional constraints was occasionally mentioned by Lawson and Cathcart, but it was a recurring theme in McGee's discourse. The experienced teachers operated from a consistent, self-reinforcing (Hollon & Anderson, 1987) belief system that had been reconciled with institutional constraints. Their classroom instruction was remarkably consistent from one day to the next and they expressed personal philosophies that were congruent with their actions in the classroom. The teachers' understandings of what science is and how students learn science in schools formed a consistent system of beliefs for guiding classroom instruction. However, McGee, the beginning teacher, was unpredictable. The data were difficult to analyze because the classroom instruction was variable and could not be predicted from interview data. It was only in asking concrete questions about McGee's rationale after the instruction that the data began to make sense and it became possible to separate what McGee believed to be desirable and what he found to be possible.

The themes of McGee's discussion on what science teaching should be included "getting dirty," "messing around," and "going off on tangents." Yet there was very little of this happening in his classroom. I believe there were many obstacles that prohibited McGee from utilizing instruction congruent with his professed beliefs. Unlike the experienced teachers, McGee had not reconciled his own conflicting beliefs or the impact of institutional constraints on his teaching. The author addresses these issues more thoroughly in other papers (Brickhouse, 1989).

Implications

The data from this study illustrate how teachers' views of science may be expressed in their classroom instruction. These philosophies are an underlying theme in conventional and STS instruction. The central role of teachers' epistemological commitments must be addressed in preservice and inservice teacher education programs if we are to encourage more advantageous classroom practices. There is considerable rage among scientists and citizens in the U.S. when they hear of schools temporarily hiring uncertified teachers to instruct students in areas for which they have little formal content preparation. We would never consider legally certifying science teachers who have had essentially no instruction on what scientists believe about the substantive content of science. Yet, we expect science teachers to teach philosophical and societal issues based on little, if any, formal preparation to help them understand what philosophers, sociologists, or historians believe about science. Although there are increasing numbers of science and society courses available to teachers today in the U.S., these often address only current issues and methods in STS education without confronting teachers' personal philosophies of science. Aikenhead (1987) found that in the absence of instruction in the epistemological and sociological nature of science, teachers do not have the prerequisite knowledge for implementing STS instruction.

Unfortunately, teacher education may not be a sufficient cure-all for this problem. It is not reasonable to assume that teachers who have been in the classroom for over a decade are acting on the same beliefs about science that they gained during their formal education. Their philosophies of science are likely also influenced by years of teaching science in American institutions that often encourage control over creativity (McNeil 1986) and reward teaching students facts under the guise of educating them. The most widely available textbooks in science classrooms present an image of science that is idealized and dull, but at least noncontroversial. Years of teaching textbook science under these conditions could also shape teachers' views about science. They may also restructure the understandings of the nature of science to fit with the type of science they have been teaching in school.

Finally, teacher education will make little impact on practice if beginning teachers are unable to implement instruction consistent with their knowledge about science. If the school environment places constraints on teachers' knowledge and thereby plays a role in its expression and development, then we must influence this environment so that it encourages teachers to be more powerful practitioners of their profession.

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