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ABSTRACT

There is general agreement that the current teaching of secondary science is not as good as it should be. Different critics identify different weaknesses, but there is agreement that students are not learning how scientists make knowledge claims and use this knowledge. This paper assumes that one powerful influence on the development of teachers is the way they have been taught. An examination of conceptions held by scientists teaching university science courses indicates that university science teaching may have adverse influence on the development of secondary science teachers. The difficulty the researchers identify is that university science teachers take most aspects of teaching for granted and lack the theoretical framework to critique teaching practices and develop alternatives. It is hoped that the illustration of ways in which consideration of education concerns could lead to better university science teaching. Includes 18 references. (Author)

UNIVERSITY RESEARCHERS INCHOATE CRITIQUES OF SCIENCE TEACHING:

A CASE FOR THE STUDY OF EDUCATION

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INTRODUCTION

There is currently no lack of criticism of high school students' understandings of science. The content of these criticisms varies widely. Peter Fensham (1986) has argued that science instruction too often results in many students who not only do not learn science but also learn that they are not capable of doing or understanding science. Anderson and Roth (1988) maintain, among other things, that science instruction too often involves the memorization of quantities of information with no understandings of the complex relations between these topics nor any idea of how these topics can be used for systematic investigations of phenomena encountered outside the classroom. Solomon (1986) has noted that even for students doing well academically, classroom instruction in science often bears no relation to the everyday understandings students have gained. Anderson et al. (1985) have studied the conceptualizations of scientific method held by prospective high school science teachers and found that many held views of science not consonant with the accepted views of how science is done.

There are a number of results postulated to attend upon these deficiencies. The concern that led us to think through this paper is the possibility that secondary students do not learn how science proceeds and how claims are justified and are not empowered to construct their own meanings about science topics in a systematic fashion.

THE NEED TO CHANGE CONCEPTUALIZATIONS

How can we change high school science instruction? It is our claim that we must first understand how it is that science teachers understand science before instruction can be effectively changed. Several lines of research and theoretical writing -- on teacher thinking, on innovation, on curriculum development and change -- have stressed that meaningful change requires full knowledge of the conceptualizations and values held by those people who will be responsible for implementing the change. (See, for example, Olson and Eaton, 1987; Olson, 1981; Clark and Peterson, 1986; Clark, 1988; House, 1979; Wilson, Shulman and Richert, 1987). These writings generally assume that the development of individuals' conceptions is a slow and often unconscious process. As Lortie (1975) and Eddy (1969) argued in now classic studies, teachers have a long "apprenticeship" of learning how to teach by being a student and observing teaching over the course of many years.

We assume that developing secondary teachers learn much about the nature of science and science teaching in their university science courses. Results we obtained from interviews with university scientists who do some of this teaching indicate that university science courses may not be good places for learning about science to occur.

Our thesis, then, is that many university science teachers do not know enough about teaching to be able to structure classes that would contribute to the development of prospective science teachers who can, in turn, help their pupils learn science. We will present evidence to support this thesis. We must make quite clear that the people with whom we spoke were concerned about teaching and considered it important. The weaknesses we identify were not due to lack of genuine concern.

SOME CONCEPTUALIZATIONS OF THOSE TEACHING UNIVERSITY SCIENCE

In analyses connected with two other, quite differently focused studies, we found that people teaching university science courses were not pleased with at least some aspects of their teaching, but that much of the time their criticisms were not articulated or examined, hence the title of this paper. Most of the people with whom we talked had a sense that the science teaching the university students were exposed to could have been improved, but lacked the language, the concepts and alternative frameworks, that would have allowed them to formulate a critique.

We believe that the notions expressed by these researchers are not uncommon -- we have no reason to believe we selected exceptional cases. On the other hand, we did not use any sampling procedures to generate representative samples because our intent was not to generalize. We wished, rather, to explore the understandings, in depth, of a few people. We assume that the ideas expressed by these few can provide keys to the habits of thought or patterns of conceptualizations that may be shared by others in similar circumstances. There were two rather different groups interviewed. One group, interviewed by Trumbull, consisted of graduate students who were teaching assistants in a large undergraduate introductory biology course. The course lasts two semesters, and is designed for students who are considering majoring in biology. The second group, interviewed by Kerr, were practicing scientists affiliated with a large research university.

THE TEACHING ASSISTANTS

The three teaching assistants referred to in this report were doctoral students in biology, nearing the end of their study. All were involved in their own research programs, experiencing the joys, frustrations and isolation of doing research. They were interviewed as part of a research project that is examining the teaching of introductory biology. They were selected because they were working as teaching assistants in the laboratory sections of a large university introductory biology course. Their remarks about their teaching were qualitatively different from remarks made by teaching assistants who had not progressed so far in their own research careers. We will not here discuss the difference between remarks made by members of the two groups of teaching assistants, but will focus on what the researcher T.A.'s remarks reveal about their thinking and work as teachers.

Scientific Inquiry

The researcher T.A.'s were articulate about the complex interactions between theory and data. As Joan (a pseudonym) replied at the end of her interview:

> Trumbull: Those I think are all of the questions that I have. Anything you would want to add?
>
> Joan: Mostly just that anything you learn about how to teach, of what's good teaching or just what people think is good teaching, it's nice to get it back to the people who are doing it so that they can think about it and not necessarily agree with it but find their own ideas and consider it.

The other researcher teaching assistants also expressed this attitude toward theories derived from studies. They would use the theories as ways to approach their situations, but remained always ready to discard or amend the theory as needed. George spoke of the relationship between theory and data as a process of "reciprocal illumination." This awareness was, of course, informed by their immersion in the processes of trying to come to understand some particular phenomenon and was expressed in a number of powerful metaphors.

All three agreed that helping their students in introductory biology to understand the nature of the processes by which knowledge in biology is created was an important goal for the laboratory sections that they taught. The agreement is not surprising. Not only is this a nearly universal goal of university biology teaching but also this was an articulated goal of the extremely well-organized laboratory course. Nearly every laboratory exercise developed by the course organizers had been designed to introduce the students to some aspect of scientific method. Lab exercises were designed to help students experience such aspects of scientific method as hypothesis testing, data gathering, data analysis, and use of data analyses to make conclusions. Despite this careful planning, the teaching assistants expressed serious doubts about actually achieving the goal.

The researchers had several critiques, one of which was that actual research does not proceed through hypothesis testing, that the format of hypothesis testing is primarily a convention for presenting one's work once it is done, or for focusing the latter part of one's research. Terry, for example, observed that in the labs that were supposed to involve students in testing hypotheses, the hypotheses weren't really hypotheses, because they had already been tested innumerable times and the outcomes of the tests were well known. As he explained:

> The students get confused when [the lab book] talks about hypothesis testing because the labs we do obviously must

work, otherwise then they just get confusing results and make no headway. But since they work, you have to do something which has been done before, so you must be careful in running the experiment and defining how much the students are supposed to know as background . . . . That hypothesis is not really a hypothesis, it's um it's pretending it's a hypothesis.

Terry also pointed out that the difficulty in doing science was not in testing hypotheses, but in the identification and posing of fruitful questions. He was quite unsure how this ability could be taught. "I don't know how to teach it. I think I need to be taught it."

Joan pointed to a problem related to "pseudo-hypothesis" testing. Some of the labs were designed to allow students to collect and then analyze a large amount of data. The teaching assistants acknowledged the tedium of much of research, but at least tacitly assumed that one's research interest allowed one to endure the tedium. In these lab exercises students did not have this driving focus since they had not created the hypothesis. Joan referred to trying very hard to make sure that students knew the reason for their data collecting but felt that for some students taking repeated measurements got to be tedious and boring, and they lost sight of the purpose of the work.

There was a second problem doing labs that required the collection and analysis of data. On occasion students collected data that could have supported more than one interpretation. George, for example, worked hard to make the point that data are not unequivocal, but require interpretation. Students were not always interested in this, and in fact George reported that some of his students were quite bored. Why? He postulated that students were not "ready" for this lesson. Joan and Terry also referred to students' lack of readiness to understand the constructed and tentative nature of scientific knowledge. None of the teaching assistants, though, could speculate much about this readiness. George thought that perhaps the students wanted just specific facts and did not want to think.

These teaching assistants took for granted the social nature of knowledge generation in science with the concomitant recognition of the importance of being able to communicate clearly one's work and have it reviewed by peers. They were quite concerned that their students work at communicating better so took quite seriously the paper students had to write to help them practice scientific writing. They did not, however, refer to other teaching practices that were explicitly designed to foster communication. Terry mentioned using small groups in the lab and calling on the better students to lead groups and help their colleagues. He did this, though, only to allow all students to work on some procedure simultaneously and was not articulate about the factors he attended to in arranging this group work. Joan mentioned the excitement of figuring out a discussion topic that interested students enough so that they overcame their hesitancy and actually talked with each other in class but was not sure that the excellent discussion was important because she did not see that it made any difference to students' performances on the next examination.

Bases for Understanding

The researchers recognized the tacit knowledge that should underlie formal knowledge of biology. George was the most articulate about the tacit or experiential basis of knowledge in biology, but all were worried that students did not get enough exposure to holistic experiences in the class. As George put it:

> I think that just getting your hands dirty or bloody or whatever is something that a lot of people don't get much chance to do in their first couple of years. . . . [The ideal introductory student would have] a background in which they knew what birds were all about, the same way a carpenter knows what wood is all about. he may not know the physics and such but he has a feel for it. And then they come to find out more, some of the deeper things that one can learn in courses.

The teaching assistants also referred to the different levels at which one could understand biology. As Joan reflected on her learning she noted:

> One thing that's rather odd for me is that I think many of those sort of pivotal moments in my educational career I've gotten really turned on by something which isn't really all that true. It might have been thought true or a theory or something, or some popular book, even, which is relatively easy to understand and gain concepts that are exciting. And later I learned how to criticize this and to realize, well, yes, sort of, and sometimes..

Joan characterized biology as spinning Rudyard Kiplingesque "just so" stories, coherent tales that, although based on data, were elegant interpretations. Terry said that he tended to tell his more advanced students that some of the explanations in the introductory biology texts were simplifications. He would expand the text explanations and add the complexifying details that would be appropriate for higher level courses.

Understanding versus memorization

All of the teaching assistants distinguished between memorizing and really understanding, but none were very articulate about the nature of understanding. They did not seem to have a language to discuss what was entailed in understanding, how it could be cultivated and how evidence of it could be gathered systematically. They held standard views about the structure of lab work and assignments.

The teaching assistants all said that the best way to tell if students were understanding was to watch and work with them as they were doing the labs. By asking "clever questions" one could see if the students understood what they were doing. Although they were aware of the importance of communication in doing science, they did not apply this principle to learning by arranging to have students talk or argue through material in laboratory.

The teaching assistants helped to develop questions for the major lab practical examinations. Most felt that these practical examinations were able to present students with some problem-solving challenges and were not displeased with them. Terry did worry about the time constraints, noting that some students might do better were they given more time.

When the teaching assistants talked about alternatives to standard written quizzes and tests, the only alternative they referred to was oral examinations, but felt these would be too time consuming to be practical. They ~~seemed~~ to assume that on written examinations there really was no certain way to test for understanding rather than just memorization. Joan contrasted evaluation in the biology course with evaluation when she taught an athletic skill. When she was teaching a skill she was able to tell immediately if her pupils had learned the skill - either they could demonstrate it or not. There was not such certainty in evaluating the learning of biology. George was most discouraged when he pointed out that it didn't seem to matter what kind of quiz he used, the same students would do well and the same would do poorly.

These teaching assistants had to deal with students who were very concerned with grades. The teaching assistants surely felt the pressure from students concerned to get good grades. As George said:

> Considering the nature of exams and the nature of time available to students and things like that, the alternative ways of evaluating people are firstly far more time-consuming and secondly much more subjective.
>
> And subjectivity is not automatically a bad thing, but for people who's life you're determining (and I was always terribly aware of that, because people made a point of making it absolutely clear to me that the grade I determined would mean the direction of the rest of their life) I'd rather go with a little bit more sure ways. .. . In borderline cases I guess there is something to be said for going with the tried and true objective [test]-- and it's really not that objective -- but things a student feels are more objective so that they think justice has been done.

THE SCIENTISTS

At the risk of doing a disservice to each of a number of strongly individual personalities in the science world, allow me to draw you a composite picture of a scientist at the university, charged with teaching a share of undergraduate and graduate courses, taking on university and department service, and conducting and publishing original research in a chosen field. This is not an unusual picture, almost all academic "scientists" may be so described. We assume that these scientist teachers understand science because they are scientists, participating in the science community by doing research and teaching. Undergraduate science majors, destined for careers that require so many credit hours of a variety of science courses, are their students. Of this career-seeking group, a percentage of young people will become those secondary science teachers getting such recent media attention -- or at least the test scores of their students have been given attention.

If it is true that many science teachers teach science as they have been taught, then what do scientists at the university have to say about teaching science, especially in relation to their experiences of learning and doing research of science? If science education students are in those scientists' classes, what beliefs do they take away about science? Do they construct beliefs from their experiences in class or simply "borrow" them as they fight their way through undergraduate classes, accumulating science knowledge along with some ideas about what science is. What can I discern in these scientists' practice that might enable science education students to reflect on their own beliefs about teaching science?

The scientist teacher: An oxymoron?

All but one of the scientists admitted that they enjoyed teaching although it took time away from their research. They spoke of teaching with concern, with an appreciation of students and an awareness that good science education was not automatic. They did not all teach introductory courses at the time of these interviews, but all had had that experience. They had these beliefs about their teaching and about teaching in general.

Teaching something is different from reading or learning something for one's own use. These research scientists had followed a fairly conventional and successful route through secondary school and college, choosing science as a career at various points in that journey. They did not particularly question the premises on which science knowledge is based until they reached graduate school and this realization coincided with the onset of their own research programs. It was at this time that, as they stated it in different ways, everything fell into place:

> I think what was different is that for the first time when I was reading biology and thinking about biology, there was something that really excited me. . . . thinking about some of the doubts that I'd had as a student and realizing that other people had those doubts and thinking that I had lots of questions, suddenly that just grabbed hold of me and it was just really exciting. And that continued in my early years as a graduate student.

As beginning researchers they were permitted to argue, explore confusions, pose their own questions. It was in the research process that they became committed to science, confident of their ability and willing to risk in order to create. They talk about this as a major event in their own learning. They separated themselves from the authority of their teachers and texts and began to learn from their own research and from their peers, having become members of the research community. The scientists exhibit a lack of pedagogical knowledge when they speak of science teaching, because the research experience, the autotomy that gave them power, becomes secondary (or non-existent) when they consider the student as a science learner. The efforts that these scientists make, as teachers, is based on the premise that the student will or will not learn because of something that the teacher is able to do. The scientists seem to teach as they had been taught, and teach as they thought they had learned.

The scientists expressed a belief that science knowledge (material) has to be organized in a different way for teaching than if it is to be learned personally. The teachers "did the work," and students were expected to get the same excitement from learning that the teachers did from developing and teaching the material. Conceptualizing the material for the students led to the assumption that the students have the same knowledge. One teacher described how much she enjoyed integrating material from original sources, and laying it out for the students in a linear way. The implication was that the material to be learned is conceptually integrated, but that the students will understand it only when presented in a linear way. The assumed, but unarticulated subsequent action, requires the students to reconstruct that integration of concepts.

Another teacher, recognizing the complexity and amount of new material for the students to learn, attempts to

> . . .distill the body of knowledge into a few essential points that can be take-home messages and giving some detail, which is, sort of hanging detail off the essential points. But trying to figure out what the essential points are instead of just running through a whole bunch of stuff, and trying to see if students come away with those, if nothing else.

Thinking about what is crucial or fundamental that students should know is a teaching skill for which research scientists have little or no preparation other than a fortuitous sensitivity to student feedback.

However, there was some acknowledgement that students had to reorganize the material themselves. Several scientists expressed their "ideal" of teaching; that of the student involved in projects and activities; taking a conceptually revealing problem and working on that in the field and in the classroom, returning for continued questioning, activities very similar to a research approach. The time to create these models and projects and evaluate them discouraged the professors from pursuing these efforts.

A physicist, trying to teach beginning physics students that they need more than an algorithm to solve problems, asks them to put books and notes away and try to solve the problems or teach someone else. The belief is that unless they can do that, as this researcher does when preparing lectures or solving problems, the students will never be creative with the material. Being creative with material is a problem. Students recognize different parts of the problem and what to do, but they don't "know how to think about it. They don't know how to create with it."

When students come in for help, complaining that they are unable to work problems on tests after they have been able to do homework or lab problems, they are asked to work through the problem until they get "stuck," then go back and learn that point until they can get past that hurdle. This teacher maintains that there is a tremendous affect accompanying that satisfactory completion, and an eagerness to go on. She claims that the student has learned more than just the problem answer, and understands all "kinds of things that they didn't think that they knew." Trying to figure out how to teach this thinking to first year students is her most difficult task. The strategy she uses is one that worked for her and so becomes the strategy she uses with her students.

__Quality and quantity__

The scientists acknowledge that in a relatively short period of time after their graduate programs they have learned a tremendous amount of material and they can't expect the students to know that much.

> ...the first time I taught the fish course, I just felt that everybody had to learn everything I knew, plus the stuff I felt I ought to know. Having been though that course once, my expectations changed. . .. and that's when it hit home that there's been this process going on in one's subconscious.

Trying to evaluate their students in relation to where these teachers were at a similar stage became more and more unrealistic. "One of the things that being a professor or being a teacher does, is that as you go on farther, you start to evaluate students not relative to you, but relative to other students."

Another says that teaching what science is about rather than teaching facts is more important because the facts are out of date in five years. Yet a recurring theme is that there is a lot of material to learn.

> I'm amazed at how much of this stuff I've learned in the last however many years, and have just forgotten what it was like not to know this information. Some of the important lessons have been how to communicate with the person who wasn't born knowing this.

Olive, reflecting on her own learning of science and on what students are going through now:

I look back on some of the elementary courses and I wonder how people can learn, because very difficult concepts are being introduced. . . . you see that certain things are being selected from your broad field and are being presented to these young students. And you wonder how they fit that in, because it shouldn't make any sense unless you know the rest. You are being forced to acquire partial things, partial facts and you just cram it all in there and eventually it gets synthesized, but not necessarily in the course.

She thinks that scientists generally assume that students have a history of science that prepares them to make sense of present day knowledge. In her own teaching she admits that she tries to remember what she went through and realizes that different people have different styles so teaches in different ways. But more than anything else, she repeats things more than one might think is necessary. Because some of her work involves teaching techniques, she thinks that repetition is important to achieving the ability to do something without thinking. But she admits that learning theory is somehow different from learning technique. She knows students forget, or fail to consider, the theory that might be helpful to understand what certain elements of a technique are achieving. She is uncertain why students are liable to forget theory.

When asked whether students are aware of where her course fits into the broad divisions of her field, Valerie replied:

I'm . . . not sure its appropriate. But I think that because the field is so broad, that even in what is called an introductory course, you are focusing on one leg of that. It really is a field where all of chemistry could be applied, and all of physics could be applied to the earth and all of evolutionary biology applied to the earth and it is a lot to digest. We ask people to do that ahead of time.

She thinks teaching is

. . .being able to inspire somebody; making someone see something straight instead of being confused; simplifying the disorder. . . . I'd never have chosen to be a lecturer because I am not theatrical, and I think you have to be theatrical to be outstanding at that.

Evaluation

Evaluation of student learning consists of routine tests and, depending on the level of the course, papers. Some recognize that these are problematic and know that they find out from informal feedback as much as from tests, but they rely on tests for grading. Typically, when asked how to find out what students know:

> Usually, it is a strange way. They ask a question and you find out that they didn't know what that word was that you used four lectures ago. I don't think really from an exam that you learn all that much. YOu learn whether they have memorized or become familiar with what is in the book. But whether they have really taken it in at gut level and gotten something out of it, I don't really think you find out that way. Or it's by accident almost. Or by following (the student) in another course or something and then you get into a more sophisticated type of discussion.

Fran refers to different ways of finding out what students are learning besides performance on exams (the main way.)

> When you give a lecture and you think it is perfectly clear and then somebody comes to talk to you and it's clear that it wasn't clear. Then you ask yourself how can I get them to think through and actually assimilate that as opposed to just having heard it. The only way for me to do that is just to do it. I mean my understanding of a subject is much different when I've just read it in a book than when I have tried to explain it to somebody else. Because you have to work through it much more actively in order to explain it to somebody else than just to learn it, even to just spit it back on the exam.

Fran thinks she is getting better at teaching but admits that progress in teaching is harder to measure than progress in research, because one depends on feedback from students or just one's feelings after a lecture. She also thinks it is hard to tell from student errors whether they have misconceptions about the material or they have just been lazy and not worked to make sense of it. She has to take student effort into consideration in order to make the distinction. When asked if she finds out what students already know before she starts the class material she replied:

> It is hard to do because if you face a class of thirty students, the chances are there will be thirty different notions or suppositions. And it is very hard to find out where any given student is. You don't find out until you give an exam and then you don't find out what their notions and presuppositions are, you find out how they coped with the material that you gave them. I even hand out a piece of paper, a little questionnaire, trying to find out what student's backgrounds are and there are no obvious correlations. There are kids without any preparation that do just fine and there are kids that have lots of preparation that are having a hard time. So, that sounds like a great idea, if you can really do it; it's hard to attain unless you only have one or two or only even three students.

When offered an explanation of ways to find out student's prior knowledge, she thought the idea was to give the students concepts "ahead of time" about the upcoming lecture material. There was no perception that the plan was to find out from the inquiry how students put certain preliminary concepts together, and then use that information to construct the lecture.

Conflicts and controversy: A case for critical examination

Most researchers recognize that there are conflicting beliefs about current knowledge in science. They either use original materials, to engage the students in these debates or admit, when asked, that there is more than one answer to a number of questions. The scientists perceive that students are frustrated with these seeming ambiguities.

The critical examination of evidence and argument that scientists are asked to do in research and that students must do in order to understand the conflicts in science is not part of the teaching episodes described by the scientists. The scientists have learned the critical process from their interpretations of experimental evidence, judgment of journal articles, and involvement in their own research. Asking students to do engage in critical examination and then evaluating them on that process requires that the students have access to the same experience. Constructing alternative explanations requires that students be able to recognize and judge the validity of alternatives.

One teacher believes that these students do not have the capacity to deal with these controversies.

> If you tell your students there is a controversy and some people think this, and some people think this, that's not right. But in fact that's the way I think the human brain works. It's a very sophisticated level before you can hold in your mind the possibility of two alternatives. Most of us through most of what we're doing want that one alternative that can be filed or not filed, but it is there. And to deal with a more nebulous concept where you don't know, therefore you can't file it anywhere, I think is more difficult.

Most of the scientists were concerned with the understanding their students had about conflict and controversy in science. Bringing in new research compounded the problem of too much material with the student's need to have definitive answers.

> I always try to tell them that they have to use their own critical faculties and I like to present conflicting evidence. If this guy says this and this guy says this, how do you reconcile it? Because you have to learn to think. . . you have to learn to judge things.

I asked how students were to be able to judge and the answer was, "Well, a certain amount of common sense and also you lead them a little bit." Another answer about making a claim for validity was "Logic, that's all you can use. You go through it, you carry through it and you come to some sort of logical resolution. Within the context."

It is possible that students perceive a difference between how scientists work (at least to them), and the conflicts in science. For a research scientist, different findings and alternative frameworks are part of the "norms" of science -- they do not expect immediate resolution, but are content that community discussion and review will eventually favor one result over another, even though it may take years. Their use of such "classic cases" in the classroom are prompted by their interest in having students exhibit some critical judgment, undoubtedly for motivation to "think" but also to pursue some exciting ideas of science. Many of these scientists admitted that they had questions about conventional textbook science while they were undergraduates, but didn't ask because they thought the questions might be "dumb," or considered irrelevant. Resolution to these questions didn't always happen after they became graduate students, but the scientists found that they were then expected to be critical and not necessarily concerned with the "right" answers. Now they want their students to do what they themselves weren't able or allowed to do until they were involved in research.

This critical activity may contradict the students more public belief in science as a way of finding out, science as a way of knowing. It is one thing to effect a resolution to controversy by working in the field with all the information; it is another to develop and use a theoretical language for discussing that situation and judging it. The scientists must have a knowledge of this kind of critical judgment before they can evaluate their students' ability to use it. While they were willing to admit to the controversy and conflict and tentative nature of science knowledge, they did not fully articulate what constituted critical judgment.

Effects of the large introductory course

Ursula expressed her dismay at undergraduate lower level courses.

> I find them not interested in the joy of the subject, but only in getting it presented to them in the way that they can take concise notes and they can memorize it.

Ursula thought the best way to teach was to get students to think, but one couldn't do that in large courses designed only for general overviews and for "feeding them information." She believed, because of these feelings, that she was intolerant and an intellectual snob. Although she admittedly enjoyed giving seminars, she did not connect those "interested" students to those who might have, a few years earlier, been in those large undergraduate courses she criticized.

She felt her inability to affect the large classes was because she did not have enough patience. She couldn't understand why students didn't understand when she made an effort to speak and enunciate clearly, have well-formulated ideas, and be willing to re-explain. This failure of students to understand made her impatient with the intrusion of teaching on her research time. She described bright students as those who "have been right there with me and who give me back what I've missed, or ask questions that showed they've been thinking."

The conception of teaching as leading to "shared meaning" was not part of her view of herself as a teacher. She believed students who could think and understand her explanations were different from those students desperate for concise notes, facts and unwilling to accept controversy in science.

CONCLUSIONS

The scientists and teaching assistants appear to take many aspects of teaching for granted, although all admit it requires a lot of time and energy. They struggle with a language for learning, wishing they had words to express their thoughts better. They do not see teaching as researchable, only as a process requiring them to accomplish certain routines. We will discuss below a few of the issues that could be much better understood using educational notions.

Equally intriguing is a point that became clear to us only very late in preparing this paper: none of these interviewees articulated the understanding that many educational decisions represent resolutions of dilemmas inherent in education, dilemmas that cannot necessarily be resolved by gathering and analyzing information because resolution requires taking a value position. We will not discuss this issue further here, but will refer the reader to the excellent work of people such as the Berlaks (1981) that explores the importance of educational dilemmas.

These university people all shared a feeling that students, particularly in lower level courses, were not ready or were not eager to learn how science knowledge was generated and validated. There are a number of frameworks that could help explain this observation. The work of developmental researchers such as Perry (1970, 1981) traces students' movements from absolutist to more negotiated views of knowledge. This theory about changes students' epistemologies could help science teachers make sense of their students' lack of readiness and would also support their efforts to introduce students to the processes of critique and inquiry. The work of Belenky et al. (1986) could provide a related way to consider how student existing epistemological assumptions <u>and</u> the structuring of work in classes might contribute to student problems with understanding how science knowledge claims are validated or critiqued.

The scientists and teaching assistants wanted their students to communicate better and become more critical, yet were not able to think about teaching situations that could contribute to students' authentic efforts. They used no explicit theories about cooperative learning or meaningful learning or group dynamics to plan for projects or evaluation formats, for example. They saw communication as important for their research work, but did not acknolwedge how important this communication was for their own learning and, of course, for the learning of others.

A political examination of schooling would help these teachers at university level to examine the effects of testing and evaluation procedures and perhaps question their own and their students' assumptions about grading. This examination would not necessarily lead to new ways of structuring science courses but would lead to an understanding of the complex factors shaping evaluation. A political view of education would also explain some of students' demands for clear facts and explicit definitions. In an educational system that values grades and considers them as significant indicators of potential, presentations of material or exercises that increase uncertainty are threatening. Also, until the sorting function of science courses -- the elimination of students from pre-professional programs or advanced work in the discipline -- is acknowledged and addressed directly, relatively high failure rates in science courses will be accepted as natural.

For many of the university teachers, the content of courses was either not problematic or was only criticized as containing too much material or not the "right" material. The university teachers had little language for articulating goals for a course other than in terms of information to be learned. Lacking a conception of other possible goals for their courses, teachers could not make changes.

An issue that was addressed very differently by the two groups was the importance of basic or fundamental knowledge to further learning. The scientists seemed more concerned that students be able to think creatively and critically, but were not explicit about how the necessary background knowledge and skills would develop. The teaching assistants were concerned that students have a full understanding of the problems investigated in labs to keep their interest high. A theorist such as Polanyi (1958) could have helped them to be aware of just how extensive their tacit knowledge of biology was and so could help them to see the value of work that did not lead to an immediate product. Reading Polanyi, a scientist himself, could also help them to see the extent to which the doing of science is impelled by an inexpressible idea of what the problem solution will be. This framework could help teachers become conscious of the amount of background knowledge that is necessary before students can critique or investigate. Recent work in cognitive science is also recognizing the complex interplay between general and specific knowledge (e.g. Perkins and Salomon, 1989).

THE TEACHING ASSISTANTS

Even though the teaching assistants expressed their awareness of the pressure to produce and justify grades, they did not seem aware of the full extent to which this pressure shaped the ways in which they considered assignments and exams. The assumption, indeed the expectation, was that grades on any assignment would be distributed normally. The assumed purpose of most graded work was to distinguish among the students. Therefore, the final test of the efficacy of an assignment or exam was the extent to which it allowed such separation, not the extent to which it may have stimulated student thinking, comprehension, or interest. The teaching assistants made no reference to any form of mastery grading that would give credit for successful completion; they never discussed assignments designed only to increase students' experience with some phenomenon, to contribute to their tacit or experiential knowledge. Class exercises designed to increase and refine student discussion and interaction were also not seen as important.

The teaching assistants did know that mere memorization was not what they wanted to stimulate but lacked an explicit theory of learning to guide their teaching. Although they recognized the importance of communication and active struggle to make sense in their research, they failed to consider ways to structure class work or assignments to encourage student engagement with the material.

THE SCIENTISTS

In contrast to the teaching assistants teaching introductory biology labs, the research scientists did not talk much about the need to teach the scientific method. The scientists dismissed the formality of the "scientific method" and talked of the relations between theory and data connection in respect to their own research and not in regard to students' learning. They seemed to feel that student ability to see the connection between theory and data and to critique was either there or not there; they spoke little about how to help students to make connections or judgments.

The scientists relied on their own experiences in planning their teaching, but failed to attend to how particular their experiences may have been. They were anxious to share their excitement and involvement in science, but seemed not to acknowledge the very real possibility that the students had not experienced the power of everything "falling into place" as these scientists had early in their graduate careers. The scientists do not mean to withhold this experience from their students, but rely more on students taking the scientists' word for explanations of phenomena, not seeing how this diminishes students' own meaning making.

REFERENCES

Anderson, C.W. and Roth, K.J. (1988) Teaching for meaningful and self-regulated learning of science. Institute for Research on Teaching, College of Education, Michigan State University.

Anderson, H.O., Harty, H. and Samuel, K.V. (1985). Perspectives of preservice secondary science teachers. School Science and Mathematics, 86(1), 43-50.

Belenky, M.F., Clincy, B.M., Goldberger, N.R. and Tarule, J.M. (1986). Women's ways of knowing. New York: Basic Books.

Berlak, A. and Berlak, H. (1981). Dilemmas in education. New York: Methuen.

Clark, C. (1988). Asking the right questions about teacher preparation: Contributions of research on teacher thinking. Educational Researcher, 17(2), 5-12.

Clark, C. and Peterson, P. (1986). Teachers' thought processes. In M.C. Wittrock (Ed.). Handbook of research on teaching. Third Edition. New York: Macmillan Publishing.

E. M. Eddy (1969). Becoming a teacher. New York: Teachers College Press.

Fensham, P. (1986). Science for all. Invitational address at the annual meeting of the American Educational Research Association, San Francisco.

House, E.R. (1979). Technology versus craft: A ten year perspective on innovation. Journal of Curriculum Studies, 11(1), 1-15.

D. Lortie (1975). Schoolteacher. Chicago: University of Chicago Press.

Olson, J. K. (1981). Teacher influence in the classroom: A context to understanding curriculum change. Instructional science, 10, 259-275.

Olson, J.K. and Eaton, S. (1987). Curriculum change and the classroom order. in J. Calderhead (Ed.). Exploring teachers' thinking. London: Cassell, Limited.

Perkins, D.N. and Salomon, G. (1989). Are cognitive skills context-bound? Educational Researcher, 18(1), 16-25.

Perry, W.G. (1970). Forms of intellectual and ethical development in the college years. New York: Holt, Rinehart & Winston.

Perry, W.G. (1981). Cognitive and ethical growth: The making of meaning. In A. Chickering (Ed.). The modern American college. San Francisco: Jossey-Bass.

Polanyi, M. (1958). Personal knowledge. Chicago: University of Chicago Press.

Solomon, Joan. (1986). Learning about energy: How pupils think in two domains. European Journal of Science Education, 5(1), 49-59.

Wilson, S.M, Shulman, L.S., and Richert, A.E. (1987). '150 different ways' of knowing: Representations of knowledge in teaching. In J. Calderhead (Ed.) Exploring teachers' thinking. London: Cassell Educational Limited.