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ABSTRACT

This case study explores the relationship between one chemistry teacher's conceptions of teaching science and his teaching practice. The teacher, Mr. Corrigan, comments on the researchers' interpretations of his thinking and practice. Mr. Corrigan exhibited a high level of disciplinary knowledge and clear views on teaching, learning, and content. His teaching focuses on laboratory work and his students' understanding of chemistry concepts, and he freely discussed his ideas of higher levels of thinking and "field trip" type experiences. Though these ideas were reflected in his practice, there were some tensions in the relationship between them and his directive teaching style and highly structured classroom and laboratory. Exploring these tensions with him revealed a pragmatic teacher thoughtfully dealing with the real world of his students and his discipline. (Author/PR)

Didactic Teaching for Meaningful Understanding: A Chemistry Teacher's Story

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Abstract

This case study, part of a larger research project, explores the relationship between one chemistry teacher's conceptions of teaching science and his teaching practice. Mr. Corrigan's comments on the researchers' interpretations of his thinking and practice are part of this paper. Mr. Corrigan exhibited a high level of disciplinary knowledge and clear views on teaching, learning and content. His teaching focused on laboratory work and his students' understanding of chemistry concepts, and he freely discussed his ideas of higher levels of thinking and "field trip" type experiences. Though these ideas were reflected in his practice, there were some tensions in the relationship between them and his directive teaching style and highly structured classroom and laboratory. Exploring these tensions with him revealed a pragmatic teacher thoughtfully dealing with the real world of his students and his discipline.

Didactic Teaching for Meaningful Understanding: A Chemistry Teacher's Story

What is the relationship between science teachers' conceptions of teaching science and their teaching practice? This question is the focus of Project DISTIL, an NSF funded project involving twelve experienced high school biology, chemistry and physics teachers (Hewson & Hollon, 1989). This case study examines Mr. Corrigan, one of the chemistry teachers in the project. We observed Mr. Corrigan teaching three topics - stoichiometry, atomic structure, and acids and bases - to one of his classes for a total of twenty-eight class periods. We videotaped the class, wrote field notes, and collected resource materials used in the class. Mr. Corrigan was interviewed after each topic, with the discussion focusing on classroom activities. A detailed discussion of the project's methodology is found in two related conference papers (Hollon, 1993; Olsen & Hewson, 1993).

We present Corrigan's practice in terms of his knowledge-in-action (Schön, 1983, 1987), that form of knowing inherent in a teacher's actions in the context of daily teaching activities. Knowledge-in-action is partly conscious and partly implicit in actions, and may be accessible through reflection on particular events. We describe Corrigan's knowledge-in-action by analyzing both his classroom actions while teaching the three topics and the three subsequent post-topic interviews. Thus we have our descriptions and interpretations as well as Corrigan's reflections with which to construct a portrait of his knowledge-in-action.

Knowledge-in-action is generally thought to be distinct from the more general propositional knowledge that a person may possess (Schön, 1987, p. 40). We describe a science teacher's general propositional knowledge as his/her conceptions of teaching science: the set of ideas, understandings, and interpretations of experience concerning the nature and content of science, the nature of learners and learning, and the nature of instruction and teaching that the teacher uses in thinking about teaching science (Hewson & Hewson, 1989). Such conceptions may vary considerably among individuals.

Researchers have recognized the importance of teachers' underlying conceptions of teaching science and their possible influence on teaching practice. However, the relationship between the two should be considered an open question.

Corrigan's conceptions of teaching science were determined by using an open-ended interview task (Hewson & Hewson, 1989) prior to observations. In this interview we asked him to comment on a series of written descriptions of instances in which science teaching and/or learning may be occurring. His interview was transcribed and analyzed as outlined by Hewson, Kerby and Cook (1992). We then compared our description of his knowledge-in-action with his conceptions of teaching science, noting areas of consistency and divergence.

Finally, we wrote up our description and interpretation of his knowledge-in-action and his conceptions of teaching science, and gave it to Corrigan to reflect on in preparation for a series of final interviews.

The main questions addressed in this case study are:

> What is Corrigan's knowledge-in-action?
> What are Corrigan's conceptions of teaching science?
> What is the relationship between Corrigan's conceptions of teaching science and his knowledge-in-action?

In examining these questions, we will present Corrigan's thoughts on our interpretations of his thinking and practice. We consider them to be an integral part of the case study. These thoughts will appear in italics to distinguish them from post-topic interview quotes and classroom dialog, which appear in small print.

In the Classroom and Laboratory

Mr. Corrigan is a tall, bearded chemistry teacher in his mid-forties with seventeen years teaching experience. He was a track athlete in college and has an undergraduate degree in biochemistry and a masters degree in education. Corrigan worked as an analytical chemist for six years before turning to teaching. He is an active member of educational organizations and is involved in curriculum development and assessment projects. Corrigan teaches four sections of chemistry and one of advanced chemistry, a biochemistry course.

The high school is in a small community within commuting distance of a city of 200,000 in the upper Midwest. There are about 750 students, virtually all white and mostly from middle class families. Most are planning to go to college.

Corrigan is organized and conducts his class with little digression or wasted time, impressing an observer as a person with a plan. Students are given a hefty packet at the beginning of a topic which includes assignments, exercises, labs and an outline for taking notes. All assignments are due before students take the exam, and since they must score at a 70% level on every exam, some students work on earlier topics to improve their exam scores.

The lecture room, separate from the laboratory, is a large room that slopes sharply upward, resembling a university lecture room. As students in the back are far away, Corrigan speaks loudly. When students are working on problems or questions, Corrigan circulates among them, asking and answering questions. Students are expected to be working at all times, and they are. Though Corrigan is efficient and business-like, he chats about sports and continually interjects dry humor. When a student said this was an exciting day, Corrigan replied, "Always exciting studying the mole, and when you put Homecoming on top of that, it really does add on."

Lab Days

Corrigan believes that laboratory experience is important, and has divided his teaching into equal parts of alternating classroom days and laboratory days. "Ideally it would be just lab and demonstrations," he said.

> They can intellectualize about two substances forming a new substance...but then to actually do it, that's another leap for them.

On lab days half of the twenty-nine students meets with Corrigan and half with another teacher The labs usually correlate with the current classroom topic, but can stand on their own.

> Sometimes the lab comes before the lecture and I've found it makes no difference...either way, it's getting the student ready to learn.

Corrigan gives a thorough introduction to each lab, describing reactions and procedures and giving tips on using equipment. Students are business-like, with everyone working. Corrigan offers comments, and asks and answers questions, but it is clear he will not do their work for them. At times he will stand by a table, just listening and watching without comment. Though the lab experiment hand-outs supply the procedure, students find the bench work, questions and calculations challenging. Corrigan wants them to explore in the laboratory, and experience more than the minimum activities necessary to complete the work. "It's dinking around, but boy, there's more learning that goes on with dinking around."

Some of Corrigan's lab handouts are his own and some are photocopies of lab manual experiments which Corrigan has modified. They consist of step-wise procedure, questions and calculations. This contrasts with what he expects students to get out of lab.

> It's like a field trip, things will happen that I can't predict. And different students are going to learn different things for each lab.

However, we did not observe Corrigan expressing this expectation explicitly to students, and most of them spend their spare lab time answering lab questions and doing homework rather than engaging in independent exploration. Corrigan is aware of the dilemma:

> The one drawback to the labs is the recipe approach...Some students see it as a task to be completed and they follow the steps without thinking about it.

Corrigan's responses: We see it as kind of a paradox too. We have some labs that they have to sort of invent themselves, but only after they've had, for example, the specific heat of a metal...We do about sixty-five labs and the open-ended are probably only eight. We would like to do more...And then it becomes a time management problem, though, too.

The lab thing, the field trip - you don't observe the expectation explicitly. I really see it as there are different levels of curiosity and interest, and I see this field trip...You take 20 kids to med school to see the cadaver and they'll get 20 different things out of it. And it's kind of the way I look at the labs too. That's when I see it so much. They'll ask a question or they'll be trying *to light the burner from the bottom and they're learning things about our world that has nothing to do with the lab.*

Well, some of them just, I didn't like the way the lab manuals did them...Just maybe rewording so that they aren't just filling in numbers, because I think the workbook aspect, the recipe aspect is bad enough. Some labs, it's getting rid of that recipe aspect - I mean if they've collected a gas by displacement of water and they've done it two times, the third time you can say, you're going to decompose this gas, what would be a good way to do it, what would you do to collect it, and they'll figure that out.

And each little lab may have it's own objectives...but always there's the underlying theme that we're manipulating materials and we're seeing how they interact and that's one of the reasons that they're there. That's not a stated objective, I mean that's sort of hidden. And I think you kind of alluded to that and I agree with that, I think the standard objectives are clearer but there's always, there's more to it. And it's not tested and it's not stated.

Classroom Days

Classroom days are held in a separate lecture room and include a variety of activities usually centered around lecture interspersed with questions from Corrigan. He is definitely the master of ceremonies, standing near the students, looking directly at them and gesturing animatedly as he lectures. "Are you with us today?" he pointedly asks individuals, leaving no doubt that their attention is mandatory. The students are business-like, paying attention and taking notes without complaint. They are aware of the topic's schedule and their responsibilities. Quizzes or written practice on questions and problems are virtually a daily occurrence. "That's the only way I can really assess how they're doing individually." He allows a generous amount of time for students to work on a problem or question while he moves around, answering and asking questions.

Corrigan is an organized teacher who runs a tight ship, and students have limited opportunities to contribute to the class and raise questions. In contrast to the lab, students' questions and comments are infrequent in the classroom. They seem hesitant to interrupt the flow with questions of their own, and do not always respond to Corrigan's questions. Though he is fairly consistent in monitoring student understanding by asking questions in lecture or during seatwork, his questioning is designed to lead students onward rather than explore students' difficulties:

Corrigan: All right, you've got the mole ratio, four to three to two?

Student: Yes.

Corrigan: Now you've got to convert those grams to moles, and I told you that's 56 so if you have 28 grams, how many moles of iron do you have?

Student: Half.

Corrigan: OK, if you have 0.5 moles of this, how many moles of rust will be produced?

Though students' questions and comments play a small role in the classroom, students occasionally do ask good questions: "Can electrons exist between energy levels?" "Is the hydrogen spectra included in the other ones?" Much of the time, they display enthusiasm:

Corrigan: Then we're ready for what this is all about, that's writing electron configurations.

Students: Yeah! Woooo!

Corrigan's responses: I agree. I think that I do like structured, productive class time. So in my note I wrote down, am I a part of the institution then...and does that kind of destroy natural curiosity? We do that in kids. We do destroy their natural curiosity. But I don't know if we do it, or society does it, or if peer pressure does it, or the institution does it... Well, I want to manage thirty kids productively. Get as many of them there as I can...I think that students feel very pressured to be successful, to do well, by society and their parents. And some students, it's very counterproductive. They want to know what the answer is...They have become great students, but they don't know how, they don't know how to think, they don't know how to integrate knowledge, but they do know how to get the right answer and give back the right answer.

I think that when students do ask questions, they tend to be higher order questions.

And maybe they don't want the teacher to know they don't know the answer so they're afraid to ask questions that explore, because of peer pressure or they may look like they don't quite know what's going on...and they won't take that risk. And once in a while you get a student that is - that they don't care...And they are the ones that are willing to go outside the institution or willing to go *outside their peers and ask strange questions or have kind of strange answers. But that's such a small number it really is kind of scary.*

Teaching for Understanding

"You understand the concept," Corrigan encouraged students before demonstrating a magnesium-hydrochloric acid reaction to introduce the idea of a limiting reagent. We found this idea of intuitive understanding to be a key part of his teaching.

> A step I always find important is to show them they do understand the underlying principles of any concept. And then it's just a matter of applying it, maybe at a little higher level.

By understanding the principles, Corrigan is not necessarily referring to some previous chemical ideas that students have learned. Indeed, in this particular lesson, he is appealing to common sense thinking. "If the limiting reagent is the oxygen, you're only going to get so much iron oxide," he told them. Students do not need to understand much chemistry to grasp the main point. Corrigan is careful to ground the new ideas by relating them to other ideas, to familiar applications, to simple skills, or to what students intuitively understand:

> Corrigan to students: You don't want to get yourselves hung up on things because you intuitively already know...(taps his head with his finger).

> Corrigan to students: What part is that element in the compound? Just like in foods, what part of the food is fat? Well it's the weight of the fat divided by the weight of the food, right?

> Corrigan to students: Let's look at the common ion effect, which you have done in the lab, and we have dealt with through Le Chatelier's principle. It's a little review, it's really common sense.

Corrigan's response: That's what I really try to do is to show them what they do know and how it is common sense at some level.

After Corrigan introduces new ideas or models a problem-solving procedure, he usually has students practice while he monitors them. He expects students to understand what they are doing. For example, he showed them how to solve stoichiometry problems by thinking in terms of mole ratios rather than using the factor label method. "I think there's more understanding with a ratio method." Students should progress from a basic perception of an idea to synthesizing it with other concepts and using it to think and solve problems:

> I'm trying to get them to work it in their minds, to create a higher level of understanding.

This theme of guiding students to higher levels of understanding is one that Corrigan talked about frequently in his interviews and explicitly expressed to students. When asked about these higher levels, he replied, "I'm talking about synthesis, analysis," and mentioned Bloom's taxonomy.

Corrigan's post-topic interviews revealed that he has definite ideas about how students think and learn, and anticipates students' difficulties and misconceptions. For example:

> I'm trying to avoid a problem that students have...They understand the law of conservation of mass, but they think there's a law of conservation of moles.

> ...and as soon as I go to grams, it becomes difficult for probably half the students.

It is difficult for us to determine how much of Corrigan's goal of understanding is met. Students are busy with lots to understand and do - at times perhaps too much for some of them to really do justice to the concepts.

Corrigan thinks that students understand new ideas by grounding them on their chemical and everyday knowledge and implicit understandings. He does not simply equate understanding with performance on exams. The exams are chiefly multiple choice questions with some problems and questions requiring students to write a few sentences. They are lengthy and thorough without any surprises. We feel that Corrigan's teaching ideally calls for a higher level of thinking than required in the exams, and wonder how many students are challenging themselves to understand concepts at the level presented by Corrigan.

Corrigan's responses: Writing those (exam) questions is the hardest part, writing the higher level, authentic questions because if you give them practice on it, then it's become a recall. No matter how good that question was, then it's simply just a recall...I've tried questions of that type (higher level)... It's so few students that can put that together, that's frustrating. So I agree, that the questions are not higher level.

I think that there's a lot of good things about the test. Reinforcing how they're learning and being successful and, you know, work pays off.

I really believe students need practice taking tests. I think they need to know what's going to be on the test, they have to know what the goals are... I don't, you know, believe in throwing hidden things at them.

Learning by doing

Corrigan's ideas on understanding and higher levels of thinking are linked to what he means by active learning. He has a clear learning hierarchy in mind:

> If you were going to rank how students learn, they learn the least from reading and they learn a little bit more from lecturing, they learn a little bit more from modelling and then when they do it themselves, they learn more and when they explain to someone they learn the most.

> The actual learning comes in when they put the pieces together. They have the questions they have to answer in the assignments and the quizzes. That's where the active learning comes in...They haven't done any synthesis or analysis of it but then when they finally have to write it down themselves, that's when I see the learning.

> That's where I think the main part of the labs comes in. They're constantly explaining to each other.

Labs play a key part in students' understanding of chemistry. "It's taking it out of the intellect and putting it into - 'Oh, this really happens!'" Corrigan wants students "dinking around" in the laboratory, as well as completing the experiment, as this encourages higher level thinking and questions.

Corrigan's responses: We've got these strikers that we use for lighting the burners. And sometimes the kids start just playing with them. Well, I find that good because they're seeing a lot of things there and they're wondering why that happens and they'll ask questions about it.

But every once in a while you get a very highly creative kid that really likes to go beyond and that's when your waste basket catches on fire as they put sulfuric acid in.

However desirable this may be, students focus on doing the experiment and asking Corrigan questions about the lab procedure and homework assignments.

Corrigan's responses: They're goal-oriented. They see what their objective is and they start calculating and solving...

The majority of questions are oriented to procedure, calculations - how do you do this? But there are open-ended questions I ask, that they ask, that are occurring on a regular basis but it's certainly a small percentage.

Corrigan encourages active learning by having students working problems and taking frequent quizzes in class, and cooperating in the classroom as well as the lab:

> Corrigan to students: If you're stuck, don't immediately raise your hand...You'll do more learning if you explain it to someone else, if you find it in your notes than if you ask me.

However, he first spends a large amount of time, sometimes the majority of class time, explaining concepts to students before having them apply the concepts in practice problems, quizzes and assignments. In the atomic structure topic he seemed compelled to cover certain content in quantum theory even though students were not responsible for it and perhaps didn't understand much of it. In these instances he lectured rapidly without pausing on a large amount of difficult material. This is an interesting point about Corrigan's teaching, since it seem to contradict his belief about learning:

> To learn, the student has to be doing it and I think the least effective mode of teaching is to explain something to the student.

If he does not believe that students learn by listening, why does he spend so much time on explanation? He is aware of the issue:

> When I give lab directions, I sometimes wonder why I do. Because I could have every student sitting there watching me and I can tell them something and it's as though I didn't say it.

Nevertheless, he feels lecturing extensively is necessary at times:

> I think it's the nature of the topic...it's harder to think of active learning activities.

> To get them started thinking along the right lines, I think the only way that I can see right now is through lecture.

We see a tension between his desire to let students learn by doing and his tendency to explain and direct, particularly in the classroom, where questions from students and exploratory discussions are rare.

Corrigan's responses: I know what I want the outcome to be and I guess whatever gets it to that outcome. And it's sort of a pattern I've gotten into of explaining it and them have them doing active things...I think the ego is involved because I want them to do well, I want to be a good teacher, and that way I feel I have more control over the situation if I am lecturing. Whereas if it's an active learning situation, let's say cooperative learning, then the teacher is more of a facilitator and that's always tougher because we feel we have less control, we don't know quite what's going to come out of that.

I think the overall goal drives everything for me...That's a good example (the uncertainty of science) of a case where it would be very hard to design a student-centered project that could get at the same thing.

I look at it (lecture) a little bit like a field trip again, that different students get different things...In lecturing you can have modelling, the modelling can tie together their learning. I also think that the lecturing sparks interest, it gives insights, human interactions, it supplies analogies.

I think back on the things I've learned, and I learned a lot from lecturing.

Goals and Methods

In furthering his goal of students being able to comprehend and use chemical concepts, Corrigan has definite goals and varied ways of treating each topic.

In the stoichiometry topic, Corrigan wanted students to understand and solve mass-mass problems.

> They will be able to apply the mole ratio...to go strictly from grams of reactant producing grams of product.

He has a clear idea of why the topic is important, linking it to the next topic, atomic structure.

> I don't see how you can really have an understanding of why Dalton thought there were atoms, or why we now think there are atoms, without stoichiometry.

In the atomic structure topic, Corrigan wanted students to understand the historical development of concepts of the atom and how science works. Whereas the content in the stoichiometry topic was organized around problem solving, in this topic it revolved around history, biography and the nature of science.

> What I want them to do is to see the flow and what science is doing...for them to understand how science grows, and that ideas are built on other ideas.

The development of this perspective occupied the majority of class time in this topic.

In the acids and bases topic, Corrigan wanted students to understand the reasons why certain substances behave as acids or bases, and become familiar with common acids and bases and the application of ideas about acids and bases to the real world.

> Corrigan to students: I think the most important part of the unit is to be able to name acids, bases and salts, to determine what happens when an acid reacts with a base, and to understand about acid rain.

Though he introduced the three main acid-base theories and had students use them, this topic had a decided practical approach and included discussions on health, acid rain, food and agriculture. This practical approach contrasted with the theoretical and historical approach in the atomic structure topic and the problem-centered one in the stoichiometry topic.

Corrigan's response: I agree, you know, I think that I see them (the goals) as being different also. Stoichiometry being solving problems, the study of the atom does give us a chance to see how science works. I mean that's just the way I, I don't know, I probably couldn't explain it more but I really, that's how I see them...And the acids and bases, seems like those are topics they read about - acid rain - and fit in more in their everyday world. I mean, there's so many acids and bases, our foods and household products...It just seemed they naturally fit into those kind of niches.

Corrigan's teaching style varied from topic to topic. In stoichiometry, problem-solving practice occupied more time than lecturing and questioning. In atomic structure, lecturing - frequently without questions - dominated as Corrigan related the development of successive theories of the atom. The acids and bases topic was more eclectic, as Corrigan integrated lecturing, questioning, demonstrations and seatwork.

Corrigan's responses: The content goals influence the teaching style because they're, in stoichiometry they're clear-cut objectives, being able to solve stoichiometric problems. And the way to do it is...you model it and then have them doing a guided practice...The atom topic is more historical, knowledge they didn't have that they had to get somehow, and so I saw that more as better suited to a narrative.

I'm very conscious of what I want the outcomes to be, what the goals are, what I want them to know, the objectives. And then it's a matter of thinking of what's a good way to get them to that.

Corrigan spoke repeatedly of a more general goal of students seeing how substances interact in the real world as a way of creating "informed consumers and voters and citizens."

> People have to have an understanding of how substances are interacting. Why is the ozone being depleted? Why would a fat soluble pesticide present problems? I think understanding very basic principles of chemistry helps a person make rational decisions.

This goal was explicitly addressed only in the acids and bases topic. There were no discussions of applications or how chemistry could be used in making decisions in the stoichiometry and atomic structure topics.

Corrigan's responses: The kid's got to fit into society and be productive and have a healthy life, and if he can't balance an equation, what's the big problem?..So my objective for that particular kid would be to leave the school being able to make rational decisions, et cetera. My objective as a chemistry teacher would be to balance equations and solve stoichiometric problems and certain, fifteen or twenty hard core chemistry things. So how would you separate the two?...How am I ever going to know if this kid can make a rational decision when they graduate from high school. But I can measure whether they're balancing an equation.

I suppose it (acids/bases topic) just seemed more amenable to it...But some day maybe I'll think of some way to do it with the others too, because it is important.

The Nature of Science

An image of science is presented in every science classroom, explicitly and implicitly conveyed by teacher and student activities. As with Corrigan's teaching methods and goals, we feel that this image varied with the topic. However, several threads regarding the nature of science were common to all topics.

Corrigan presented science as unified, with concepts that are connected to each other. For example, in showing students how to work mass-mass problems in the stoichiometry topic, he explained how moles, mass, atoms, Avogadro's number, balanced equations, and mole ratios can together explain and predict reaction results. In addition to relating such abstract concepts to each other, Corrigan frequently related such concepts to what students intuitively understand or to familiar applications. Science should make sense because its principles are connected to each other and to what students already know.

Corrigan's response: I think it was Cat's Cradle, he (Vonnegut) had a poem in it. And I thought that this is science: "Tiger got to hunt, bird got to fly, man got to sit and wonder why, why, why. Tiger got to rest, bird got to land, man got to tell himself he understand." And that's what I think science is. We wonder why and we explain it and our explanations now are different than they were in the 1800's, and that's how I see science. It's a natural thing, we want to know why, and we explain it. And I think I've tried to point out to students that science is such a natural thing. We do it since we're one day old, we're trying to figure out our world.

Though careful to explain ideas in language students can understand, Corrigan nevertheless gives the content a formal structure, using precise language and technical terms. For example, he described stoichiometry as the last topic on the mole and displayed a brief explanation of it on the overhead:

> Corrigan to students: That's exactly what we're looking at today, it's called stoichiometry. Stoichiometry. And the term is probably more difficult than anything.

Corrigan's response: Yeah, I really believe strongly in this. I noticed this last student teacher I had was not precise and I really had to work with her on that because you can't misuse these words or be imprecise...because it's amazing what they'll pick up.

Corrigan expects his students to get more out of lab than just completing the experiment, but we're not sure how much of this expectation is being met. Nevertheless, with labs every other day, students spend a lot of time in hands-on work. The labs are not simply illustrations of lecture material. Indeed, in the acids and bases topic, students were introduced to normality and titration calculations in the laboratory. Labs are sometimes referred to on classroom days, but are not discussed in any detail. They usually - but not always - correlate with the current classroom topic, and can stand on their own. One has the impression of two trains running side-by-side on parallel tracks.

Corrigan's response: They (labs) used to be directly integrated in the classroom but I separated them so that the labs do stand on their own (for ease in team-teaching).

The textbook has a limited role in providing students with an image of science. Corrigan, rather than the textbook, is the content authority, and neither he nor the students refer to the text in class. It is simply another resource. "I actually wonder if I could do the course without the text."

Corrigan's response: And we're working to try to change that some. (The outline) is always cross-referenced to the text...And some things on the outline are not lectured on, they're strictly in the text...But the studies have shown, you know, I think you only retain about 10% of what you read, it's very low.

We feel that the three topics did show some difference in their treatment of the nature of science. In stoichiometry, the classroom and lab activities presented a picture of science as a highly organized activity with specific procedures. Students focused on understanding concepts and using them to work problems. There was no explicit discussion of the nature of science. Though there were also concepts to understand and problems to work in the acids and bases topic, the emphasis was on applications - science as useful knowledge. Again, there was no discussion of the nature of science.

The atomic structure topic was radically different from the other two topics regarding the presentation of an image of science. The topic was organized around the historical development of concepts of the atom from Democritus to quantum theory and the nature of scientific knowledge. Corrigan presented scientists as real people, frequently mentioning some interesting aspect of their lives, "So you know he was a real person." He explicitly presented scientific knowledge as uncertain and ever-changing:

> Corrigan: You accept atoms at face value, you read about atoms...It's common knowledge there are atoms...You're not basing your thinking about atoms on facts, but on the belief that everyone thinks there are atoms. But is knowledge certain? Or is it uncertain?
>
> Student: Uncertain.
>
> Corrigan: Why is it uncertain?
>
> Student: It's people's thoughts.
>
> Corrigan: It's people's thoughts. Even if it's proven, could there be aspects of it that are uncertain? Yeah. So I think that knowledge is uncertain...knowledge is constantly changing.

Corrigan emphasized the idea of belief, as opposed to certainty. In the following discourse, Corrigan is talking about a scientist using a tunnelling electron microscope:

> Corrigan: All of a sudden he realized what he was looking at on the screen were the images of atoms, and tears came to his eyes.
>
> Student: How does he know those were images of atoms if no one had seen them before?
>
> Corrigan: OK, how did he know those were images of atoms - only from the work that had led up to it and from the things he had been doing...yeah, at some point you do have to take a leap of faith.

His idea of belief is not simple, and he was not afraid to point out incorrect ideas. "Established people are established because of old ideas and they tend to want to keep those old ideas," he told students. A few days into this topic, he had students draw pictures of three successive models of the atom and discuss with each other what was wrong with each one. Nevertheless, he believes we do know certain things:

> Student: Could the atom be wrong?
>
> Corrigan: We don't know everything about the atom, but we do know quite a few things about the atom, and the atom isn't wrong.
>
> Student: Is it definite that it's there?
>
> Corrigan: It's definite that it's there.
>
> Student: I just wanted to make sure. (laughs)

At times, science can be complex and difficult to understand. In introducing the quantum model of the atom, he said:

> Corrigan to students: There's no picture we can draw on a piece of paper. It's a mathematical description.

> Corrigan to students: This is kind of an unfortunate name - orbital - because the electron does not orbit the nucleus...the term orbital refers to where the electron can exist.

Later in that lesson he said:

> Corrigan to students: Einstein never accepted this quantum mechanical model. Einstein said nature is simple, nature is pretty, and this is not a simple picture, not a pretty picture.

Corrigan's presentation of science in this topic is one of a complex process carried out by real people producing imperfect, sometimes baffling, but useful results. Science does not produce certainty, but nevertheless provides a progressively more accurate picture of nature.

Corrigan's response: I think that students especially at that age...they think it's the gospel, it's as the teacher said it or it's in the book....So that's what I'm trying to get across, right, that it's not all black and white, certainly not, and it's not certain. There are certain reasons why we think what we think - but. You know, once in a while a student will say, well, what will be the picture of the atom in a hundred years? That is interesting - what will it be?

Conceptions of Teaching Science

We analyzed Corrigan's conceptions of teaching science interview task using the procedure described in Hewson, Kerby and Cook (1992), and identified four themes as representative of Corrigan's conceptions of teaching science. We compared each of these themes to our description of Corrigan's knowledge-in-action in order to see the degree of correspondence, and asked Corrigan to reflect on the themes and our comparison. The themes appear in bold-face type and are followed by our discussion and Corrigan's response.

Theme 1: Science learning requires higher levels of thinking (see Bloom's taxonomy). Corrigan tries to ask questions and present situations that will encourage this in students.

We feel this theme is reflected fairly well in Corrigan's knowledge-in-action. Corrigan expects his students to progress from a basic perception of an idea to synthesizing it with other concepts and using it to think and solve problems. He checks for understanding through questioning and monitoring students' work in guided practice. In his conceptions of teaching science interview, Corrigan emphasized that simple recall or blindly following an algorithm is not science learning. This theme of higher levels of thinking was also found in his post-topic interviews following each topic and was occasionally mentioned to students.

Corrigan's response: I'd say the assignments bring out the most (higher level thinking). And the questions I ask in class, too...I'd say there's something always at some time that's engendering higher level thinking...Probably some topics lend themselves more to higher level thinking also.

An aspect of this theme of higher levels of thinking from the interview was Corrigan's description of science as a process which includes observing, analyzing, forming opinions, hypothesizing, predicting and testing. Though students may engage in one or more of these activities at any given time, we feel that they do not experience the process as an integrated whole. They do not seem to be carrying out the kind of investigations implied by the description.

We think that Corrigan's teaching emphasized science as a body of knowledge and skills. This does not correspond to his understanding of the nature of science as a complex process which produces tentative knowledge. By his actions, he seems to be saying that there is a necessary difference between science and learning about science.

Corrigan's responses: They're still sort of getting the ground work. Or is it just because it's easier to have goals and as far as the teacher is concerned, to have goals when you're dealing with just content and to measure those goals? Whereas if you're dealing with an abstract problem, I think I feel less comfortable trying to evaluate what their product is and monitoring what they're doing as they're going along.

Even the open-ended lab are, to them they're solving a problem of mechanics, how to do it and what they're trying to find. But it's still not, it's really not science, it's not an unknown, it's not a mystery, it's not trying to figure out something that no one has the answer for.

It still is fragmented for them. I think they certainly see parts of it, they see where observation is a big part of it and they see that forming a hypothesis about what they've seen is a part of it.

Theme 2: Hands-on is crucial to science learning. Corrigan's ideal chemistry class would be 100% lab and other "field trip" experiences. He believes this would serve the goal of helping students appreciate the natural world so they can be responsible citizens.

With 50% of time in the lab, Corrigan acts on his belief that hands-on experience is crucial. But we wonder to what degree students are experiencing the "field trip" aspect. Though addressed in the acids/bases topic, an appreciation of the natural world seemed absent in the first two topics.

Corrigan's responses: One of the problems with chemistry is that even, you have labs but you still can't see the atoms interacting. You can't see that happen. You have to really take it, it's a leap of faith and you put zinc and hydrochloric acid and you test for the hydrogen gas but you can't see it...And so, you really couldn't have

100% labs because somehow you have, you have to make the analogies, you have to kind of get them thinking about what's probably happening at a molecular or atomic level.

Appreciating the natural world, yeah, I think that can certainly be incorporated more...When we talk about polarity and dissolve a polystyrene cup...that really brings up a nice discussion of McDonald's stopping using them and was that really a wise decision and why did McDonald's do it. But once again, it's really kind of a superficial discussion and they participate, but there's no - they aren't tied into it and there's no economic loss or gain for them, there's no reason for them to take a stand one way or the other.

Theme 3: The teacher's learning objectives should fit the situation: Focused for lecture, broad for lab or other "field trip" experience where students are allowed to play/interact with material on their own. This experience also furthers the goal of students' appreciating the world.

Corrigan's desire for students to have "field trip" experiences seems to run counter to the highly organized nature of his labs. It is also in tension with another of the themes:

Theme 4: Lecture is necessary to give students information to prepare them for college.

Corrigan thinks that both "field trip" experiences and lecturing/modeling are necessary. The "field trip" aspects of Corrigan's class, both classroom and lab, seem secondary to his desire to explain concepts and direct students' activities and thinking.

Corrigan's responses: Yeah, I would say that it is probably secondary, right...My desire is...to have them be successful. And so that probably comes first and I want it structured and organized and I know what the goals are, so that probably does drive the whole thing and then the others are all just like the - how does this affect society - are all kind of layers underneath.

I don't see as much tension between the two as maybe you do...If you have a group of students and you show them something, have them experience something, different students are going to take different things out of that experience... And you can't predict what they they're going to get out of it...So the lab is structured and they have a certain outcome and we talked about that too, and I think that there is some tension because I want them to solve the problems, to *be engineers, to think about how they're going to do it and to think of what the variables are and what their product is going to be and how they control that product. But on the other hand, I know I'm dealing with a hundred and some kids and they can't all do that, so I make something that they can all do. And for some of them it's a recipe and others, they are going to be manipulating and figuring some things out. So I think the opportunity is still there and that's how I see it, even though it's structured, and so I don't see quite the tension that maybe you see.*

I do see some ironies there and some things that are sort of counterproductive. But I also, I guess, am willing to have that sell out because I know I have to deal with 120 kids.

Discussion

We have described Corrigan's thinking and practice from three perspectives: our observations of - and interviews about - his teaching, his conceptions of teaching science interview, and his comments on our efforts to represent him. The interaction among the three adds another dimension to our understanding. We think it unlikely that all the major issues we discussed would have emerged from a single perspective. Corrigan's ideas on higher levels of understanding, on learning by doing, on labs, on lecturing, on appreciating the natural world, and on the field trip aspect of his class emerged from his topic interviews and his conceptions of teaching science interview. These ideas interacted with our descriptions and interpretations of his classroom and lab: his goal of teaching for understanding, his highly structured classroom, his sometimes extensive lecturing, the infrequent questions from students, the extensive lab time, the procedural nature of his labs, his topic goals, his variable teaching style, and the image of science in his class.

Corrigan responded freely during all the interviews, and did not seem defensive when discussing our interpretations of his teaching and thinking. "Actually I was pleased that I was pretty consistent," sums up his overall evaluation. He thought that the themes which emerged from his conceptions of teaching science interview did reflect his thinking and teaching. When asked, "Is this Corrigan?" he replied "Yeah, I would say yes."

We identified aspects of his practice which he recognized as being key issues. At times, Corrigan would say that he had not thought of a point we raised, but he would agree that it was important. This, of course, brings up the question of the power of suggestion, and we did feel uneasy. But Corrigan is a self-assured teacher, and we don't think he would agree with a statement if it didn't strike a chord in him. This aspect of the case study is consistent with the nature of knowledge-in-action: much of it is implicit and perhaps not directly knowable to the practitioner, and therefore difficult to discuss.

So what is the relationship between Corrigan's knowledge-in-action and his conceptions of teaching science? Are his conceptions at the core of his practice? We agree with Corrigan that his conceptions of teaching science themes are apparent in his teaching. But it is not a simplistic cause-and-effect relationship, even for the themes we identify as most consistent with practice. We feel that the relationship is filtered through the realities of his teaching situation, particularly his sense of his students and his discipline, and his own priorities. We see a directive teacher with definite content objectives which address some of his themes - preparing students for college and encouraging higher levels of understanding - but not others. The "field trip" aspect of his class and the experience of science as a process rather than a body of knowledge and skills are not directly addressed by his practice. While appreciating our point, Corrigan takes a pragmatic stance, and does not think there is much discrepancy in the relationship between practice and themes.

How much consistency is it realistic to expect? Here we have a self-assured teacher with a strong personality who discusses the fact that his practice is somewhat removed from his ideals as represented by his conceptions of teaching science themes. And from what he has said, it may not be possible - or even desirable - to change this relationship very much. His conceptions of teaching science themes are not entirely compatible with each other in practice, and he has definite priorities. Though his practice is not static, it is framed by these priorities. "I really feel that I'm always changing my teaching and I think my overall philosophy has pretty much stayed the same." His students cooperate and buy into his system, and appear satisfied and energetic. Corrigan is operating in the real world of his students, his school and his discipline, and he is satisfied with his efforts.

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