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Gail Richmond
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INTERNS' NARRATIVE AND PARADIGMATIC WAYS OF KNOWING SCIENCE

By

Mark Robert Olson

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ABSTRACT

INTERNS' NARRATIVE AND PARADIGMATIC WAYS OF KNOWING SCIENCE

By

Mark Robert Olson

This dissertation explores how pre-service secondary science teachers' ways of knowing science shape the opportunities for students to learn science. A new interpretive framework is developed and used to show that knowing science can be construed two-dimensionally in terms of narrative and paradigmatic components. Case studies of three pre-service secondary science teachers were constructed from classroom observation and interview data collected over the course of a year-long teaching internship. These cases illustrate how instructional representations in practice are shaped by teachers' ways of knowing science. Such instructional representations formed the basis for their students' opportunities to learn science. The dissertation argues that how pre-service teachers understand science as subject matter not only shaped the opportunities for students to learn in their classrooms, it also served to constrain the trajectories of their own learning over the course of the year. These findings suggest that how pre-service teachers understand science as subject matter has profound implications for their students' learning as well as their own learning as science teachers and is a significant factor in the persistence of traditional teaching practices.

This dissertation is dedicated to all my students and friends at Kelso High School.

Go Hilanders!

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Researchers investigating how people learn to teach find themselves on difficult terrain. Despite advances in our understandings of what it means to learn to teach, the effectiveness of teacher preparation remains a contentious issue. From the perspective of pre-service teachers, the problem is often teacher education itself. Though graduates of teacher education programs value the importance of field-based experiences such as student-teaching, they often view educational coursework as trivial, irrelevant and overly theoretical (Britzman, 1991; Lortie, 1975; Segall, 2002). After decades of reform, many pre-service teachers continue to believe that they learn how to teach by teaching, and find teacher preparation courses distracting and unhelpful.

Teacher educators see the situation quite differently. They feel their pre-service teachers come to the door of the university largely shaped by their experiences as students in classrooms. This apprenticeship of observation acts as a conservative force that causes pre-service teachers to discard everything that does not meet an immediate pragmatic need (Lortie, 1975). Teacher educators also point out that pre-service teachers learn the heart of teaching -- subject matter -- outside schools of education with "subject matter specialists." Unfortunately, even those with academic majors often lack accurate and deep content understanding (Brookhart & Freeman, 1992). Further, teacher educators note, in both these university science courses as well as the schools in which pre-service teachers do their fieldwork, experiences are often entrenched in traditional modes of instruction that diametrically oppose, rather than support, reform-based visions of science education (Duggan-Haas, 2001). As a result, the efforts of teacher educators and pre-service teachers often are at odds.

The empirical research on how candidates learn to teach is thin and often privileges the perspective of the teacher educator (e.g., Wilson, Floden, Ferrini-Mundy, 2001). Such privileging creates a hierarchy between teacher educators who produce theoretical knowledge and the pre-service teachers who are supposed to put that knowledge into practice (Cobb & Yackel, 1996). An unfortunate outcome is that the pre-service teacher is depicted as someone to be "convinced", "taught", "apprenticed" or "shown" and is someone who typically has "fragmented" or "insufficient" knowledge about subject matter. Their personal understandings and learning experiences are seen as barriers to developing more progressive notions of teaching (e.g., Adams & Krockover, 1997).

Numerous scholars have taken these critiques seriously, arguing for and researching particular strategies meant to address pre-service teachers' shortcomings. Those strategies are numerous and detailed. For example, programs should be longer (e.g., Holmes Group, 1988), offer early field experiences (e.g., Lortie, 1975), address subject matter (e.g., Ball, 1990; Shulman, 1987), place pre-service teachers with experienced mentors (e.g., Schon, 1987; Feiman-Nemser, 1986). The setting of this study, Midwestern State University (MSU), has taken the research on pre-service teachers' learning seriously. Though Chapter 2 details the program in full, suffice to say that the program has "fixed" many of the concerns the research literature has identified. The program is five years long, offers three years of field experiences in schools with mentors with which Midwestern has enjoyed long positive relationships. And it has a four-semester science-intensive methods sequence designed to address pre-service teachers' subject matter knowledge. In short, the program is a place in which we would expect these many interventions to have "worked". But problems remain. These problems, which I call "problems of practice," drive this study. I will briefly sketch the problem of practice that is the genesis of this dissertation study.

Jacob, an undergraduate senior when I first met him, was an exceptionally bright chemistry major and physics minor, who was hard working, had great rapport with his students, took teacher education seriously, and was thoughtful and reflective about his emerging practice. In short, I considered him to be an outstanding teacher candidate and someone who would likely have a long and successful teaching career. I was Jacob's instructor in the four-semester sequence of science-specific teacher education courses at Midwestern State University. I was also his university field supervisor, making bi-weekly visits to his classroom. Jacob and I had a strong positive relationship, and I felt that we were making strong progress in learning to teach in reform-minded ways.

Near the end of his yearlong internship in a suburban high school, I co-planned an inquiry lesson with Jacob about color perception. The lesson we designed allowed for Jacob's physics students to make systematic observations of various objects as viewed through one of a set of red, blue and green colored filters. The afternoon before the lesson, we spent three hours making our own observations and designing the scaffolding students would need to engage the relevant ideas. When I observed Jacob teach the next day, I was completely baffled. Though he went through "the motions" of an inquiry lesson, Jacob allowed students to simply observe various objects passively and make only casual observations. After the students had looked at a number of objects through several filters, Jacob went over what they should have observed as he introduced the rules of color addition and subtraction. This was certainly not an inquiry lesson! And it did little to capture the sense of discovery and amazement that we ourselves had experienced together with the same materials just the day before.

This experience seriously shook my sense of efficacy as a teacher educator. It reminded me of a chemistry professor who once told me that he felt he was a terrific teacher until he happened to give an exam. He explained that no matter what he did, he could not find a question about molarity that more than 60% of his students could answer correctly. Realizing that there must be something else going on (and presuming his instruction to be not entirely responsible) he began to seriously investigate students' learning of chemistry concepts. Similarly, I came to graduate school to become a teacher educator. I loved teaching high school mathematics and physics, and I endeavored to share my knowledge and enthusiasm for science teaching. However, as a novice teacher educator, I recognized that my understandings of, and ability to help shape, learning to teach science was emergent. I viewed my work with the cohort of interns to be generally successful and I felt some satisfaction in my assessment that I helped produce well-started beginning science teachers.

But Jacob was not the typical pre-service teacher. He was someone whom I felt was going to be a terrific teacher right off the bat. But my experiences around this lesson on color forced me to re-assess what I was doing as a teacher educator. Why did Jacob and I have such different views about what was to happen in that lesson? Though we appeared to have communicated about the means and aims of the lesson on the previous day, Jacob and I obviously had different understandings about what students might learn and how they might learn it. Where I saw this lesson as an opportunity for students to engage in the search for *patterns* in phenomena (which I take as a central part of learning science for understanding (Anderson, 2003)), Jacob saw this lesson as a means of confirming the *rules* of color addition/subtraction. Where I considered our afternoon of exploration to be full of discovery and amazement, Jacob considered it to be "background" work, done to preview and test out the activity. The more I thought about the episode, the more I realized that until I observed this lesson, Jacob and I had been "talking past" each other without realizing it.

With this awareness, I became suspicious that Jacob might not be an isolated case. Perhaps there were more students in my teacher education classes whose learning over the course of the program differed from what I thought. I began to question the ways in which "progress," as evidenced in classroom participation, course planning assignments, and reflective essays, might more accurately describe "progress" in my students' abilities to "do" teacher education. Complicating these suspicions was the fact that the pre-service teachers I taught generally seemed to honestly engage and value their teacher education experiences. I know that this was the case with Jacob. My initial hunch was that for some reason, interns and I were "talking past" each other. In other words, though we had developed what appeared to be a common language for discussing teaching practice, the actual meanings we attached to such language and analyses were subtly different.

The Research Question

Jacob's teaching that day is a situation that teacher educators who venture out into classrooms routinely encounter: an inexperienced teacher tried to teach in a reform-minded fashion and was unable to pull it off. Once again, it seems, the persistence of traditional practice prevailed in spite of the earnest and thoughtful efforts of teacher educators to the contrary. What might be the explanation for this Sisyphean event? What role, if any, did Jacob's subject matter knowledge play in the ways in which he chose to teach? Perhaps it was differences in our how we understood science that enabled us to "talk past" each other?

This dissertation takes this question as the basis for its investigation. Specifically, I ask the following research question: How do pre-service teachers understand science as subject matter and in what ways do their understandings impact their teaching practice?

I begin by describing two influential explanations of the persistence of traditional teaching practice: Lortie's (1975) "apprenticeship of observation" and Cohen's (1990) notion of "adventuresome teaching." Next, I examine Smith's (1996) argument about reformer's notions of adventuresome teaching and the available efficacy opportunities provided therein, as a way of understanding how pre-service teachers might think about teaching. I then examine an account of subject matter knowledge in teaching, Ma's (1999) investigation of "profound understanding of fundamental mathematics," to focus on the pervasive role of subject matter in instruction. Finally, I step back and broaden my focus to provide a more general overview of the literature on subject matter knowledge in teaching. Building on these relevant literatures, I conclude this chapter with an explication of a new framework -- one which I will make use of extensively in this dissertation -- of how pre-service teachers know science as subject matter and how it impacts their teaching practice.

Getting Into the Problem of Practice

The literature on the persistence of practice attempts to explain why teaching appears to be so resistant to change despite over a century of efforts on the part of educational reformers. This literature provided potential explanations for my problem of practice with Jacob. For each potential explanation, the format is the same. I briefly outline each way of thinking about the persistence of practice and then explain why that particular way of thinking left certain aspects of my experience with Jacob unexplained.

The first and most common explanation for the persistence of practice is Lortie's (1975) notion of the *apprenticeship of observation*. Lortie uses this term to denote the socialization effect for students in classrooms who have spent upwards of 13,000 hours of time sitting in classrooms while tacitly observing the work of the teacher. Because the work of teaching is largely cognitive and thus hidden from direct observation by students, it follows that student perception of that work is largely passive, imitative, and simplistic. The main effect of this apprenticeship is to imbue students with the notion that teaching is much simpler than it actually is. And instead of gaining insight to the professional knowledge of the teacher, students are left with largely affective and simplistic assessments of teaching. Such students of course, grow up to be future teachers, and are the students of teacher education (Lortie, 1975).

As an explanation for my puzzle however, this explanation was less than satisfying. First of all, Jacob wasn't observing teaching from the students' perspective any longer. While the apprenticeship of observation might well predict an initial expectation on the part of a beginning teacher education student that she already knows what she needs in order to teach, Jacob and his cohort of fellow interns had extensive experiences in classrooms early and throughout their teacher education program. Such experiences were quite effective in making the challenges of learning to teach apparent, and in fact, interns typically found teaching to be a challenging, rather than simplistic, endeavor. Further, as an intern nearing the end of a year-long internship experience, Jacob was well aware of the need for professional knowledge and he worked hard to develop his thinking about teaching. Secondly, the apprenticeship of observation failed to account for my sense that Jacob and I were talking past each other. And based on my experiences over two years, I did not feel that Jacob considered teacher education to have little to offer. What was clear, was that our sense-making of teacher education differed. And lastly, the apprenticeship of observation failed to help me understand what I might have done differently as a teacher educator.

I turn next to one of my favorite pieces of scholarship, David Cohen's *Teaching Practice: Plus Que Ca Change* (1989). Cohen describes how reformers' notions of "adventurous teaching" have been both rhetorically popular, and in practice, decidedly rare. First he discusses four broad categories that researchers have conceptualized as the ways in which reform-minded teaching has been stifled: school organization, conditions of teaching, flaws in reforms, and incentives for change. He asserts that we tend to believe the persistence of practice is the result of barriers or constraints, and with the removal of those barriers and constraints, adventurous teaching would result. That this is the implicit argument of reformers, he notes, is a testament to the power of Dewey's (1902) vision for the possibility of educative experiences in schools. Instead Cohen argues that it is fruitful to ask the question: what makes adventurous teaching hard to do? He nominates two fundamental reasons. First, adventurous teaching runs counter to powerful and historically entrenched views of knowledge and learning. And second, that teaching is a practice of human improvement that is inherently difficult to do.

While I found the first part of Cohen's argument to be compelling from a sociological perspective, it left me with questions about how to interpret my experience with Jacob. In our small case, the potential disruption of canons of teaching and learning did not seem to be so strong. The lesson that I had envisioned, and that I had thought we "co-planned," did not require students to completely forgo traditional teacher-student relationships. The activity, as Jacob structured it and as it played out, was not completely foreign to the kind of activity that I had envisioned. What was different was the way the activity was situated epistemologically within the lesson. Where I had seen student's amassing evidence for patterns in their experience, Jacob was viewing the activity as a chance for students' to "get their hands dirty" so to speak.

Despite not directly addressing the kind of problem I had with Jacob, the second part of Cohen's work provided the analytic turn that I needed to begin thinking about my work as a teacher educator in a different way. Instead of focusing on what prevented pre-service teachers from teaching in more reform-minded or adventurous ways, I might profitably look to investigate what it is that is difficult about adventurous teaching itself. This line of thinking resonated strongly with my own experiences with teaching and learning. As a high school teacher, I had the opportunity to work with both academically struggling pre-algebra students who were repeating the course (some more than once) as well as the academically elite physics and calculus students. I found each to be tremendously challenging but for different reasons. While my colleagues were correct to assume the pre-algebra class was a challenge to teach, I was (secretly) frustrated by their comments that it must be great to teach the calculus/physics classes because those students could "teach themselves." Certainly, it was great to work with academically talented students, but there was still a tremendous challenge to find ways to engage them with ideas in meaningful ways. In many respects, adventurous teaching goes directly against the grain of the "performance for grade exchange" (Doyle, 1983) that so many academically "elite" students master in schools. Having talented students might well facilitate teaching adventurously, but it remained a sophisticated challenge nonetheless.

Another perspective that informed how I thought about my problem of practice with Jacob is represented by Smith's (1996) analysis of the tensions between reform-based pedagogies and more traditional teaching methods. The role of the teacher is at the center traditional didactic teaching. Good teaching consists of "telling" clear and complete explanations of the subject matter. Teacher efficacy can thus be founded upon the sense that a teacher is the cause of learning for the student. However, in reform-based pedagogies the teacher is de-centered from activity in the classroom. Teachers do not so much *cause* learning as they *facilitate* the conditions under which students can learn. Additionally, under reform-minded practices teachers and texts are no longer primary sources of curricular authority, which may work to undermine traditional power dynamics between teacher and student.

Perhaps Jacob's instructional choices were influenced by the need to feel traditionally efficacious in his teaching? Perhaps teacher education had failed to provide sufficient support for what might serve as "new moorings" for reform-based teaching efficacy. Such moorings might include teaching work that focused on: activity design, prediction of student responses, effectively directing classroom discourse, and "telling" when appropriate (Smith, 1996). I do not know the answer to these questions as they pertained to Jacob. But by enlarging the question of what it takes to teach in reform-minded ways to include how teachers might feel efficacious. I was able to refine my investigation of how learning to teach science made sense to pre-service teachers.

My initial problem of practice, that Jacob and I were talking past each other without realizing it, resulted in my search for perspectives that might help me think about my work as a teacher educator in new ways. I have here discussed how Cohen and Smith's arguments helped shift my thinking to that of the perspective of the intern, what might be hard about teaching in these ways, and what sources of efficacy teaching provides.

A third object of my attention was implicit in both Cohen's and Smith's accounts; what role does subject matter knowledge play in adventurous teaching? Here I was deeply impressed with the work of Liping Ma (1999) and her examination of the "profound understanding of fundamental mathematics" of elementary mathematics teachers in the United States and China.

Much of the science content that pre-service teachers teach in secondary schools is neither substantively nor directly addressed in university science courses. This contributes to the impression that the subject matter of high school courses is basic as compared to the subject matter that constitutes an academic major. What Ma compellingly demonstrates in elementary mathematics however, is that basic mathematics often engages fundamental ideas from the discipline. Applying this notion to the subject matter of science helped me focus attention on the ways in which even "simple" topics in science might also engage questions about what fundamental knowledge in science is.

Ma's work however, did more than simply point my attention to looking at the role of subject matter. It also helped solidify, in conjunction with my thinking about efficacy issues, my emergent recognition that much of the research on the relationship between subject matter knowledge and teachers has two characteristics in common. First, there is the assertion that a teachers' knowledge of subject matter is arrayed along a continuum. On one end knowledge is considered deep, connected and conceptual. On the other, knowledge is considered shallow, disconnected and procedural. The second characteristic is that most studies identify (and classify) teachers' knowledge, but do not attempt to explain how such knowledge makes sense to the teacher as subject matter. It might well be assumed that a teacher who has "deep, connected and conceptual knowledge" has deep insights into the structure of the discipline, and views knowledge in a sophisticated, more accurate way. But what about teachers whose knowledge is classified as shallow, disconnected and procedural knowledge? What does it mean to think about subject mater in shallow, disconnected and largely procedural ways? How does that make sense? Ma does not investigate this question.

But this is an important question. Ma (1999) notes explicitly that the American teachers in her study were "above average" (p. xxi). Nearly all felt they "could handle" basic math, slightly fewer felt they could learn advanced math, and that well over half of the sample considered mathematics to be their "strength" area of knowledge. The more experienced teachers in the study felt they were "'more dedicated and more confident' mathematically" (p. xxii) than their peers. And yet, brilliantly, Ma shows the profound limitations in these teachers' thinking. Her careful analysis of teacher subject matter knowledge influenced my thinking about learning to teach science in two important ways. The first way confirmed that subject matter knowledge is foundational for providing the opportunities to learn for the pupils in a teachers' classroom. Second, Ma's work helped point me to the question at the heart of this dissertation study; how do pre-service teachers make sense of their subject matter knowledge?

Taken together, these perspectives helped found a particular stance toward investigating the ways in which learning to teach science made sense to pre-service teachers. First, I began thinking about what is challenging about adventurous teaching as experienced by pre-service teachers. Second, I became concerned with the ways in which learning to teach and teaching science is efficacious. And third, I began thinking carefully about the ways in which fundamental ideas of science are used and made sense of by intern science teachers.

In the next section I broaden my consideration of the literature and consider a few of the ways other researchers have engaged the study's question. I then explain the study's interpretive framework.

Previous Research

As noted earlier, a recent review of the research base for teacher education finds uneven evidence supporting the impact of teacher education programs (Wilson, Floden & Ferrini-Mundy, 2001). Further, the graduates of teacher education programs largely do not value their professional preparation -- with the exception of their student teaching experiences. Teachers continue to believe that they learn to teach by teaching and that coursework in teacher education does not contribute significantly to their development as teachers (Lortie, 1975). None of this is news to teacher educators.

Efforts to understand the subject matter knowledge of pre-service science teachers often employ a straightforward strategy. Based on the premise that a teacher must know subject matter in order to teach it, researchers attempt to measure the amount of subject matter knowledge teachers have (e.g. Lederman, 1994). This strategy is used to assess many dimensions of knowledge required to teach science such as pedagogical content knowledge (Gess-Newsome & Lederman, 1999), the nature of science (Abd-El-Khalick, 2000, Lederman, 1992), and the history and philosophy of science (Gallagher, 1991).

The explanations for this state of affairs are also well known as the craft knowledge of teacher educators. Pre-service teachers value practice and are unable to connect it to theory. Pre-service teachers lack the "head-space" to consider more than classroom management & survival-related issues. And finally, pre-service teachers teach largely as they themselves were taught.

As a teacher educator, I found these explanations little help for my work with pre-service teachers. I realized the reason they weren't helpful was that they were really re-statements of the problem. They failed to explain why pre-service teachers value practice over theory -- other than to assert that they do. They failed to explain why head-space is available for some kinds of knowledge but not others -- other than to assert that it appears to be so. And they fail to explain why the apprenticeship of observation is so strong -- other than to assert it's why traditional practice endures despite earnest efforts to the contrary.

The literature in science education, as Mary Kennedy (1998) points out, fails to inform our understanding of the crucial link between knowledge and practice:

> What is missing in all of [these studies] is clear evidence of how any of these characteristics of knowledge, understanding, or attitudes contribute to actual teaching practices. There seems to be two nearly independent bodies of work: One reasons backward from a stipulation of an ideal classroom to a portrait of the cognitive skills teachers need to engage in that type of teaching. This body of work is important, for in the absence of many (or perhaps any) classrooms that match the ideal, some method is needed to envision a route from typical practice to ideal practice. The second evaluates what either college students or practicing teachers currently know or believe or understand about mathematics or science. This body of work is also important, for we need concrete evidence of what students, prospective teachers, and practicing teachers do in fact understand about the subjects they are learning or are teaching. However, there is no strong link between these two bodies of work. (p. 261)

There have been efforts to inform the link between knowledge, understanding and attitudes and that of actual teaching practice. Pam Grossman (1990) presented compelling contrasts between the teaching practice of secondary English teachers who had university-based teacher education and the teaching practices of teachers who did not. Her study was particularly important because it demonstrated the shortcomings of strong content knowledge alone as the basis for creating the kinds of pedagogical representations that adventurous teaching requires (Grossman, 1990).

Carlsen (1991, 1992, 1993) showed that teachers tended to use different discourse patterns during instruction of familiar and unfamiliar subject matter. When teachers lectured on unfamiliar topics they tended to talk more, longer and allowed for fewer student questions. Questions asked by teachers tended to be at a low cognitive level as well. Carlsen also showed that in high knowledge teaching (as measured by teacher familiarity with topic) the teacher was more likely to use whole-group strategies, as well as talk more during laboratory exercises. Carlsen attributes his findings to the needs of the teacher to control discourse in the classroom. Because he uses "familiarity" as his subject matter determinant, and doesn't closely examine the way in which subject matter was engaged, these studies provide limited insight into a more nuanced view of how subject matter knowledge impacts teaching. In a later study, Carlsen (1997) found significant differences between the argument structure of the questions asked by the teacher during familiar and unfamiliar instruction. Teachers who were more familiar with the subject matter allowed for more student questions for example. Though Carlsen's work is helpful in many ways, the work leaves the notion of familiarity with subject matter relatively unspecified. The work relies on teachers' self-appraisal based on experience teaching the topic, thus, the substantive quality of subject matter familiarity is unclear.

Numerous case studies of teachers have been written by researchers (Ball, 1990; Britzman, 1991; Cohen, 1990; Elbaz, 1983; Wilson, 1990). Teachers have also written poignantly about their own teaching and their dilemma's of practice (e.g., Lampert, 1985; McDonald, 1992). Both sets of case studies demonstrate the tremendous complexity and multifaceted work that characterizes teaching. Such work informs the ways in which scholars understand how teachers learn to teach and what they learn from teaching.

In the particular case of prospective science teacher learning, there have been many efforts to understand either one or another side of Kennedy's link between teachers' knowledge and teaching practice. Demographic surveys, studies of women's ways of knowing and research on the content of prospective teachers' beliefs have been used to inform understandings of who becomes teachers and what dispositions, attitudes and understandings they bring with them (e.g., Feiman-Nemser & Remillard, 1995). Prospective science teacher understandings of the methods, purposes and nature of scientific thinking have received considerable attention in recent years, as presumably they are critical for attaining reform-based visions of science education (Brickhouse, 1990; Gallagher, 1991; Lederman, 1992).

Additional research endeavors to illuminate the practical knowledge of pre-service teachers through examination of their images for teaching and learning (Calderhead & Robson, 1991; Clandinin, 1985; Johnston, 1992). Practical knowledge is considered broadly as knowledge of action. Thus, it largely consists of tacit, personal, and contextual understandings that are not readily communicated. However, by examining these images of teaching one can begin to gain insights into the beliefs and values held by pre-service teachers, an understanding of which can serve to improve the professional preparation of teachers (Feiman-Nemser & Floden, 1986; Pajares, 1992). Similar efforts to access the beliefs and values of prospective teachers focuses on their uses of metaphor and the subsequent changes in metaphors over the course of experiences with teaching and learning (Bullough, 1992; Munby, 1990). The richness of the characterizations presented here informs my own work as a teacher educator in providing images for interaction with individual pre-service teachers. But because these studies assume that the practical knowledge of teaching is personal, it is difficult to apply to other situations -- other than, as I mentioned, as a method of investigating and interacting with teachers around issues of practice.

Unfortunately, much of the research that has been done on prospective teachers tends to reinforce the now classic characterization of learning to teach as a developmental stage theory (Fuller, 1969). First, the beginning teacher is consumed by survival concerns; next, attention can be diverted toward teacherly performance; and finally, attention can be directed toward students. I consider this characterization to be unhelpful for two reasons. It doesn't deeply match with my own experiences working with prospective teachers. In my experience, prospective teachers are concerned with many different things -- survival is one of them. But they are also concerned with making science interesting, being respected by students and their mentor, and getting enough sleep. Further, pre-service teachers do not always make linear progress through a set of stages, but instead confront challenges as they arise. But most importantly, simple stage characterizations do not provide an adequate basis for building a knowledge base and theory of learning to teach because they over simplify the complexity in learning to teach. A richer portrait of prospective teacher learning is needed.

The well-known explanations I have described in this section are insufficient for my work as a teacher educator. The patterns that they identify are indeed observable. I suspect that every teacher educator at some level "knows" these patterns well. But as explanations -- they are unsatisfying to me because 1) they don't help me understand *how* these patterns occur (i.e. what the mechanisms for these patterns are), and 2) they do little to inform how, as a teacher educator, I might do things differently in my work with pre-service science teachers.

As is the case with many seemingly chronic dilemmas, a new perspective is necessary in order for us to overcome the "talking past" that seems to happen between teacher educators and the students of teacher education. This study addresses this dilemma by deliberately attempting to understand teacher education from the perspective of the pre-service teacher. Specifically, it looks at the ways in which pre-service teachers make sense of their student teaching experiences as they plan, teach, and develop their understandings of what it means to be a secondary science teacher. Central to this study are the pre-service science teachers' understanding and sense-making of science subject matter. This study is different from many before it. It does not conclude that the problems teacher educators face are pre-service teachers who simply have poor understandings of science content and how to teach it. Instead, it places pre-service teachers' understandings of learning to teach within a framework that helps us understand the mechanisms that connect science subject matter knowledge to science teaching. The study offers insights into why teacher educators and pre-service teachers so often seem to talk past one another. It pushes us to understand how pre-service science teachers know subject matter.

The Interpretive Framework

I propose an interpretive framework for how pre-service teachers make sense of subject matter. This framework designates two primary constructs of intern sense-making, which I call paradigmatic and narrative ways of knowing. These constructs, or "ways of construing knowledge," together with disciplinary subject matter knowledge, serve as the central mechanisms for examining the ways in which pre-service teachers understand subject matter and how this impacts their students' opportunities to learn science. In this chapter I briefly explain the framework and its constitutive constructs, but in Chapters 3, 4, and 5, I fully illustrate the framework's use in three case studies. I use this framework as a way of illuminating *how* pre-service teachers make sense of subject matter knowledge. Though this is obviously related to *how much* pre-service teachers know about the subject matter, the shift from "amounts of" knowledge to how pre-service teachers make sense of the knowledge they have, is generative. As I will show, this alternative view of teachers' subject matter knowledge has important implications for the opportunities to learn science for the pupils in these teachers' classrooms. But first, the framework.

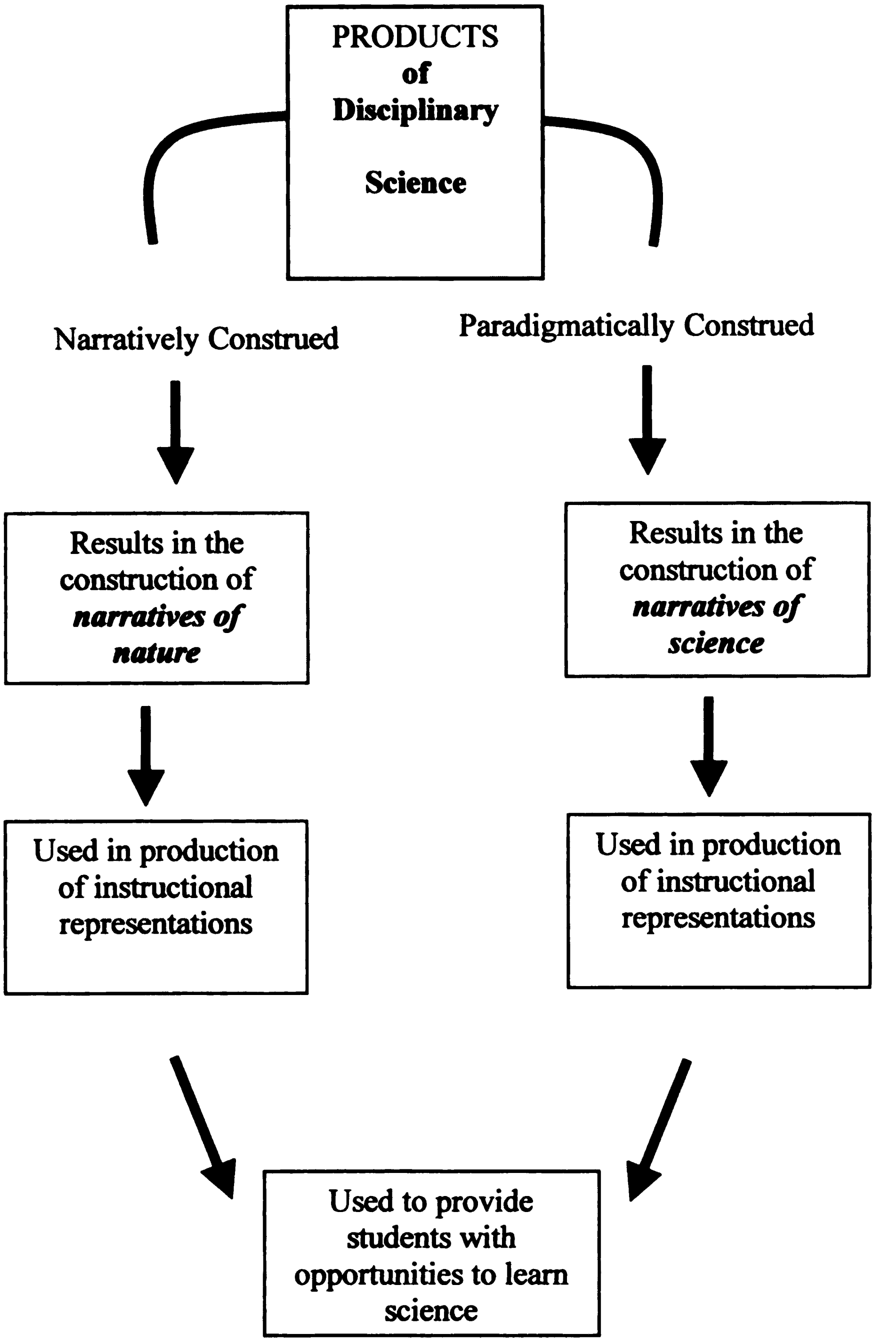

Figure 1.1. Interpretive framework of science as subject matter.

The central structure in the framework is my formulation of the subject matter of science that draws upon Schwab's (1978) notion of the substantive and syntactic structures in a discipline. The substantive resources, or scientific practices, include established facts, concepts and ideas about the natural world, as well as methods of inquiry and theoretical frameworks for defining and generating questions. Syntactical resources, or scientific norms, include the types of arguments, investigative protocols, procedures for establishing and verifying claims that scientists use in their work. The substantive structures are those "conceptual devices that are used for defining, bounding, and analyzing the subject matters they investigate" (p. 246). Such conceptual devices or *products* of the discipline include the concepts, theories and relationships used in a particular science discipline. They are products of the discipline in that conceptual devices are not simply *found* in nature but instead are conceptual tools produced and used by communities of people to interpret physical and natural phenomena (Driver, Squires, Rushworth, & Wood, 1994). An example of a product of the discipline is the Bohr model of the atom. People using the Bohr model consider the atom to consist of electrons circling a central nucleus in precisely defined orbits. This model is used to make accurate predictions for a set of observations regarding photon absorption/emission from atoms and is historically interesting for its role as an early atomic model.

The other two primary constructs of the framework: the paradigmatic and narrative construals of experience, are based on Jerome Bruner's assertion that these ways of knowing are complementary, different and fundamental (Bruner, 1985, 1986, 1996). This framework considers that the ways in which pre-service teachers' construals of subject matter can be either paradigmatic or narrative.

Paradigmatic ways of knowing have generally been considered a form of logico-scientific thinking. Such knowing aims to establish verifiable, empirical evidence as the basis for general causes. It is driven by testable hypotheses. Paradigmatic thinking is concerned with the construction of conceptual categories and the ways in which these categories are used and maintained to form a system. These conceptual systems are expected to apply equally across all applicable examples.

A paradigmatic construal of the Bohr model focuses attention on how this model can be used to *interpret* phenomena. Going back to our earlier example, the Bohr model precisely accounted for the energies of photons emitted and absorbed from the hydrogen atom. However, this model failed to explain the behavior of larger atoms, which helped motivate the search for a more successful model. There is no real sense that the atom is as simple as the model specified -- a nucleus with electrons in precise circular orbit. However, if one assumed these features, predictions could be inferred and tested in experiment. The Bohr model of the atom was a conceptual tool used to *interpret* data within a paradigmatic construal of physics.

Narrative ways of knowing consider the objects of science as characters in a story that have "human or human-like intention and action and the vicissitudes and consequences that mark their course" (Bruner, 1985, p. 98). Narrative ways of knowing aim to produce good stories that are not explicitly constructed around underlying principles or categories. Instead, narratives must ultimately be believable. Though there may be somewhat "universal" storylines, these universals act more like templates -- as in genre -- than the principled and generative statements of paradigmatic understandings.

A narrative construal of the Bohr model focuses attention on how this model *described* what happens to a hydrogen atom during photon absorption/emission. A narrative construal would be to consider the model as not a predictive tool, but as a (more or less) accurate description of what an atom looks like. In such a construal, electrons are actually orbiting the nucleus, and when photons are absorbed or emitted, then electrons change orbits. If you consider the Bohr atom as a simple representation of the atom, then it is easy to believe that it *describes* what happens in an atom with adequate level of accuracy.

Believability is slippery characteristic. In fact, Schwab criticized narrative construals of science precisely because they failed to include reference to disciplinary structure and were therefore too easily believed. He considered such construals as instances where "[curriculum developers] ... simplified the fruits of disciplines to the point where it appeared self-evident that they could be correctly understood without reference to the structure which produced them (p. 242)." Though Schwab's critique points to the ways in which representations of science can obscure their own production as "fruits" of the discipline, this study does not engage questions of curriculum design. And indeed, Schwab was centrally concerned with the design and development of science curriculum[1] and worked to create representations of paradigmatic construals of science. I, however, am not engaged with such curriculum design and instead concerned here with developing a model that helps me understand how pre-service teachers make sense of the subject matter of science.

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[1] Rudolph (2002, 2003) argues that a primary aim for Schwab was to establish the scientific community as the source of "epistemic authority" (Rudolph, 2002, p. 68) for scientific knowledge. This effort was subsumed under the larger goal of educating a public that could support (and continue to fund) the scientific enterprise -- which Schwab deemed a central purpose of science education.

Therefore, I include the narrative way of knowing in the interpretive framework because it represents an important way of making sense of science. As the primary purpose of this study is to understand how pre-service teachers make sense of disciplinary science as subject matter, it is important to include both paradigmatic and narrative ways of knowing to explain the range of science pre-service teachers' sense-making.

As noted, paradigmatic and narrative construals of disciplinary subject matter knowledge differ fundamentally. These differences have been characterized by Myers (1990) who makes similar distinctions between *narratives of science* and *narratives of nature*. Myers examines the ways in which accounts of popular science, such as articles written for *Scientific American*, differ from articles written for professional scientific journals. He analyzes the ways in which three scientists wrote articles about their research for each of the two different contexts. Despite writing articles regarding the same research content, each author's articles fundamentally differ in their construals of the subject matter, depending on the journal of publication.

Myers (1990) explains these differences:

> The professional articles create what I call a *narrative of science*; they follow the argument of the scientist, arrange time into a parallel series of simultaneous events all supporting their claim, and emphasize in their syntax and vocabulary the conceptual structure of the discipline. The popularizing articles, on the other hand, present a sequential *narrative of nature* in which the plant or animal, and not the scientific activity, is the subject, the narrative is chronological, and the

syntax and vocabulary emphasize the externality of nature to scientific practices (all emphases in original) (p. 142).

The differences between the popular and professional articles were designed to meet the perceived needs of their different audiences. These differences, however, were not simply differences in rigor, or in complexity. The popular accounts were not "watered down" versions of the professional journal articles. Though based on the same studies, it was the author's use of language that was different. If one assumes that differences in language produce differences in meaning (Gee, 1999), then as Myers (1990) notes, "even when two articles seem to be about the same research, it may turn out that one is about garter snakes and the other about the isolation of a pheromone" (p. 143). If it is true that the subject of one article is snakes (an animal in nature) and the subject of the other article is the isolation of a pheromone (an activity of science), despite being representations of the same study; it follows that what can be learned from each article is also different. Narratives of nature and narratives of science produce complementary yet different construals of experience.

To summarize, paradigmatic construals of science tend to:

- Follow an argument about the relationship between conceptual devices (often models) and scientific data (events).
- View particular events in relationship to general principles.
- Arrange events according to their relationship to an argument about the general principles rather than in chronological order.
- Use syntax and vocabulary in ways that emphasize the conceptual structure of the discipline.

Narrative construals of science tend to:

- Place the animal, plant or object of study, and not the scientific activity, as the subject or main character of a story.
- View particular events with respect to other particular events.
- Arrange time chronologically.
- Use syntax and vocabulary in ways that emphasize the externality of nature to scientific practices.

Myers provides an important analysis of the epistemological consequences in the writing of science for popular and professional audiences. He builds on the work of Charles Bazerman (1988) who shows that paradigmatic ways of knowing were actually forged in the historical development and evolution of the written scientific article. Even given the historical and substantive contributions of Meyer (1990) and Bazerman (1988), the reader might reasonably question how an analyses of written articles can serve as the basis for examining the ways of knowing of secondary science pre-service teachers.

In response, I assert that the production of representations of subject matter by a teacher in a school classroom is suitably analogous to the production of representations for a science articles. In both cases, the production is done with an audience in mind and for a specific purpose. The audiences of popular science articles are similar to students in that they are not likely expert in the subject matter. Popular science articles are designed to be compelling -- a standard toward which pre-service teachers also aim. In both cases the purpose is to convey scientific information. By looking carefully pre-service teachers' instructional representations, we can better understand the ways in which they construe science in their classrooms.

Overview of the Dissertation

Having provided the reader with the literature that informs this study as well as the interpretive framework through which the data are displayed, I now turn to a brief overview of the remainder of the dissertation. Chapter 2 explains the methods and context of the research study. Chapters 3 thru 5 use the interpretive framework to examine the practices of three interns. The cases explore the ways in which narrative and paradigmatic constructs can illuminate how interns' make sense of teaching science. In the 6th chapter, I look across the three cases to investigate the relationship between teachers' ways of knowing and students' opportunities to learn science. And finally, in the last chapter, I conclude with a discussion of the implications of this study for science teacher educators and science education more broadly.

Chapter 2

Method

Study Design

This interpretive study examines pre-service science teachers' understanding of science and the ways in which those understandings provided opportunities for students to learn science. Five pre-service science teachers (whom I call "interns") were observed and interviewed multiple times over the course of the 2002-2003 academic year as they completed the fifth year of a subject matter-intensive, university teacher education program. Data was collected through audiotaped structured and semi-structured interviews, field notes, journals, written lesson and unit plans, other teacher education course assignments, and videotaped classroom observations. In addition, there were numerous documents collected from individual interns, such as student handouts, that were used during lessons I observed. The resulting data set consists of approximately eight hours of teaching observations and 15 hours of interviews for each of five pre-service secondary science teachers. I conducted all interviews and observations. While I was a doctoral student at the university, I was not affiliated with the pre-service teachers in any official capacity (i.e., I was not a field supervisor or course instructor).

The Context

The interns were in their final post-baccalaureate year of a nationally recognized, five-year university-based teacher education program at Midwestern State University. This program produces some 200 secondary teachers each year; approximately 50 are certified to teach secondary science. The final year of the program consisted of two concurrent activities: a year-long internship in a secondary school teaching science and two graduate-level education seminars each semester.

The structure of the teacher education program paid particularly strong attention to disciplinary subject matter. Teacher candidates undertook a four-semester sequence of courses (two in the senior year for a total of 11 credits, and two in the internship year for a total of six credits) as a subject matter cohort. In science, this meant that both university faculty instructors as well as the teacher candidates typically stayed together over the four-course sequence. The course instructors for the interns in this study were highly experienced science educators and advanced science education graduate students. The intern cohort for academic years 2001-2003, was the third such cohort taught by this team of science educators.

During the internship year, the interns spent the vast majority of their time working in schools with a tenured science teacher as their mentor. For 10 of the 14 weeks in the academic semester, interns were in schools four days a week, Monday through Thursday. On the ten corresponding Fridays, they returned to campus for two, back-to-back, three-hour graduate seminars. Of the remaining four weeks, interspersed in the first semester were two, two-week "limited teaching periods" (LTP). The first LTP was designed to give the intern experience taking primary instructional responsibility for a two-week sequence of lessons, with a single class of students. The second LTP, several weeks later, was similar except interns typically taught two or more classes. The number of courses taught depended upon the comfort and preparation of the intern as well as the expectations of the mentor.

The second semester of the internship was similar to the first. The Fridays of 10 of the 14 semester weeks were devoted to graduate courses on campus. The primary difference between first and second semester was that instead of two LTP's, there was a single, 10-week "extended teaching period" (ETP) in which the intern took primary instructional responsibility for at least four classes during the day. The goal across these two semesters was to provide interns a scaffolded set of experiences. The interspersed immersion with periods of lesser intensity was a structure intended to provide space for interns to develop into reflective practitioners.

Sample Selection

Intern volunteers were recruited at the beginning of the school year from the entire cohort of pre-service secondary science teachers. In a class of 50 interns, 35 volunteered and a purposive sample of five was selected. The resulting sample is purposely diverse and representative with respect to 3 variables. The first variable, I call "the degree of alignment" with the teacher education program and it was a minor consideration. The other two variables: subject matter preparation, and grades taught/school setting were the primary selection variables. I next explain each of these in turn.

The "degree of alignment" was approximated by asking the science education faculty instructors to roughly classify the interns with respect to what kind of teacher education students they were. Appraisals included such assessments as: this intern tended to frequently question what we do in the program, this intern was quite articulate about how his ideas differed from the program's stance, this intern worked hard but often had difficulty with assignments, and this intern really did outstanding work. I wanted to understand how different students thought about teacher education -- and not only interns who were doing well in the eyes of their instructors -- but also those interns who seemed to benefit less from their coursework. Therefore "alignment with program" was one, although relatively minor, consideration in the sample selection.

Subject matter background was a primary selection variable. I wanted to have the opportunity to observe how differences in disciplinary preparation might affect the ways in which the internship was experienced. In my experience as a teacher educator, I have noticed some general trends in the ways biology majors think about teaching that differ, for example, from chemistry majors. Among these differences, I have noticed there are different affective perceptions regarding what's interesting about a subject. Many biology majors love nature and have extensive experiences as nature guides at parks or camp counselors. Chemistry majors often love to do bench science and experiment with chemicals. Earth science majors often enjoy thinking about earth formations with respect to geological time scales. While these are off-the-cuff characterizations, I wanted to create a sample that would enable me to think more carefully about how disciplinary preparation might interact with learning to teach.

I also wanted to include interns in both middle and high school placements. My reasons for this were two-fold. First, the perceived "level" of subject matter depth in science differs between middle and high schools – it is typically thought that high school teaching requires deeper subject matter understanding due to the more advanced courses. Second, middle and high school teachers are sometimes drawn to teaching for very different reasons -- despite their identical disciplinary background preparation from the university. Some middle school teachers tend to focus on the social development of students, while others are attracted by the chance to make science fun for students. By selecting a range of middle and high school interns, I was able to explore how these differences played out during the internship.

I also suspected that the experiences of learning to teach are often dramatically filtered through the context of the interns' school placements. Having a range of schools -- urban, suburban, and rural -- in the sample allowed me to explore how context interacted with learning to teach.

To recruit the participant interns, I visited the first class of the Friday seminar in the Fall of 2002 and made a brief invitation to participate in this study. I handed out sheets of paper that requested the information described above. With this information in hand, I set about to select 4 to 6 interns that would maximize diversity along the dimensions of interest -- subject matter preparation, school level and school context. Five interns (selected from the 35 volunteers) ended up providing sufficient range across the dimensions of interest.

A brief description of these interns and their names (pseudonyms) follows.

Sam was a chemistry major and psychology minor who taught chemistry in a rural high school. His instructors noted that Sam didn't say much in class, but participated appropriately.

Jennifer was a chemistry major and biology minor. She taught 8th grade science in a suburban middle school. Her instructors noted that Jennifer sometimes had difficulty with assignments, but worked very hard to do a good job.

Carol was a biology major who had minors in both chemistry and earth science. She taught 7th grade science in a suburban middle school. Her instructors noted that Carol was one of the very top students in her teacher education cohort.

Nate was a biology major and a chemistry minor. He taught biology in a suburban high school. His instructors noted that Nate always participated and had insightful comments to share in class.

Mike was a physical science major and mathematics minor who taught physics in an urban high school. Mike tended to disagree with much in the program, but was articulate about his differences and raised them often in class. His instructors appreciated his forthright participation.

Each of the five interns would have been interesting to consider individually. Each of their experiences was unique and would have illuminated the ways in which interns learn to teach science. However, I chose to focus my analyses on three of the five interns -- Sam, Jennifer, and Carol -- for a particular purpose. I wanted to portray a particular range of ways of knowing and the three cases I chose allowed me to do this. In addition, these three cases allowed me to make illustrative cross-case comparisons. So while all five cases were interesting in their own right, and I had similar amounts of data for all five, the three I chose were better suited to help me explain the relationship between interns ways of knowing and their students' opportunities to learn. I should note that it was only after initial data analysis for all five cases, that I was able to choose which three were the best candidates for this report. It is possible that future analyses of these data will include the two cases not reported here.

Data Collection

This interpretive research study takes as its object of analysis the teaching practice of the intern -- the planning of lessons, the teaching of the lessons themselves, and the interns' reflections on planning, instruction, and professional priorities. Over the internship year, each of the interns was observed teaching a pair of lessons over consecutive days. Such a pair of observations was conducted twice each semester or four times (t_1, t_2, t_3, and t_4) over the course of the year. Semi-structured interviews took place before, in-between, and after the intern taught these lessons. Together, the observation and interview data constitute a "set"; and four sets of data, together with an initial interview constitute the core of the dissertation data for each intern. In addition, various lesson and unit plans, class handouts, teacher education course assignments, and email journals were collected.

The collection of each data set followed this general sequence. First the intern was contacted by email or by phone the day before the "day one" observation. Occasionally, this pre-observation contact was made just prior to the observation. During this brief contact, information about the lesson such as the goals for the class, what the intern anticipated would go well and what might be challenging were discussed. Also, if there were things that the intern nominated as potentially interesting in the lesson, I would try to pay attention to these. Such intern-nominated activities might be for me to pay attention to the ways students worked in groups, how well a particular explanation was made, or if an interesting demonstration made an impression on students.

The day one lesson taught by the intern was then digitally videotaped. Because the practice of the intern was the focus of the study, the videotape aimed to capture the instructional moves of the intern. The intern wore a wireless microphone so excellent quality records were made of intern talk; and efforts were made to follow the intern with the camera as she or he went around and worked with students.

After the observed lessons, I would conference with the intern. These conferences were during a preparation period soon after the observation. If that was not possible we conducted the conference after school the same day as the observed lesson. On one occasion, this post-conference was done by phone in the evening. The topics discussed in these conferences were focused around the experiences of the intern. As my intent was to try to understand how the internship made sense to the interns, I asked interns questions that focused on their priorities, concerns and perceptions of learning to teach.

Two conferences occurred; one between and one after the two observed lessons. My intent was to understand how the lessons went compared to expectations. I also asked the interns how their lesson related to the larger context of the teaching unit and their overall goals for student learning. I offered to share selected video clips as well as entire videotaped lessons of their teaching with the interns, and to watch any clips that were interesting to them. This happened with each of the interns at least once, but with the exception of Carol, the interns were not very interested in watching video of their teaching. I did not force interns to do anything they did not want to do because I did not want to jeopardize my relationship with them. I did make many tapes of lessons that interns used in their teacher education courses, which required video submissions as a course requirement.

Because I was intent on gaining broad information about the ways in which interns made sense of learning to teach, my interview protocols were designed to nominate broad topics and then follow the direction taken by the intern in their responses. This stance had many useful benefits. First, I believe that by taking a largely non-evaluative, and more interpretive stance toward the practice of the interns, I was able to more freely enter into conversation about their challenges in learning to teach. I think that for each of the five interns, I was able to build a positive rapport founded on my respect for the hard work they were doing and their efforts to be good teachers. Second, because I tried to listen much more than talk, I found that the interns were more than willing to talk about their experiences. Many of the people who worked closely with the interns around their teaching and learning were mentors, university field supervisors and university instructors. For better and for worse, those relationships brought with them formal roles and power dynamics. In these relationships, the interns were often positioned as a novice who was to listen and learn. In contrast, I was someone who became quite familiar with their teaching practice, but because I did not have a formal instructional role, I was considered more as a peer, and was able to interact quite freely with them.

My position as a graduate student working on a degree requirement also affirmed in the interns' eyes that I was in a similar position to them. Two of the interns asked me to write letters of reference for their placement files (which I declined to do citing the study as a conflict of interest) and one told me that I knew better what he was like as a teacher than anyone.

Instruments

The interviews were designed to capture the range of intern thinking about learning to teach, and were therefore semi-structured. The structure and content of the interviews depended greatly on the responses of the interns – both the topics they nominated and the issues that arose in the lessons I observed. This approach was taken so that deductive categories did not drive data collection, thereby (potentially) obscuring issues and concerns the interns might have had. By nominating topics and questions designed to elicit the intern's priorities, perceptions, and concerns, the interviews provided a broad canvas upon which to map out the terrain of intern sense-making. As such, issues surrounding subject matter and how to teach subject matter often became explicit topics.

Data Analysis

My inquiry focused broadly on informing the question, "how does learning to teach make sense to interns?" and I began my investigation with an image of learning to teach that situated the intern at the intersection of a number of different discursive practices or discourse communities (Gee, 1999). These discursive practices included the university science teacher education program and the science classroom in which the intern was placed. Each of these discourses had a set of norms and practices and the intern was charged with negotiating and learning to participate in each of the discourse communities (Cobb & Yackel, 1996). The tension in participating in two discourse communities arose from the differences between the communities. Although there is significant overlap in the norms and practices of these two communities there are also explicit and implicit differences. It is beyond the scope of this study to explicate these differences a common characterization is that universities engage in theory and that schools engage in practice. A difference like this, whether real or imagined, might cause tension for a beginning teacher. I was interested in looking at how interns navigated the tensions between the two discursive practices and I initially considered "learning to teach" to be learning to participate in the discourse of schools.

I began with two central questions in the generation of grounded theory (Strauss and Glaser, 1990). First, what are the concerns, priorities and perceptions of the interns? And second, in what ways can these data be organized into categories? In this effort, I endeavored to construct concepts grounded in the data and then use these concepts to build a theoretical understanding of how learning to teach made sense to these interns.

The analysis and collection of data operated in a recursive fashion throughout the study. However, the writing and reflection upon an observed lesson in March, 2003 prompted my close attention to the role of subject matter. This lesson, which will be presented in Chapter 4 (the case of Jennifer), caused me to inquire about the ways in which this intern made sense of teaching science. The differences between Jennifer and Carol, another intern, were striking, and caused me to refocus my attention on how to explain those differences. This sent me searching again for perspectives that might inform my thinking. My reading of the cultural psychology literature resonated with what I was observing in the interns' classrooms.

In particular, I was impressed with Bruner's collection of "folk pedagogies" (Bruner, 1996) that broadly classified the ways in which learners are often construed by teachers. In this case, I was interested in the more fundamental question of how people make sense of experience period. This is when I read Bruner's "bald" assertion that there are but two ways of understanding: narrative and paradigmatic (Bruner, 1985; 1986). Here Bruner's treatment of paradigmatic understanding presumes the reader applies the construct automatically to the domain of science, I was struck by the possibility that instead of simply assuming that all scientific understanding is paradigmatic, perhaps one can have a narrative understanding of paradigmatic knowledge. After developing a rudimentary analytical framework, I went back and wrote a fuller case to see if the framework was sustainable. Using this approach, I wrote a preliminary case for one of the interns, Carol.

This process resulted in the need for a more systematic framework. So the knowledge representations framework was devised, and new cases for Jennifer and Carol were written. And, most importantly, this new framework was applied to the case of Sam. Sam's case, being quite different from that of Jennifer and Carol, served as a test of this interpretive framework. It also resulted in the further expansion and revision of the conceptual framework. The result is a framework that is useful for interpreting a wide range of intern teaching practices.

There are four categories or "sites" of knowledge representation in practice with which the episodes of intern classroom teaching were analyzed. These four are: intern-directed situations, intern-student interactions, intern planning, and intern reflections on subject matter. These categories and their associated sub-catagories are listed here: Intern-directed situations with specific attention to classroom routines, assignments and activities, and lecture. Intern-student interactions with specific attention to the use of examples and the questions posed and asked. Intern planning with attention to student learning objectives and the ordering of classroom activities. And finally, I examined intern reflections on subject matter specifically with attention to: What interns think they need to know about subject matter, and, what interns think is hard/easy about teaching and learning their subject matter.

The analyses resulted from an iterative process that started with the writing of preliminary cases, the development of a rudimentary explanatory framework, the re-writing of the cases, revision of the framework and its test against the data from a third intern. This process produced a more general interpretive framework that can now, in future work, be extended to the remaining two interns as well as other situations.

Before turning to my final comments about the constructions of the cases, I should note that one method of data collection and analysis I anticipated would be very generative, was not. To gain insight into intern thinking, I used a form of stimulated recall. I videotaped interns teaching a lesson and then used the video in a subsequent interview as an open-ended stimulated recall prompt. Video was, in my expectation, an opportunity to gain novel access to intern thinking. My efforts to use video were framed as a way for the interns to look at something in their teaching that they would like to improve, and because they had to produce video for their teacher education courses and perhaps for a teaching portfolio, I offered to make video copies for each intern and to produce video clips that they could use for such purposes. During our conversations, I also would ask them if there was a particular part of the class that they would like to look at again. Although I thought that this would be a very productive and helpful service to the interns, as well as provide me with insights into how interns made sense of their own teaching, the process did not play out in anticipated ways.

Four of the five interns expressed very little interest in watching themselves teach. While I did make video copies of early lessons for each of these four, none of them asked for subsequent lessons. Also, as I asked them about possible segments that they might want to look at again, they had great difficulty in nominating possible topics of interest. For example, Sam would ask to look at a segment where he was trying to explain something that was "tricky." Jennifer, similarly, said that we could probably find a segment where she could have "explained things more clearly." Mike and Nate expressed no interest in watching the video and wanted to have copies made solely for the purposes of completing their teacher education course assignments. Though this approach did not play out in expected ways, it was interesting nonetheless. For these interns, watching the video served little purpose. They already, so to speak, had "been there the first time." So watching the lesson again did not provide them with additional insights into what they might do differently.

However, the fifth intern, Carol, responded in quite a different manner. Carol was frequently very interested in looking at video of her teaching, and she was often very motivated to look at a particular segment. For instance, after a lesson in which she suspected that she had "cut-off" a students' response to a question, she asked to look at that particular exchange again. In review, she was able to see that in fact she had mis-interpreted the student's question and that this student was expressing a very subtle understanding of the topic. Carol was very pleased to have "discovered" what this student was attempting to communicate. In general, Carol would look at the video as an opportunity to "slow down" the exchanges of the classroom so she could more carefully think about how the students were making sense of the subject matter she taught. As will be discussed at great depth in the cases, this reaction to video echoes a larger and more substantive difference in the ways in which Jennifer and Sam thought about teaching science and how Carol did.

Case Design

Teaching and teacher education are much too complicated for simple analysis. I offer one note before I begin the first case in Chapter 3. I offer this note here, in the methods section of the dissertation, so that the reader will understand, upfront, my stance toward this work. I understand and respect the complexity of teaching and teacher education; but I also recognize that a single cut through the data -- a cut that privileges subject matter -- can teach us much about how new interns learn how to teach.

The three cases I present in the following chapters are designed to provide a sufficient amount of detail from a series of instructional activities within an observed lesson. Because of the interpretive nature of this framework and the complexity involved in teaching, I have made an effort to include detail that will better allow the reader to examine the cases from a number of alternative perspectives. I claim that the ways these interns know science significantly impacts their teaching of science. Although there are points for which I think my interpretation is quite compelling, I fully recognize that there are also many individual points where the data are inconclusive. By including a significant amount of data, I show the reader that in looking across the case, at the entirety of the data, there is indeed a compelling case for my interpretation. As such, I do not mean to suggest that interns' instructional moves are not influenced by a range of forces. Certainly, issues of authority, goals for student learning, pedagogical competence, lesson preparation and so forth, can be tremendously important. Rather, my analysis pulls one thread from the tapestry of teaching -- subject matter. My analysis focuses only on the thread of science subject matter and works to interpret the ways in which it is used in the instructional moves of the intern. In simplifying my focus to this thread, I am not dismissing the tapestry, and I am not arguing for a reductionist view of teaching based only on a single thread. As the cases will demonstrate, I show how the subject matter thread is woven throughout the tapestry of teaching and is a central element in shaping the opportunities pupils have in school to learn science.

Chapter 3

The Case of Sam

Overview of the Cases

The cases that follow in Chapters 3, 4, and 5, provide contextual information about the schools and placements for each of the interns. Using detailed accounts of particular lessons taught by each intern, I present the reader with a rich portrait of the intern's teaching. I then consider four sites of teaching practice: intern directed interactions, intern/student interactions, planning, and reflections on practice. Across these four sites of teaching practice, I argue that the respective interns have particular ways of knowing subject matter. In each of the cases, I then consider other teaching instances in order to demonstrate that the analysis extends across observations and is indicative of larger patterns of practice.

Together, the three cases demonstrate that the ways in which interns know and understand science has profound implications for the ways in which they teach science. These implications center on the kinds of learning opportunities that are possible for the interns themselves as they gain experience teaching science, and for how these new teachers will likely develop along a particular trajectory of learning. Perhaps even more important however, is the dependency between the ways the interns themselves know science and their pupils' learning opportunities. This dependency has fundamental implications for science education more broadly.

The three cases that have been selected span an important range of science teacher preparation. But this range is not simply one of competence. The cases do not describe good and bad teaching. In fact, each of the three interns would generally be considered successful beginning teachers: they competently prepare for classes, they engage multiple pedagogical strategies and they have positive relationships with students and their mentors. In a phrase, each is a "well-started beginner." Though not exhaustive, the three cases illuminate significant and representative facets of learning to teach science.

This study examines closely the ways in which new teachers understand subject matter knowledge. In doing so, it does not aim to simply document the errors and inaccuracies of the interns' knowledge. All new teachers have much to learn about their subjects and to simply point out the mistakes they make would do little more than prove what we all already know -- they are beginners. This study instead, examines the ways in which knowledge is organized and represented by new teachers -- I call this broadly the interns' *ways of knowing science* -- and draws important implications for the future preparation of science teachers.

Sam

Sam taught chemistry and physical science at rural Chesterfield High School. The school is the focal point for the town and enjoys broad support for its athletic teams and performing groups. Chesterfield is a high school like many high schools in rural America. There is a strong sense of pride and identity in being a Chesterfield Cardinal—many students wear letterman jackets, hats and shirts announcing their various affiliations with school teams, clubs, and groups.

The school recently converted to a four-by-four block schedule. Students now take formerly year-long classes in a single semester. Four classes a day met for 90 minutes. Sam had one of these periods for planning, and then taught two periods of chemistry and one of physical science. I observed Sam teach primarily in his chemistry classes. Sam majored in chemistry and minored in psychology and showed great enthusiasm for being a teacher of science. He often acknowledged his tendency to be a bit nerdy, and he used that stance well to moderate and promote his interactions with students.

Students liked Sam and responded to his management style. Sam was enthusiastic about chemistry and strove to create a fun atmosphere while maintaining a clear focus on educational objectives. Sam also was effective in his efforts to diffuse conflicts in situations by overtly recognizing that mistakes might have been made, and that he would work to make things fair. For instance, when students complained that they missed a problem on a homework assignment because they had been given incorrect information, Sam quickly accepted responsibility and told students that this problem would not be counted against their homework score.

Sam worked well with his mentor teacher, Charlie Simon, who is a long-time chemistry teacher at Chesterfield. Owing to a remarkable physical similarity between Sam and Charlie, there have been numerous comments made by students about a genetic link between the two. Charlie even joked that he planned to adopt Sam as a son. Sam fielded these as compliments because of his great respect for the kind of teacher Charlie is -- and perhaps as an implicit confirmation as the teacher for whom Sam someday hoped to be.

Sam and Teaching

The chemistry lesson I describe below occurred on a Monday in February, 2003. I describe it because it was typical of the lessons I observed Sam teach. It also included a variety of instructional elements and dealt with topics Sam felt were important. The lesson began with Sam wrapping up an overview of atomic history and then moving to a topic considered by Sam as essential to success in chemistry -- the mole. In our subsequent conversation about the lesson, Sam felt that this class went very well. Therefore, I consider this Monday to be both a representation of the kind of teaching practice Sam aimed for, as well as an instantiation of that practice.

Rutherford and the gold foil experiment. Sam was absent from the previous class session on Friday, and Charlie taught the lessons that day. On Monday, before Sam introduced the mole concept, he first had to finish the overview of atomic history begun by Charlie. Sam had briefly consulted with Charlie about how far this class got. After opening class with a short set of announcements concerning assignment due dates, Sam began his instruction saying "And without further ado, I get the privilege of finishing atomic history today. I know Mr. Simon started it Friday. So what I need you to do is take out your notes." While they did so, Sam turned on the overhead projector. Sam used the same set of transparencies prepared by Charlie to go through the major scientists in atomic history. Sam continued, "so if I remember correctly, you left off somewhere with J. J. Thomson?" Several students informed Sam that they actually got through Millikan. Sam nodded and said, "All right, that means today we get to start off with my favorite -- Rutherford!" Several students made light-hearted comments about having a favorite scientist and Sam played along as if Rutherford might indeed be their favorite scientist too. Another student claimed to have never heard of Rutherford. "Ok," said Sam, "last year, physical science -- I know you guys talked about him." Sam asked if there was anyone who remembered who Rutherford was. The class remained non-committal. On the overhead Sam put a transparency with the following written on it:

1911 Rutherford and Geiger

Discovered: nucleus

protons

alpha, Beta, Gamma (X rays)

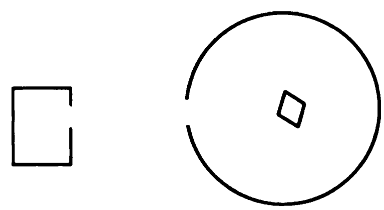


Figure 3.1. Atomic history overhead: Rutherford.

A student, obviously reading the overhead, submitted that Rutherford discovered the nucleus. Another said something about protons in the nucleus. Sam said, “besides discovering the nucleus of an atom. What was his experiment? [he pointed to the screen and the diagram illustrated above] There’s a good little demonstration of it up there -- a good little note.” Sam walked back to the projector and began to explain the diagram.

Sam referred to his notes as he labeled the diagram. He labeled the box on the left as he said, “this is a lead radioactive source” and he pointed to the diamond-shaped figure in the center of the circle, “and this is a gold foil. And what Rutherford did was he shot all sorts of particles at a sheet of gold foil." Sam drew a line from the source to the foil. Next Sam asked, "And what did he find out?" A student suggested that he found out how radioactive the source was. Sam replied, "Not exactly. What he actually found out was sometimes, when you're shooting these particles through here [he motions to the diagram and draws more arrowed lines on it] some of them would go straight through, some of them would be deflected, and occasionally one would bounce straight back at the radiation source." The diagram now looked like this:

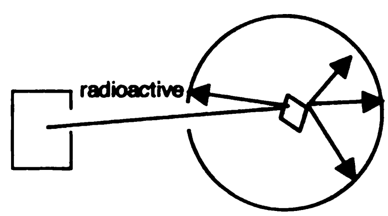


Figure 3.2. Rutherford gold foil experiment diagram.

A student asked how Rutherford was able to "monitor" where the radiation would end up and Sam explained that the outer circle in the diagram was made of photo-sensitive material that would make a blip of light wherever radiation hit, so Rutherford would be able to see what was happening.

Sam stepped back from the projector and addressed the class, "and what did this let him do?" When no one responded, Sam said, "Come on, I know you're awake this morning. I see some of your eyes droopin' a little bit. But, what did this allow him to do? What did this say?"

The same student who earlier said that Rutherford discovered something about the nucleus said "that there's a charge on the atom?" Sam asked, "Say what you said the first time." With consternation, she replied, "That's what I said!" Sam clarified his request, "No, I mean earlier when I asked what you remembered about Rutherford." She tried again, "oh, that there are protons in the nucleus?" Sam nodded encouragingly and addressed the class, "That there is a nucleus in the atom and that there's a lot of empty space. What Rutherford did, was because he did this experiment, he saw that there was a lot of empty space—and that there was something small at the center of atoms." The reader may notice that Sam did not explain how these conclusions might have been made; he stated them as if they followed from his description of the event. Neither Sam nor his students engaged the question, "How did this experiment provide evidence to suggest that the atom was mostly empty space and that a small nucleus was at its center?"

Sam next moved back to the overhead and he wrote as he repeated the following: "But he found that *an atom is mostly empty space* and that the *nucleus is very small!*" [phrases in italics were written on overhead transparency as below].

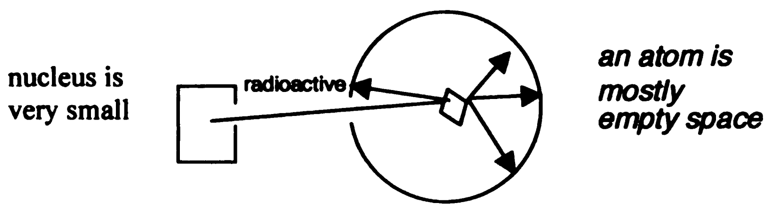


Figure 3.3. Notes added to overhead diagram.

As the students copied the labeled diagram into their notes, Sam introduced the next activity. "And, what we're going to do right now, is we're going to pretend to be Rutherford." Sam retrieved a tray from his desk that had a number of clay balls on it. He passed a clay ball and a toothpick to each of the students. When each student had the materials he said, "Now what I want you to do, is I want you all to be Rutherford. All right? And when I say I want you all to be Rutherford, I want you to take that toothpick, and I want you to push it into here [he holds up a clay ball to demonstrate], and I don't want you to dig in here and tear it up. You're going to poke it through here, and you're going to try and tell me -- is there anything in there, and if there is a something in there, tell me what it is."

A student quickly exclaimed, "There's something in there!" And Sam replied, "Well you've got to keep on lookin'. You've got to keep on lookin'. Cause you have to do this enough times so that you can tell me what it is." Students were actively engaged and they made various comments such as, "This is cool!" and "The nucleus!" A student asked what happened if the toothpick went all the way through. "If it goes all the way through, it goes all the way through....We're exploring our atoms [Sam holds up a clay ball], we're exploring our clay balls -- just like Rutherford did." After students had probed their clay sufficiently, Sam had them share what they thought was inside. There were a number of different objects such as a thumb-tack and a small cube, and the students identified each of them. Sam then concluded the activity with the following comment:

> As I was walking around I heard someone say, 'This is so unfair. It's so small, I couldn't see it.' Well, how do you think that Rutherford felt doing his

experiment? Seriously! He wanted to find out if everything would bounce back or whatever he wanted to find out. But, what he did discover, when he did these experiments -- well of course he said, 'It's unfair. When I do this experiment, why can't I see what's in there?' Well, he did get some good results. His experiment let us figure out a little bit more about what's going on inside of an atom. That's why he's like my favorite scientist. He's my favorite one. (Sam Hastings, transcription notes)

In the clay ball activity the activity itself was emphasized. Sam introduced it as an opportunity for students to "be Rutherford." Though students did indeed probe the mysteries of the clay ball with a toothpick, the connections to the Rutherford experiment were not made explicit. In effect, the activity of the clay balls was what was going to be recalled -- not how the Rutherford experiment provided evidence for the structure of atoms. This activity therefore provided the means by which the narrative facts of atomic structure might be "learned" but it did not provide the opportunity for students to build an argument based on the patterns in the data, nor even identify what types of patterns might support Rutherford's conclusions. The use of narrative means to support the learning of narrative accounts of science will also be evident in the following example.

Introduction to Avogadro's number: The mole discussion. After Sam very briefly discussed a few more scientists, including Mendeleev, Mosely, and Bohr, and students copied the information from the overhead into their notes, he transitioned to an introduction to Avogadro's number and the mole.

Sam began by apologizing for not being able to bring in any "mole comics" because he didn't get the chance to make overhead copies that morning. He promised that he would bring them in tomorrow and that they were very funny. He told them that they would be taking "very few notes today," but would continue with notes tomorrow because he wanted "them to do the lab today."

Sam opened with a question, "And what is the mole? The students started to offer possible answers which included "a measurement" and "a small, underground, digging animal." Sam interjected and told a student to "say that louder." She replied with, "It's a measurement of…" [she didn't finish her sentence, and her voice trailed off]. Sam then stated to the class, "It's a measurement."

He walked to the whiteboard and wrote as he spoke, "It's the amount of substance that has Avogadro's number of particles." After a brief pause, he asked, "What else is a mole? It's also the number of grams in one atomic weight. [pause] Where do we see it?" Sam immediately answered his own question, "Grams per mole." He then spoke as he wrote: "It's the number of particles in one atomic weight of something. But most importantly [Sam emphasizes these last two words and a student whispered loudly, "star this one" in your notes], most importantly, it is a comparison number."

He continued, "And that comparison number is...?" A student offered, "One." Another said, "Avogadro's number," and Sam picked up on this and said, "Which is six point oh, two, two, times ten to the twenty-third. And I can actually tell you how they found this number. And that is Avogadro's number." A student asked, "How *did* they get it?" Sam repeated the student's question and then explained "Avogadro did many experiments and lots of calculations. And through his many experiments and calculations he was able to come up with a constant number that could compare all things by. And that number he came up with, was 6.022 times ten to the 23rd."

Sam wrote on the whiteboard:

The mole	=	amount of substance that has Avogadros no. of particles
	=	Molecular weight
	=	number of grams in one atomic weight
	=	g/mol
	=	number of particles in one atomic weight of something
	=	6.022×10^{23}
	=	Avogadros No.

Figure 3.4. Mole equivalents written on the whiteboard.

Sam next relates his experience learning about the number pi in a high school mathematics class as similar to the way in which Avogadro's number was determined. Sam told them that his class had measured the lengths of strings that were wrapped around various cylinders. He and his classmates tried to find the constant number that was the same for all of the cylinders. The number they found in this activity was pi. Sam explained to his students that, "It's the same principle here [with Avogadro's number]…this constant number that bridged all of the measurements and calculations together, was Avogadro's number."

"Now," Sam continued, "I've got an example for ya. Because what is this? This is a number, it's just a conversion factor. It's just another way that we can compare things together." He then introduced his next set of examples. "All right, when I say "couple" what pops into your mind." A girl said, "my mom and dad." Sam said, "Ok, well, 'mom and dad' is how many?" "Two" answered the girl. Sam nodded and continued, "If I say, 'dozen' what's the first thing that comes to mind? Twelve. A dozen eggs, a dozen pencils." Sam continued in this fashion with a gross and ream. Then he asked, "How many 'whatever' are in the mole?" Sam wrote 6.02×10^{23} on the board as the students wrote it down in their notes. A student asked questioningly, "That's the answer?" and Sam said, "Yeah, that's the answer."

A student asks "So a mole is six point oh, two times ten to the twenty-third of *something* just like a couple is two of *something*?" Sam confirmed this and then picked up some containers from behind the desk. "All right, well then I've got something else for ya. What if I had one mole of sulfur?" Sam held a small jar of powder above his head so that students could see it clearly. "This is about one mole of sulfur right here. All right?" he said as he placed the jar on the desk of a student in the first row. He told her to pass it around and he went to retrieve another jar. "Or, if I had one mole of iron." Sam held up the iron and then said to the girl with the sulfur that he wanted her to compare their weights. "Does one feel heavier than the other?" He asked. "It should, because in each jar," Sam explained, "There is one mole of particles, one mole of atoms." A student mumbled that he was totally lost. Sam responded with, "What is a mole? All a mole is, is a number." The student who claimed to be lost said "Number of *what*?" "Exactly!" said Sam. "All the mole is, is a number. It's a conversion." Sam pointed out that the sulfur and iron that are being passed have different weights, but that what's common to each is they both contain "a mole of particles." The student who was confused understood this explanation and offered a parallel example involving a dozen jumbo eggs as heavier than a dozen small eggs. Sam acknowledged this and continued on by producing a mole of copper sulfate. "What would it look like if I had two moles of copper sulfate?" Several students responded that you'd have twice as much. Sam then reached into the cabinet and said "But what would it look like if I had just two moles?" "Eeww!" shrieked the girl in the front row, as Sam set a jar containing two stuffed moles of the mammalian type on her desk. The class burst into laughter, and Sam explained that these moles belonged to Mr. Simon. He went on to say that he hoped Mr. Simon would find two more moles for him so that he "can do this demo next year" in his own class.

Sam exclaimed "We made a break-through here! A mole is just what? [without pausing he continues] A mole is just a conversion, it's a unit of measure, it's 6.02×10^{23}." A student asked if it is just like joules. Sam responded, "not exactly, but very similar. It's just like a conversion factor though." Another student asked, "So there's one mole in everything?" Sam replied "Only if it's one mole of substance." He wrapped up this discussion by saying that tomorrow they would do a lot of problems, to "bring this concept of the mole into more light."

The Mole Lab Exercise. Sam transitioned to the next activity by handing out the lab instructions sheet. The students each took a copy but remained largely engaged with the jar of stuffed mammalian moles. After a minute of additional discussion about the critters, a student asked if they would be working with partners and Sam confirmed that they would. Sam elaborated the activity and what students would do.

> This one, actually, will not take you the entire hour to do. This one will probably be due at the end of the hour today -- just because, I know that you guys are tough workers. I'm giving you about 55 minutes to do it. This lab probably will only

take you half an hour to do, plus the calculations. So we're probably going to have a little bit of a wrap-up on the mole. But, what are we doing today? On each one of these flasks, back on the back tables, there is a number on it -- a weight. That is the weight of the actual container itself. That is not the weight of the substance inside it. What you're going to be doing, is you're going to be working with a partner and you're going to go to each station and weighing those substances. And what are you going to have to do to find out what the weight of what's inside of it? (Sam Hastings, transcription notes)

Several students chimed, "Subtract." Sam continued with a nod,

> Subtract them. We're doing weight by difference today. So, when you're done weighing a substance, you don't have to take it off and re-zero the balance. In fact it would be better if you just left it. Leave it balanced out so they can do their subtraction, and they can have their weight. That's going to go under, 'mass of the compound'. All right? You need your flask number here first, then the compound name, which is going to be on here, and then you have to get the formula. You have to get the correct formula. All right? So if you're having problems guessing what the formula is or finding what the formula is, let me know and we'll work it out together. Because the formula has to be right. If the formula is not right, you're not going to be able to get the right mass for one mole, and you're not going to be able to get the right number of moles of the compound. (Sam Hastings, transcription notes)

During this explanation, Sam stood at the front on the side of the room opposite the lab area. As he made the detailed comments above he referred only to the lab instruction sheet and the students followed along with their own copies. He told them that they will have to find the mass of the compound, and then asked, "Where are you going to find the mass of one mole of the compound?" Sam waited several seconds expectantly. "Where are you going to find out that number?" he asked again. A student ventured, "Divide it by 6.02 times?" "Nooo," said Sam as he cut off the student's response. Another student suggested the textbook. Sam acknowledged that the book would be "A good place to look; but there's a better place." A student finally suggested the periodic table. Sam repeated her statement "the periodic table," and continued, "Because what does the periodic table do? What are these numbers up top -- these red numbers?" Sam used a pointer as he directed the class's attention to the large periodic table poster to specify which red numbers he referred to. Another student said they are the atomic weights. Sam told them that this was also the "grams per mole weight." After a few more procedural clarifications Sam sent them back to the lab stations to complete the laboratory exercise. He told them to find a partner, that today's lab didn't require aprons or goggles and concluded with a cheery "Let's get to work!"

The students worked diligently with their partners at the lab stations. For a half-hour, they rotated through the stations. During this time, Sam constantly monitored student work and responded to the ever-present questions. These questions were all similar in that they focused on correct procedures for producing correct answers. For example, "How do you do number seven?" and "Is this right?" were typical. Sam responded to each question with directness, patience and good humor. He reassured one student that it was ok to not "get it" right away so "don't be frustrated." Sam did not ever ask students about their thinking or what was confusing to them. Instead, he answered their questions quickly and precisely. For instance, a student asked Sam if it was supposed to be 2K or K_2? Sam replied, "[it's K_2] Cause remember we're dealing with subscripts first. We deal with coefficients when we're balancing equations, but subscripts when you're balancing formulas." Without further comment, Sam turned and walked to a different pair of students. There he addressed a similar set of questions regarding coefficients and subscripts that he answered in a similar way.

The last thirty minutes of class were spent again as a large group. The students finished making their weight by difference measurements and worked on determining the correct chemical formula for each compound. Sam did several problems on the board and walked through each step in a clear and straight-forward manner. After each new step within a problem, Sam would typically ask the class, "Now what do I do next?" After the demonstration of one such problem, a student asked how many decimal places they should include. Sam told her to "Just do significant figures." When she said she didn't know how many, Sam said, "Then just use two." The students spent the last fifteen minutes finishing up their calculations and Sam walked around and answered individual questions. The students worked at their desks until the bell rang. As they began to file out the door, Sam bade them farewell, "All right -- have a good day! Remember that this is going to be due at the beginning of the hour."

Across Rutherford and Avogadro's Number

In both Sam's treatment of the mole and in his sense of what is difficult about teaching the mole, Avogadro's number itself plays no role. For example, one of the striking aspects of Avogadro's number is that it's a tremendously huge number. Diemente (1998) notes that there are as many molecules in 50 mL of water, as there are grains of sand in the Sahara desert. It is common for teachers of chemistry to develop instructional activities to help students appreciate this (e.g., Diemente, 1998; Uthe, 2002). Sam however, did not see any reason why the mole might be a difficult concept. He considered it to be simply a number that, like pi, is used to do certain procedures. In this sense, he was absolutely correct. Both pi and Avogadro's number are numbers that are used in procedures. But they are also different in important ways. Avogadro's number is based on arbitrary units, much like the foot and meter. Pi is not. Pi is a fundamental characteristic of circles regardless of unit choice. For Sam, and for his students however, the parallel holds. Both Avogadro's number and pi serve as numbers that consistently show up and are required in order to do the problems. Though it might be a purely philosophical quest to ponder why pi = 3.14159265... instead of something else, this is not so for Avogadro's number. Avogadro's number arose from the need to make comparisons between different chemical elements and compounds.

The point here is not to claim that Sam should know the history and development of Avogadro's number. This is something that Sam might well be able to learn as he gains experience teaching chemistry and reading. What I claim this example demonstrates, is that Sam is not aware that there might be something more to the idea. Instead of something that is rich and multifaceted, with implications for a deep understanding of chemistry, Sam instead reduces or flattens the notion to its procedural end. It is, for Sam, just a number -- like any other number that shows up. You just have to learn to deal with it. Sam is not alone in this perspective. Indeed, many introductory textbooks take a similar approach. Sam is likely the product of an education that relies on such textbooks.

The second thing that is typically missing from Sam's teaching and his discussions of teaching is a sense that there is something to figure out here -- that chemistry is the pursuit of questions that arise from the physical world. Instead, Sam teaches chemistry as if it's part of a never-ending advance of knowledge and that the school class called "Chemistry" is the enterprise where pupils learn the major characters in that story. People like Rutherford are included as people who participate in advancing knowledge, but for the pupils in Sam's class, the pursuit of knowledge is not about understanding phenomena. The pursuit is about recapitulating what others in history, have done.

Ways of Knowing Across Teaching Practice

The ways in which knowledge is represented to students is part of the enacted curriculum and is as much a part of the subject matter as what is more typically considered the content. Schwab discusses this distinction succinctly when he claims that how a subject is taught is as much a part of what is learned as is the object of that teaching (Schwab, 1978). In this section, I examine both the content and ways in which this content is presented. I claim that together, this constitutes how the subject matter is represented. I organize my analysis by examining how knowledge is represented in four contexts: intern-directed situations, intern-pupil interactions, intern reflections on subject matter, and in planning for instruction. I will draw upon the description of Sam's teaching already presented as well as instances from across my observations and interactions with Sam over the 2002-2003 school year. The overarching argument is that Sam relies on a narrative way of knowing science.

Knowledge Representation -- Intern-directed Situations

Teacher-directed situations are those in which the teacher uses assignments, activities, demonstrations and lectures to present subject matter. In this section I will address the following questions: (1) How is knowledge represented to pupils verbally in lecture or demonstrations? (2) How is knowledge represented in assignments? (3) What kinds of activities does the teacher choose to engage pupils in the subject matter?

Classroom routines. Sam emphasizes procedural routines in his presentation of subject matter content. As it was generally true across my observations of Sam as well as in the previously described lesson, Sam quickly brought the class to attention and focused them on the tasks they were to complete. Such tasks were often referred to as "work" that needed to be done and included taking notes, completing labs, and solving chemistry problems. Sam created a productive work atmosphere where students were given clear expectations about the work they were to do, and how that work was to be accomplished. Sam actively aimed to reduce the complexity of material so that students could understand it more easily. For example, by slowly enunciating phrases as he wrote on the overhead that the atom consisted of "mostly empty space" Sam clearly indicated to pupils that they needed to know this important finding. In focusing on the work to be done, the clear message was that tasks in this class depended more on effort than an appreciation of cognitive complexity or engagement with the ideas. If a pupil took careful notes and made an effort to study them, then she would likely be rewarded on the next test or quiz.

Across observations, Sam introduced labs and activities with only a procedural overview. In the lecture and activities that dealt with the Rutherford experiment, Sam emphasized what Rutherford *did* while ignoring the reasoning that Rutherford employed.

In the Mole Lab exercise, Sam informed the students that first, there would plenty of time to complete this lab. This is in keeping with the idea of managing the work that students would be expected to do. Sam asked the students rhetorically, "What are we doing today?" and he answered it directly by telling the students what each of the steps would be in the procedure for the lab. He does not ever directly inform the students what the purpose of the lab is, though it does come out as the conclusion to the long set of instructions quoted earlier:

> Because the formula has to be right. If the formula is not right, you're not going to be able to get the right mass for one mole, and you're not going to be able to get the right number of moles of the compound. (Sam Hastings, transcription notes)

The purpose of the lab is to "get the right number of moles of the compound." What is needed, in order to achieve the right number, is the ability to follow carefully the printed instructions to measure the weight of the compound, to come up with the chemical formula for the compound, to determine its atomic weight and then perform the conversion from grams to number of moles. Careful attention to these procedures coupled with an industrious attitude, are the keys to success. Sam considered the procedures *themselves* to be tasks to be efficiently completed and that they were not done to make a larger argument about physical measurement and/or explanations of patterns in the physical world. Because these lab activities required few or no inferences, they were not designed to "test" anything. Instead, the labs employed by Sam are used as "elaborate visual aides" (Millar, 2000) to provide illustration for ideas already introduced.

Keeping the ball rolling: The role of omitted information. A second characteristic of knowledge representation in Sam's teaching I call "intentionally omitted information." Sam routinely omitted information so that pupils would ask questions and thereby participate more actively in activities and discussions. Examples of this are found in the Rutherford account as well as across my observations of his teaching. Recall that in the Rutherford gold foil experiment, Sam asked his pupils to tell him what the experiment allowed Rutherford "to say." When his pupils did not offer any suggestions, Sam implored them to shake off their droopy eyes; which in effect was suggesting that had they been paying better attention they might indeed have answered appropriately. Sam repeated his question again, apparently not appreciating the fact that Rutherford received a Nobel Prize for his interpretation of the data which revolutionized notions of the atom, and that perhaps asking students to come up the same conclusion might be a stretch, particularly since only a shallow depiction of that data was presented. So how does such a question make sense to Sam? I assert that by considering the Rutherford experiment to be a story simply to be learned (i.e. committed to memory), that it is indeed not so hard to imagine a student recalling that an atom is mostly empty space and that the nucleus is very small. Indeed, in Sam's representation of this experiment -- both verbally and in the clay ball activity -- this version of the story of the Rutherford experiment is indeed likely to be remembered. Having an overhead representation, supplanted with the clay ball visual aides, pupils are likely to recall that Rutherford found something in the middle of the atom that he couldn't see. They might even remember that it was called the nucleus.

Another example of intentionally omitted information was from a lesson in which Sam was teaching the Gas Laws. Sam told the students that they were going to put all of the gas laws together. He wrote, "PV = n __ T" on the board and then asked his pupils what was missing. He added that he would be "very impressed" is someone knew the answer. A student finally exclaimed out "R" (I saw him reading out of his textbook) and Sam noted that it didn't count because the student cheated by looking it up. Sam continued to explain that "this R is what ties it all together. This is our constant." There was clearly no way -- unless consulting from the text -- pupils would have been able to supply what was missing from the formula. But, as a strategy for keeping students' attention, for getting them to write the formula down in their notes, and for demonstrating to students that Sam had knowledge that they too might well need, it was an effective and reasonable approach.

When Sam gave incomplete data and asked for a conclusion, he was engaged in a "dialogical" telling of a narrative story. Though pupils were given the chance to interact, they did not have the intellectual resources to fully do so. They were, in effect, pawns that served narrative and dramatic ends in that they set the narrator's surprise ending. That this conclusion is "of course" obvious to the narrator, further positioned the pupils to listen ever more carefully to pick up the clues that they must have missed.

Assignments and classroom activities. Subject matter knowledge in assignments took a very problem-based approach in Sam's chemistry class. Ideas and concepts introduced in lecture were quickly framed as problems to solve or calculations to perform. Both Sam and his mentor Charlie believed that facility in problem-solving and formula manipulation resulted from extensive practice in a supportive environment. Sam endeavored to provide such an environment and actively promoted opportunities for his pupils to ask questions about assigned problems. Sam's approach to problem-solving was essentially one of puzzle solving. Sam helped students to view each problem in a puzzle-like fashion, in that each type of problem had a set of procedures that would solve the puzzle if deployed properly.

Students of chemistry are likely to remember the emphasis on balancing chemical equations and solving ideal gas law formulas. Obviously, both chemical equations and gas law formulas are intended to be descriptive tools for figuring out some kind of physical question. In practice however, both the "chemical" in chemical equations, and the "gas laws" of the gas law formulas were effectively removed. For both Sam and his students, these problems were simply equations and formulas disconnected from a physical reality. Formulas were manipulated purely algebraically, to isolate the unknown variable; and balancing equations required constant reminders that "We deal with coefficients when we're balancing equations, but subscripts when you're balancing formulas."

Another particularly powerful tool that Sam, like many chemistry teachers before him, spent a great deal of energy on, is dimensional analysis. Sam called it "setting up a line factor." Line factors are a part of a procedure for converting from one unit of measurement to an equivalent unit of measurement. For example, 14 days is equivalent to half a month. Mathematically, one can "compute" this result more formally using a line factor. Figure 3.5 demonstrates this procedure.

$$14\ \cancel{\text{days}} \times \overbrace{\frac{2\ \cancel{\text{weeks}}}{14\ \cancel{\text{days}}}}^{\text{Line factor}} \times \underbrace{\frac{1\ \text{month}}{4\ \cancel{\text{weeks}}}}_{\text{Line factor}} = \frac{1}{2}\ \text{months}$$

Figure 3.5. Example of line factors for converting days to months.

The need to convert between different units is of tremendously important in the study of chemistry. And it arguably deserves careful attention in chemistry classrooms. For Sam and his students, this process was an end unto itself. When I observed Sam demonstrate how to solve a problem using line factors, he would often set up the entire equation on the board, ask a student to calculate the solution, and then simply append the correct unit to this answer. If a student were to forget to include one answer's units, it was automatically worth half credit. Sam would often remind the class in general to not "forget the units."

The reason that students might find it easy to forget to include units was because the numbers themselves were not viewed as measurements in the first place. The units in effect were simply tag-along vestiges that were important to include in order to receive maximum credit on assignments. Through thousands of iterations, Sam had disciplined himself to remember to casually add the units on at the end. Across the numerous instances I observed of Sam utilizing line factors, I did not observe him explain what the reasoning was behind the process. I did observe on many occasions his use of procedural reminders to determine what unit should "go on top" of the fraction and what unit should "go on the bottom."

Sam was himself, adept at solving such problems and he aimed to prepare his students to be as proficient as he was. When students asked him a question, Sam would immediately explain the correct solution as he did in the previously described lesson. Sam elaborated to me that it was helpful for him to observe pupils solving problems, because he could then quickly identify "misconceptions" and subsequently "stamp them out." For Sam, misconceptions were equivalent to simple mistakes or easily addressed misperceptions rather than highly structured conceptual (mis)understandings.

Knowledge Representation -- Intern/pupil Interactions

Questions posed and asked. Sam posed questions to pupils that required them to be very familiar with factual and procedural knowledge. Often questions related specifically to fostering pupils' skills in manipulating formulas. For example, when working with an ideal gas law problem, Sam would pepper the class with questions such as, "What is the volume? What is the pressure? Does R stand for something or is it just the constant in this equation? What is the STP for liters? Does anyone have any questions? I can't help you if you don't ask questions." Sam often lamented during our interviews, that some students just would not ask him any questions. Two reasons he noted explicitly were that they were just lazy or they didn't think they were good at chemistry.

The kinds of questions that Sam asked of his students were reciprocated in kind. His students typically asked numerous and entirely procedural kinds of questions. On those occasions where a student exclaimed that something "didn't make sense," after

Sam explained exactly how to do the problem, the student often felt more comfortable. It is important to consider that what the student meant when he said something "didn't make sense" was really a statement of "I don't know what to do next." After Sam provided an answer to this second question, things were back on track.

Another example of this concerned a pupil's question about the number of significant figures a particular answer was supposed to have. The student asked, "How do you know how many significant figures to use?" Sam replied, "Go for three, three is a good number to use." And so the student used three. This is an interesting example because, in fact, the number of significant figures (i.e., the precision of a measurement) is a very important thing to understand about measurements and calculations involving measurements, because it is a measure of the confidence one can have in a result. Despite this, many science teachers avoid teaching significant figures. Many teachers reason that it is not worth devoting limited time, effort and resources to a topic when simple rules, such as "just use three" allow students to continue working their problems. It is true that teachers generally find significant figures to be difficult to teach (and perhaps many also find the notion difficult to understand). I claim that teachers for whom significant figures is not an important concept -- like Sam -- are also not attempting to help their students make arguments based upon patterns in the physical world. To establish arbitrary limitations on the precision of a measurement is to shift the focus of problem-solving from actually *solving a problem based upon physical measurement* to the manipulation of equations -- here called problem-solving. In this mode of problem-solving, the numerical answer is produced to establish correct procedural competence and is not an indicator of physical relevance.

One might reasonably wonder what questions pupils raised and did not raise? Pupils in Sam's class also asked questions about problems they were unable to solve, but framed these questions as requests for demonstration. For example, "Can you [Sam] do number 23?" Students did not ask questions about the way activities might fit with the learning goals. Students had accepted the fact that Sam would provide a number of activities and assignments that mapped well onto what it is that they were supposed to learn. By staying close to the textbook, Sam gained in authority by helping *translate* the textbook material, and providing *visual aides and experiences* that illustrated the science content. Engagement of the content (in ways that promoted paradigmatic understanding) was not expected by Sam or by the pupils in his class.

When a pupil did ask Sam a question for which he did not have a ready answer, Sam would say that he would check on that and would return the next day with a response. I did not observe Sam do any explicit "reasoning" with his students. I mean that I did not observe him do anything that looked like: "Here's how you might think about something like that." Sam's tendency to focus on the procedural aspect of chemistry is further illuminated in the following section which explores the ways in which Sam thinks about student thinking.

Interactions around student thinking. What does Sam do to assess student thinking and to gain insight into how his students understand the material? When I asked Sam about this he admitted that this was something that he was learning to do through the internship experience. One of the main benefits to Sam for teaching a block schedule was that it afforded him the opportunity to experience the whole class sequence nearly two times. Sam felt that his knowledge of what worked was developed principally through such experience. As for knowing about specific pupils and their thinking, Sam noted that it was largely up to the individual to ask questions if they were confused. As was evidenced in the molecular weight example, Sam aimed to create an atmosphere where pupils asked questions, and he answered them. If pupils weren't "getting it" they had ample opportunity to ask Sam questions in class. Sam frequently advertised that he was available both before and after school to help students. For Sam "getting it" was ascertained by the pupils' ability to produce correct answers to homework questions, performing correct calculations on labs/worksheets, and active participation in discussions.

In the course of completing an assignment, if Sam found that more than a couple students were making a similar mistake, he would address the class as a whole and directly explain how to do the problem correctly. Sam was typically very quick to make judgments about student thinking. Because Sam devoted significant time in each class to working problems and doing calculations -- which was facilitated by the 90 minute block period -- I had many opportunities to observe Sam working with students. These interactions were also opportunities for me to see how he assessed student thinking. The vast majority of questions were students asking how to solve a particular problem. When faced with such a question, Sam would proceed to explain the solution in clear step-by-step detail. He would start at the beginning of the problem and continue to the end. Across numerous instances, I did not observe Sam ask the pupil what about a particular problem was difficult, what the pupil was confused about, or to have a student explain how they approached the problem.

Sam explained to me that one of his students had basically given up trying in class and would often just sit quietly at her desk. When I inquired about what it was that made her stop trying, Sam said that it was because she had convinced herself she was bad at math and science. Because she no longer believed she could do it, she prevented herself from succeeding in Sam's chemistry class. I asked if perhaps there might be something about her math background that truly did make it difficult for her to be successful in class, and Sam pointedly shook his head and said that her problems were because she wouldn't even try. By equating success in mathematics to effort is to fail to appreciate the cognitive complexity of mathematics. Obviously, there is a role to be played by self-esteem and effort. But by flattening the challenges of learning into effort and self-esteem, portends a view of the subject matter as something without cognitive complexity -- complexity that cannot be overcome through diligence and effort alone.

Knowledge Representation -- Intern Reflections on Subject Matter

What do interns need to know? Sam noted that he needed to know "the chemistry" very well if he was going to be able to help his students. Precisely what Sam means by "the chemistry" is in part, the focus of my attention. The way in which Sam thought about the subject matter of chemistry was largely narrative in structure with numerous embedded procedures. These procedures are related to the larger narrative of chemistry, in that they are the procedures that chemists use. They are also the procedures that university chemistry professors will require future university chemistry students to do. Sam's understanding of "the chemistry" was therefore, well aligned with both the way he taught chemistry and the kind of chemistry that he prepared his students to do.

This way of thinking about chemistry is evident throughout the following analysis of Sam's subject matter.

In thinking about Sam needed to know in order to teach, Sam identified two concerns. He believed that his teaching required him to be able to manipulate equations and formulas to get correct answers. Sam also felt that he needed to quickly "diagnose" (as he called it) misconceptions students had, and then be able to show students the correct approach.

In many ways, Sam felt he was already on the road to learning the two skills identified above. Sam felt that he learned "what works" through his experiences as an intern. He noted that once he got the basic approach down, teaching would be a matter of tweaking things. He felt that this had already happened for him because of the block schedule. He claimed that he "over-prepped" the first semester, so that during the second semester he was able to make ample use of his first semester plans.

What is hard/easy about their subject matter? Sam considered his subject matter knowledge to be strong, but he conceded on occasion that it was sometimes hard to know how to present certain ideas to pupils. In such cases, Sam often relied on his mentor Charlie to suggest productive ways of explaining things to pupils. As he did in the lesson on atomic history, the mole activity and the molecular weight lab -- all of which were designed originally by Charlie -- Sam would tend to have a general sense of the ideas, but would struggle with the way in which to sequence and coordinate the different lesson components. When I watched Sam interact with Charlie during their preparation periods, Charlie would explain how he would teach a particular topic, and Sam would listen intently. But while doing so, Sam would also interrupt Charlie with numerous statements of concurrence such as, "Now I see how it fits," or "Ahhh, I was thinking of doing it that way."

Sam felt that he had a good handle on each of the pieces of his subject matter but putting them into a larger narrative of a chemistry course remained a challenge. But the construction of such a narrative was a challenge that Sam clearly understood had been addressed. The writers of textbooks together with the experiences of long-time teachers formed a wisdom of practice that Sam accepted unquestioningly. Sam aligned himself with both textbook and mentor teacher because he considered what each was doing to be wholly aligned with the job of a chemistry teacher. He desired what Lave and Wenger (1991) claim as essential for meaningful learning, legitimate peripheral participation (LPP). In this context, Sam was engaged in LPP. What was hard about participating was learning the dominant narrative of the chemistry teaching practice.

Though Sam believed that there was much to be learned about teaching chemistry, the challenges his students faced in learning chemistry were apparently of a different nature. Sam believed that most of his pupils' problems resulted from either laziness or from self-defeating beliefs about themselves as learners of science. He viewed the reluctance of his pupils to ask him questions when they didn't understand "the material" to be one of his major challenges.

Sam valued students who asked questions. He thought that those students who asked questions were actively testing and extending their own understanding of the material. They also gave Sam unambiguous evidence that they were expending effort to learn the material. And because Sam felt most efficacious when he was able to respond to the questions that students asked, those students who provided Sam with the opportunity to be assisted, also provided the opportunity for Sam to derive satisfaction from helping his pupils learn.

Sam's narrative understanding of the work that teaching requires is also evidenced in the ways in which Sam planned for teaching. It is to these data we now turn.

Knowledge Representation -- Planning for Instruction

Sam held high standards for what he wanted his class to look like. Sam was very aware of the kind of atmosphere his best teachers created, and he wanted very much for his teaching to be similar. Sam and Charlie agreed whole-heartedly that chemistry at Chesterfield was a college preparatory course. As such, Sam often substantiated his rationale for teaching particular topics and skills by saying "because they are going to need to know this for college." To achieve a blend of good atmosphere and high academic goals, Sam utilized a problem-based teaching style supplemented with a variety of activities. Chemistry at Chesterfield had the reputation as being a tough class. Sam accepted this as a given. He planned full periods of activities and assigned daily homework.

Instructional variety served primarily a motivational tool for Sam. Sam planned activities with an eye toward keeping students on their toes. He commented several times that one of his strategies for doing so, was to vary the inflection and volume of his voice so that students would not be lulled into inattentiveness. Taking a cue from Sam's university field supervisor, he also paid attention to using multiple representational schemes to address the needs of auditory and visual learners. Attending to these different learning styles helped authenticate the role of variety in instructional strategies, but for

Sam, the affective gains of variety were more squarely appreciated. Sam noted that having lab activities interspersed with lecture kept class more interesting than lecture alone.

There are two distinct discourse communities within which Sam thought about planning. The first I will describe was his planning for his teacher education class. Sam typically struggled to produce plans that were acceptable to his instructors. One construct that Sam often found difficult was the planning construct of a "Big Idea." The university teacher education program required plans to be built around an explicit statement of a Big Idea. This statement was intended to be a short, concise wording of the central content to be learned by the students, and some indication of why this was important. The typical challenge faced by Sam was to write something that did each of these in a concise fashion.

For a plan on chemical bonding, Sam used 340 words for his Big Idea statement and articulation for the unit's central ideas There are three things that are important to notice in Sam's statement. First, the statement was not concise. Second, each of the five paragraphs could be read independently of the others. The topics of each paragraph were: compounds, types of bonds, covalent/ionic bonds, metallic bonds and systems of naming compounds. What is striking here is the level of detail given for each topic. Instead of a distillation of the central ideas, the paragraphs read more like a comprehensive listing of the topics to be covered. And third, the statement failed to address why any of these topics were important. In other words, why these ideas were "big" is missing. The warrant for their inclusion was simply assumed. What Sam had written for a Big Idea statement was actually an annotated listing of the topics he wanted to address in his class.

The plans that Sam produced for his teacher education coursework were in substantive ways, quite different than the planning that Sam did to prepare for his daily teaching. Across the range of my observations, Sam consistently struggled to produce written plans for the lesson he taught -- though each time I was to observe, he assured me that he would have a copy available for me. The plans that he made for the lessons that I will discuss are typical for new teachers in that they are scripts of things to say and do. As such, the plans that Sam created for his use in the discourse community of the Chesterfield chemistry classroom are substantively different from the plans prepared for his teacher education course. In the Chesterfield plans there is no mention of a "big idea." Though the template Sam used for plans included a place for lesson objectives, none were recorded. Under the heading "Activities" Sam wrote the exact phrases and examples that he would work for students at the board. A typical example taken directly from this scripted plan is as follows (Sam is introducing content that requires students to balance chemical equations):

Let's look at a combustion reaction. Remind me what that is? (reaction where something is burned in the presence of oxygen that releases energy in the form of light or heat.)

$$C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$$

Balance equation first with them, then go on. (Carbon first, Hydrogen next, Oxygen last. Sometimes we need to double the Carbons so that it works out)

(Lesson plan, 11/13/02)

The conversational tone is apparent in the use of parenthetical remarks that serve to remind himself of the correct "response" to his questions or important steps in the presentation of examples. Such notes provided support for a procedural rendition of the subject matter. What are missing are the logical connections between these procedures, the chemical models they represent, and the conceptual notion of what *balancing an equation* means.

Objectives for student learning

Sam chose objectives for student learning that mapped directly onto the goals of producing procedural competence. Often, there was little difference between a lesson activity and the objectives for that lesson. This distinction was made clear in the following example from a titration lab, "Purpose: To use the process of titration to determine the concentration of the bases in your cleaners." Here the objective was to do the lab. A listing of objectives from other lessons are similar: "Describe the kinetic molecular theory of gases", "apply the kinetic molecular theory to the gas laws", "describe the gas laws", "describe the three major trends of the periodic table", and "describe the basics of bonding characteristics." In each of these, the objective can be directly mapped to the simple completion of the activity. This was characteristic of Sam's teaching which embodies a narrative construal of science. This would differ from a paradigmatic stance where the objective denoted how to use knowledge for a purpose other than to self-referentially "do it." Paradigmatic reasoning in science is about using knowledge to explain phenomena, where explanations are based upon patterns derived from physical data.

Ordering classroom activities. Sam's class was a very traditional course. Lecture, homework sets from text, worksheets, lab activities, quizzes and tests, comprised the vast majority of instructional strategies. Sam and his mentor considered this course to be a college preparatory course in chemistry. As such, it was meant to prepare students to do what is done in a college course. Sam explained to me that his chemistry course actually taught the subject matter at the same pace as MSU, except that at MSU students met three times a week, and at Chesterfield they meet five. Therefore, the high school course differed primarily in that it could be "more supportive" than a college course.

Sam sequenced activities in parallel with the text and with the sequencing used by his mentor. Sam worked to prepare his students for collegiate coursework in chemistry; to do otherwise would have failed to recognize the wisdom of both his mentor and the writer of his textbook. Because there are few or no sources of conflict between his own experience as a student in college chemistry, and the content/sequencing espoused by Charlie or the textbook, there was little motivation to do otherwise.

University teacher education assignments. Sam felt that the planning frameworks used by his teacher education courses at MSU were centrally about accountability and communication. Sam believed that MSU was trying to ensure that students from the program were teaching appropriate curricula. To monitor this, they had to require teacher education students to submit lesson plans. Sam typically had difficulty completing lesson planning (and associated) assignments to the satisfaction of his instructors. He felt that this was due to the inherent difficulty in communicating the nature of teaching. One situation he discussed with me regarded a conference with an MSU instructor. The instructor had challenged Sam's rationale for sequencing the activities of a lesson in a certain way. When Sam described what his intent actually was, he said the instructor replied, "Ok, now I see how you're thinking about this." Sam took this as tacit agreement with his plan, and he described the exchange as simply a case where he was unable to write his original plan with sufficient clarity. Further, he felt, that if this instructor could "actually see" him teach, there would be absolutely no conflicting views about the nature of his instruction.

Sam viewed the coursework at MSU as something of a necessary evil. Because he viewed assignments to be largely accountability measures, he recognized that the university needed to require them, but the assignments were not central to his thinking about what to do in the classroom. Sam claimed that his number one priority was his classroom and his pupils, second was getting adequate rest, and third was working on MSU related assignments.

A specific example about Sam's view of the task of clarifying the big ideas of a lesson, can illustrate his perspective. Sam had difficulty knowing what to write under the big ideas heading in an MSU planning assignment. When the instructor finally told him, after extended discussion, that the big ideas were essentially what you want your pupils to walk away from class with, Sam said that this description clicked for him. He had difficulty however, in synthesizing such knowledge into a short statement (which, according the course instructor, was one of the goals of this planning assignment). Instead, his section on big ideas was an extended paragraph that included *all* of the ideas he was going to teach during the unit.

As described above, Sam felt that the big ideas were the ideas that he wanted his students to learn. In his case, this was all of them. He did not endeavor for either himself or his students to understand the material as an interconnected set of evidence-based warrants for a set of principles, which could be used to explain and interact with physical phenomena.

Sam appropriated the central idea of the big idea construct from his MSU course to mean that students will learn things better if there are examples that they can relate to. Therefore, Sam pledged to aim for at least one real-world example for each class. Examples (i.e., data) for Sam took the role of visual aides that would assist pupils primarily in remembering information correctly. Laboratory activities played a similar role. Sam did not spend time in class describing or engaging the connections between observations made in lab and the ideas they were to illustrate. Instead, Sam would say things like, "You'll see what happens when you get to lab" or he would ask pupils to remember what we "saw in lab."

This simple association between the presentation of an idea abstractly through either lecture, reading or discussion, and "seeing it" in a laboratory activity, constitutes the relationship Sam endeavored to illustrate for his pupils. This is a narrative technique that builds the connections in memory between conceptual ideas and physical events. It does not build a paradigmatic understanding that would allow someone to understand "why this and *not* that." And it does not use data as evidence for a particular pattern.

Conclusion

I have argued that Sam has a narrative understanding of science. I have supported this argument by drawing on evidence from almost every part of Sam's teaching -- his planning, his goals, and his use of activities. We now turn to Jennifer, our second intern who also views science narratively, but does not share Sam's procedural focus.

Chapter 4

The Case of Jennifer

Overview

The case of Jennifer follows the case of Sam. Though both cases show that these interns exhibited largely narrative ways of knowing in their teaching practices, their practices had interesting differences in addition to their similarities. Whereas Sam tended to embed his narrative of chemistry of "what chemists do" with procedural knowledge and skills, Jennifer used hands-on activities and interactive strategies to bring to life the narratives of science she engaged. Jennifer's case also investigates one of the challenges that was inherent to her approach: the challenge of "uncooperative" illustrations of science.

Jennifer

Jennifer's Teaching Context

Jennifer completed her internship teaching 8th grade science at Maple Middle School, a well-regarded suburban middle school. Jennifer was well-aquanted with both the school and her mentor, Tom Gondwick, because the previous year Jennifer taught in Tom's room for her senior field placement. Tom had eight years of middle school science teaching experience, all at Maple Middle. Jennifer and Tom had a strong and cordial relationship that often included humorous jabs at each other during the course of the day. Tom told me early-on that Jennifer was already quite an accomplished teacher and that it was better for him to "stay out of the way" than to try to fix something that wasn't broken.

Jennifer majored in chemistry and initially intended to pursue her life-long dream to be a doctor. However, a summer stint volunteering in a clinic early in her college career proved to her that the overall time demands of the job were not to her liking. Her friends encouraged her to apply to the college of education, because she had the ability to explain difficult topics in clear ways. Jennifer noted she was a good science student whose favorite undergraduate course was organic chemistry though she also thoroughly enjoyed mathematics. However, she felt that teaching science would be more fun because of all the activities and labs. When offered a choice for why she wanted to be a middle school teacher between being interested in helping kids become "good people" or being able to teach science content, she emphatically replied, "to teach science!" Though she also acknowledged a sincere affection and concern for kids, the reason Jennifer wanted to teach was centered squarely on science content. In particular, Jennifer wanted her students to be well-prepared for both high school and college science courses.

Jennifer enjoyed a tremendous amount of autonomy during her internship year. Though still relatively inexperienced, her planning and preparation for class coupled with strong interpersonal and classroom management skills enabled Jennifer to largely teach what and how she desired. It was evident across the year I observed and talked with Jennifer that she thoroughly enjoyed teaching. She even made a point of emphasizing that she enjoyed grading papers and lesson planning. Overall, it was clear that Jennifer's students enjoyed being in her class, and she enjoyed being with them.

Jennifer and her Teaching Practice

The science lesson I describe here is from a Tuesday in March 2003. As with Sam, this lesson was selected because it was representative of the lessons I observed

Jennifer teach. Also as well, this lesson included a rich variety of instructional elements. However, this lesson differed in an important respect from Sam's in that here something didn't go as anticipated. That there was such a surprise was actually not typical of my observations of Jennifer's teaching. In fact, Jennifer was a meticulous planner whose preparation left little to chance, and her knack for anticipating students' reactions contributed to most lessons being taught without a hitch.

So why might I choose to describe a lesson that didn't go precisely as planned? I do so for two reasons. First, the preparation and teaching of this lesson was consistent with all other observations I made of Jennifer's teaching. So, despite the surprise, it remains representative of her larger practice. Second, the practices that Jennifer engaged in this lesson allow me to complement and extend the analysis of teaching practice begun with Sam's teaching. In doing so, I develop more fully the argument for the ways in which narrative ways of knowing both constrain and enable future learning. This case demonstrates that narrative sophistication alone fails to provide the necessary resources and opportunities to learn science in a paradigmatic way.

The lesson I describe in detail shows how Jennifer taught magnetic fields due to permanent magnets. Though initially, (and generally) satisfied with this lesson, in our subsequent conversations about the lesson, Jennifer recognized that there were some problems with how things went. This lesson consisted of a brief discussion of a previous test on electricity, and then a set of activities were engaged to introduce students to magnetic fields. The central activity was for each student to use a compass to map the magnetic field lines of a small bar magnet onto a sheet of paper. This activity was followed by Jennifer's concluding demonstration on the overhead projector using the same type bar magnet and iron filings, after which students answered questions on a handout about magnetic fields.

The Lesson on the Magnetic Fields

Jennifer stood behind the demonstration table at the front of the room as her students rushed into class. Because there was a short four minute passing period, students had to transition between classes quickly. To communicate explicitly when students became tardy, Jennifer would count from five to one out loud—if you weren't in your seat at the count of one, you were tardy. Unfortunately for Don, he was still walking across the room at "one" and Jennifer said, "congratulations Don for being tardy" as he made his way to his seat. Don shrugged his shoulders and sat down. Jennifer told Andy, another student, that she had a "chore" for him which was to "pass these [papers] out as fast as you can without running, thank you." Andy hopped up from his chair and quickly passed out papers as Jennifer finished taking roll. An efficient two minutes after the bell had rung, and Jennifer was ready to start class.

As she walked to the front of the demonstration table, Jennifer told the class that there were a couple of announcements to make. First of all, she asked if "there was someone who could tell her when the 'home projects' were due?" A student raised her hand, and said "Thursday!" Jennifer acknowledged that was correct, but then announced that she was going to change this due-date and push it to Friday to give them an extra day. Many students voiced their appreciation for this extension. Jennifer then reminded them about another semester project that would be due the next month on simple machines. A student asked what Jennifer "meant by simple machines", and Jennifer turned the question to the class. "What are simple machines? Somebody give me an example..." A girl says, "a see-saw." Jennifer acknowledged this and repeated, "A see-saw. A see-saw is an example." Another student said, "levers, inclined planes..." another offered "pulleys." Jennifer repeated, "inclinded planes, pulleys—all good examples." Further examples ventured by students included screws, a wheel and a wedge. While these last examples were stated, Jennifer was transitioning to her next activity as she turned on the overhead projector and organized a short stack of transparencies.

I find it interesting in the interchange about simple machines first that the student asked, "what do you *mean* by simple machines?" and second that only 'examples' were given as a response. This seems to be another instance of the illustration of ideas/concepts/facts. That examples should suffice is an interesting threshold for explanation. There are of course, other things a teacher might choose to emphasize when asked, what is meant by simple machines. I don't have the "definition" here, but simple machines for me are ways of doing work that reduce the amount of force needed by increasing the distance through which that force is exerted. I know that there is something technically incorrect about that last bit, "distance through which that force is exerted" but simple machines make work easier is the bigger point. Simple machines can also be though to answer to some kind of technological question—How can I lift this? How can this be moved?—no such questions were brought to light, and for the student, I would argue that the responses given leave to chance that these questions would arise on their own. It is also interesting that for the students, this was an acceptable response to the question of "what do you mean?" In an important way, it might be quite literally true. What Jennifer meant by "simple machines" was the ability to generate a set of examples.

Now, it is important to note that I am not arguing that Jennifer does or doesn't know more about simple machines. In the context of the above announcement, Jennifer was preparing to do another activity and was simply aiming to remind students of an upcoming assignment. She likely had not planned to discuss simple machines here, and may have responded as she did because she knew that they would address the issue in much more depth at a later time. I am noting however, that the responses given to this question—from a learning opportunity perspective—provide at best, only illustration of the term simple machines. Further, there are actually six general classes of simple machines and the examples given were only a haphazard subset of these six. This fails to provide the opportunity for the student to recognize that actually the screw and inclined plane (and wedges) are the same simple machine.

The papers that Andy passed back were students' recent tests on electricity. Jennifer began by her discussion of these papers by explaining that "the multiple choice (problems) were worth two points each." She reminded the class to pay attention because she was "not answering these questions again" so she wouldn't have to answer them "six times" to people individually. She next placed a transparency of the second page of the test on the overhead and explained that each of the first three problems here were worth two points and the last question was worth "one point for each type of energy" for a total of three points. Jennifer asked if there were questions, and a student asked how many points a problem on the next page was worth. She told him they would get to that.

The next page of the exam Jennifer noted was the page that "most people did bad on. This page is worth ten points, the first question is worth four points. two of those points came if you just said, 'no, it does not light.' The second two points came if you said, 'it doesn't light because of least resistance.' That was the phrase I was looking for—least resistance. That's why the light bulb doesn't light. Electricity takes the path of least resistance through that extra wire." The next question, number twenty, asked "what is the difference between current and voltage." Jennifer noted that this was the question most people "did bad" on. On the overhead, as in Figure 4.1, she wrote the following in the exam's answer space:

+ 6

Current—rate of electrons flowing

Voltage—potential difference

Figure 4.1. Electricity exam "answer" on for question 20.

She noted that for the first part, "a lot of people forgot to mention 'rate' or how fast they're flowing" and for the second part, she said that she wanted students to explain what 'potential difference' meant—that if you just wrote it down, you lost two points. A student said he didn't realize that he needed to elaborate on the phrase, 'potential difference' to which Jennifer responded that, "when you have questions like that, you need to explain everything—ok..."

She put the third page of the exam on the overhead, and had written both the correct answer and the point values in the answer spaces. Jennifer noted that this third page went well for most people. She introduced the fourth page as she placed it on the projector, with "then the last page is four points, four points, and the extra credit was three points. Are there any questions, comments or concerns? [short pause] Ok, what I want you to do..." and she then gave instructions about what to do with their copy of the exam and then hand it in. The only questions asked by students were the two noted previously.

While students passed in their exams, a couple of students came up to Jennifer to ask for clarifications about individual questions. One girl thought the thought she missed only three points instead of four, but she didn't remember that the multiple choice problems were worth two points. A boy explained to Jennifer that he in fact "put the symbols" on the diagram, and so he didn't understand why he lost points. Jennifer replied that "they weren't the proper symbols" to which he said, "oh, I thought they were." "Nope—they weren't the proper symbols, that's why you missed a point." The student said "oh" and went back to his seat.

In this exchange, Jennifer did not show the student what the correct symbols were, and the student didn't ask—nor did he appear to want to know. He simply turned and went back to his seat. This brevity was typical in situations where grading was in question. As is the case with many interns making decisions about grades is difficult and it was so as well for each of the interns I worked with.

Before Jennifer transitioned to the next activity, she asked another student to quickly pass out a stack of handouts. So far, only ten minutes of class have transpired. It is worth noting that it is no small feat to get a class of eigth graders' attention; and to have passed out, discussed and collected a test and in ten minutes and be ready for the next activity—which she introduced as follows.

> "Ok, the next thing that I want you to do is take everything off your desk, all you need is a pencil or a pen to write with. And the sheet of paper that Alexis is passing out to you." The students cleared off their desks and Jennifer referred to

the handout as she said, "ok, the first question on there is 'what is a compass?'" Jennifer holds up a compass and shows the class. "This is a compass. What does a compass do? Raise your hand. Tell me what a compass does." The student Jennifer called on said, "says which way north is." Jennifer nearly repeated this (substituting *points* for *says*) and said, "points which way north is. How does it know which way north is? Perry?" Perry said, "because it follows magnetic north." Jennifer repeated, "magnetic north...magnetic north of what? Does anybody know? Cassie?" Cassie said, "The earth's magnetic field?" "Yes," confirmed Jennifer, "it actually detects the earths magnetic field." And Jennifer then placed an overhead transparency on the projector that showed a diagram of the earth with magnetic field lines coming out the top and bottom of the round earth and connecting in broad, circular lines. Also labeled on the diagram, though not mentioned by Jennifer or the students is the word, "Magnetosphere" which was near the outer edge of the nested set of field lines. A student asked why the diagram wasn't symmetrical, (the representation included the magnetic influence of the sun, so one side of the diagram differed from the other), and Jennifer said, "because of stuff we're not going to discuss today. But later, if you want to come we'll talk about it."

Jennifer moved away from the projector and addressed the class, "What else do you know that has a magnetic field? It's something really obvious that would have a magnetic field." A student offers, "a refrigerator," and another says, "a magnet," after which Jennifer repeated, "a magnet! How could we show that a magnet has a magnetic field? What could we do? Mathew?" Mathew replied, "stick it up to the compass."

Jennifer, apparently agreeing with Mathew, said, "we could use the compass to detect the magnetic field...what we are going to do—well first, before we continue on, I want you to write down what a compass is. It detects a magnetic field, usually of the earth—pointing north. Ok, so under there I want you to write in your own words what we just discussed about what a compass is. What does it detect?" The students wrote down their responses on their handouts. After a couple moments, Jennifer transitioned to the next activity.

"Ok, the next thing that you're going to do, is with your partner or in your table-groups, is you're going to detect the magnetic field of the magnet. Ok, there are a couple of simple things that you're going to be careful of. What you're going to do on your paper in that big box, that's where you're going to work—you're going to place your magnet in the center of this box and you need to remember which way the magnet's pointing. [The handout is a sheet of white paper with a large rectangle printed on it. There are some questions typed on the back of this paper as well.] You should put the words [printed on the magnet] facing up. Then what you're going to do, is you're going to take the compass and you're going to place it all the way around the magnet."

Jennifer stood at the front of the room during this explanation and demonstrated where to place the magnet on the handout as she held it up in front of her. "I want you to note which way the north arrow—which is the red one—points all the way around. So you're going to put it next to it, and if the arrow is pointing out, you're going to draw it pointing out—ok? Or whichever way the arrow is pointing—I want you to note it on your paper. Ok, are there any questions about that? Ok, when we are doing this activity, I want you to stay seated—don't wander around the room—if you have a question for me, just raise your hand. Who would like to help me hand out magnets? Cassie? Just give a magnet to each pair of people ok?" Cassie took the tray of magnets and started to hand them out.

Jennifer then followed Cassie and handed out a compass to each pair of students. Not long after, Jennifer went around the class and assisted students to get started. She advised students to center the position of their magnets with respect to the box on the paper, and confirmed that they were "doing good." The students were all quickly engaged with the activity, and Jennifer walked around responding to various pairs. One student asked if she was doing it right, and Jennifer explained, "you might want to do a bunch [determinations of the arrow direction of the compass] around the ends[of the magnets], and then maybe a couple spots in between. *What you want to do is you want to see a pattern around the magnet* [italics mine]." I think that it is worth noting here, that Jennifer told the student that "what you want is to **see** a pattern." I argue that this is a different endeavor than wanting to "find" a pattern. To see a pattern in a physical phenomena is to seek *illustration* of an idea or concept. This is different than attempting to find a pattern—which is to find some regularity and then endeavor to explain it with respect to an idea or concept. I claim that this difference between trying to "see a pattern" and trying to "find a pattern" is an instance, which will be repeated in kind, of the narrative knowledge representations Jennifer used in her teaching.

Jennifer continued to circulate around the room. Many times, she advised students to focus their efforts with the compass direction near the ends of the magnets and she encouraged students to make many notations. As well, she frequently reminded students that they were to "try and see a pattern." For a student who was getting frustrated, Jennifer defused the tension with a gentle chuckle, and assured her that she was actually closer (to the correct pattern) than she thought. Jennifer told her to continue recording the compass needle direction and again, to "try and see a pattern." Another student told Jennifer that he had found the pattern with just two arrows. Jennifer said, you couldn't see it with just two, and that you needed instead, "maybe six or seven." So the student reluctantly put the magnet back on the paper and continued to make observations.

For another set of students Jennifer asked them, "look at these three arrows. If you were going to try to draw a line to connect them—including the magnet—how would you draw that?" The student replied, "a straight line?" Jennifer then traced with her finger on the paper, "well this one is pointing this way, and then this one is pointing back towards the magnet. So kind of out the magnet, around, and then coming back in." The student appeared to not yet recognize this pattern, and pointed to one arrow line and said, "this one ought to be pointing the other way." So, Jennifer suggested that the student continue to make notations of the compass direction nearer the ends of the magnet so she could see better what the pattern was. Jennifer then moved to another table and advised a student to check an arrow that seemed to point in the wrong direction—she said it looked "questionable." The student's partner said to Jennifer, "no, check it out—see?" as he demonstrated that their observation was accurate. Jennifer said that this was because he was holding the compass too far from the magnet—and that he needed to hold it closer. As he continued to try to get a different reading, Jennifer moved to a different group. When a student in that group said, "but this arrow is pointing the other way" Jennifer replied, "I know, that one is kind of a tricky one" and then went to help a different student.

As Jennifer continued around to assist other students, I trained the video camera on three students' papers as they were recording the compass arrow directions as they moved the compass around the magnet. In each of their diagrams, there were arrows that pointed directly inward or outward to the longer sides of the magnet. This was not the direction that I was anticipating. At the time, I recall thinking that these students had not made careful recordings—but later, as I reviewed the video, I could see that the camera clearly recorded the compass arrows pointing directly into and out of the longer sides of the magnets. The students were indeed making accurate records of their observations.

After 18 minutes of the magnetic field activity, Jennifer moved to the front of the room and got the class's attention. "Ok, sit, sit sit! Sit, sit, sit—I'll answer your questions in just a second" she said. After a couple of questions not directly related to the activity, including 'what would magnets do if there was no gravity?', Jennifer announced that she would now "show you what the magnetic field looks like, using iron filings and one of your magnets...Ok, so what I am doing—at this point you should pay attention, so stop playing with your magnets on the table. Andy! [Andy stopped playing]. Everyone should be looking this direction and not playing with their magnets. What I'm going to do is put iron filings on this overhead transparency." As the class watched the screen, Jennifer laid a transparency on the projector, and then carefully shook the fine, black filings onto it. She noted that "you can actually get this [iron filings] out of Total cereal." On top of the sheet with the filings, Jennifer placed another clear transparency sheet to effectively shield the filings from the magnet that was soon to follow. "Now I'm going to use Andy's magnet here. Let's hope that it works!" She placed the magnet on the overhead and the following pattern observed:

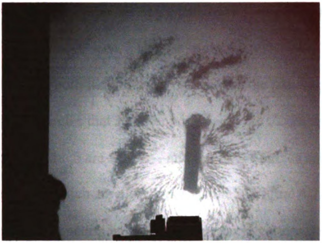


Figure 4.2. Magnetic field pattern demonstrated on overhead for magnet and iron filings.

Jennifer looked up from the projector and asked the class, "what kind of pattern do you see here?" A student blurted, "it's the magna-doodle!" Another said, "circles," and so Jennifer made circular motions over the top part of the filings with a pen as she said, "you see circles?" Then she asked the other student, "the magna-doodle? Is that [like] an etch-a-sketch?" Several students commented on these toys before Jennifer redirected their attention to the overhead. She used her finger to trace along as she explained, "So what you should have seen, is some type of swirling pattern. Where at the top, if you'd done it really good, you would have seen a tiny circle at the top, and then circles that continued all the way down to the bottom. Like this." Jennifer moved her finger from the upper short end of the magnet to the lower as she spoke.

There are a couple of very intriguing things to note in this last section. First, Jennifer placed the magnet on the overhead and asked the class what "patterns do you see." Of the responses that the students gave, only one was related to the pattern. This was the single word, "circles." The other comments were about toys. "Circles" was then taken up by Jennifer to describe both the filing pattern shown on the overhead, as well as the pattern that "you should have seen." The use of the word "circles" served as a vague referrent to denote either or both the observed pattern and the pattern you should have seen. These two potential circles that Jennifer considered are the "tiny circles" at the top short end of the magnet—which are visible—and the larger circles connecting the top to the bottom of the magnet—which are clearly not visible in Figure 4.2. I claim that Jennifer glossed over the distinction between the two circle patterns because the student's comment provided a narrative bridge between the demonstration and the image of magnetic fields that Jennifer wanted students to learn.

Jennifer kept the bar magnet on the iron filings for 45 seconds before she said, "so if I take this [the magnet, filings and transparencies] out, I'll draw [the pattern you were supposed to see] with the overhead pen." Jennifer carefully collected and poured the loose filings back into a vial. She took out a clean transparency and wrote on it as she explained, "generally, what you would have seen -- a lot of people saw arrows like this or very similar to this. If we were going to draw the magnetic field, we could just connect these with a half circle. Ok, magnets have a north and a south end. So, if the north arrow [here at the top] is going away from it [the upper end of the magnet], does north attract north?" A student offered that, "north repels north." Jennifer repeated this, "North repels north. The north arrow's away on this side, so it would be what—the north or the south?" Andy said that it was north, so Jennifer wrote an "N" on the upper end of the magnet. Jennifer asked him to explain why. He replied that he had a "50% chance" to which Jennifer smiled and said to him, "no...do you know why? Which way is the arrow pointing—away or towards?" Andy said, "away" and Jennifer repeated this, "Away. The north arrow is pointing away from the north side." Figure 4.3 below shows the drawing that Jennifer made while conducting this discussion.

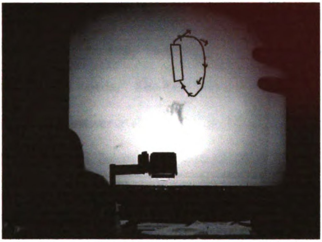


Figure 4.3. Diagram of "what you should have seen" for the field-line pattern with compass direction arrows.

Some students then commented about using a compass if you were lost in the woods. They wondered why you would want to know which way north was. After Jennifer and some other students talked about this for a short time, Jennifer walked back to the overhead, and pointed to the diagram in Figure 3 while she said the following, "Well, anyway, that's what you should have seen!"

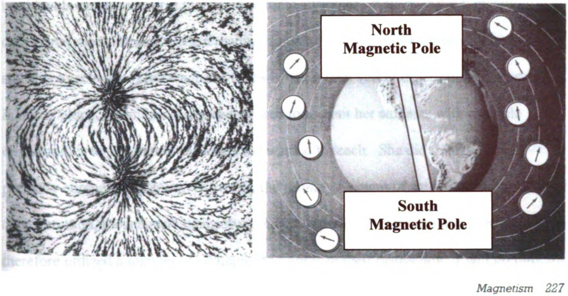
She then looked at her watch and said, "did I forget something? We're running way ahead in this class...What I want you to do for the remainder of the time, is to flip [your handout] over to the back side [Jennifer flipped over a student's handout at his table as she said this]. You should be able to get this finished by the end of the hour. What I want you to do -- this is in section 9.2 of your book. Ok, 9.2 you can answer the questions from. 9.3 will give you the answer to that second question. We'll talk about that one."

As the students took out their books, Jennifer helped coordinate so that each pair of students had a book. A student asked her what she wanted for the second question, "explain why some things are magnetic?" Jennifer came over to his table, and turned to the relevant section in the book. She said, "this section right here will explain. And I just want you to write it in your own words." She then told the class as a whole, that section 9.3 would be the place find the answer to the second question. As Jennifer next collected the bar magnets and the compasses, the students worked quietly at their tables on their questions. The last 20 minutes of the class period were spent working these questions and finishing up other homework assignments and their home projects. Jennifer spent a couple minutes of this time re-arranging materials to be prepared to conduct the same set activities for her science class, next period, and the remaining eighteen minutes consulting with students about their projects. At the end of the period, Jennifer concluded the class as she said, "ok, it's time to go. Make sure you turn in your sheet before you leave." The students got up and made their way out of the room.

Commentary on magnetic field lines lesson. First, from the lesson, it's clear that Jennifer had a well defined idea of what the magnetic field lines were supposed to look like, and she spent a lot of her time and energy trying to reconcile this view with the actual observations that students made. For instance, she assumed that the reason the compasses were not giving the anticipated direction was because they were too far away from the magnet—so she advised students to look very close to the magnet. When students claimed that they found arrow directions that pointed directly to the long side of the magnet, Jennifer dismissed this observation as "a tricky one" and shifted students focus to the ends. Each of these efforts on Jennifer's part were efforts to make the phenomena fit the illustrative purpose she had hoped for. On some level, she "knew" that magnetic field lines went from one end to the other in a bar magnet. And it is also true, that I, even as a high school physics teacher who's read a fair number of books in his life, was completely shocked to see the iron filing pattern that appeared on the overhead. But, it is in how my reaction differed from hers that signaled to me that Jennifer was viewing the nature of the experience in a way different from my own.

Because I had an hour to wait until Jennifer was able to meet me for our interview, I took the opportunity to go to the library with one of the bar magnets and a compass so that I might do some investigating on my own. I made a detailed mapping of the compass arrow directions as I systematically moved the compass around the magnet. Because the arrow orientations remained at such odds with my own preconceptions, it took quite a while before the pattern that is now readily apparent became clear to me. One thing that doing this activity myself demonstrated to me was that the number of arrows necessary for me to find the pattern was quite a few. I made sixty-one arrow notations, which was many more than the number that Jennifer asked her students to make. Second, even with the arrows drawn carefully, it was not—at least to me—immediately obvious what was going on.

Jennifer used this activity as a visual aide for the content that she wanted her students to learn. In this instance, that content was that magnetic field lines came out of one end of the magnet and went into the other. In fact, diagrams supporting this view are included in the textbook used in the classroom as in Figure 4.4.



Figures 4.4. Magnetic field representations from the class textbook.

It is clear that both of these representations would support the pattern that Jennifer herself was attempting to help her students re-create. Also, both representations in the book would resonate well with the activities that Jennifer prepared for her students. In this way, Jennifer use of knowledge representations could be characterized as providing "real" experiences that coordinate with the representations in the text of magnetic field lines.

The question naturally is raised then, what would have happened if Jennifer *did* know what was happening with the bar magnets she used? Unfortunately, for this instance, there is no way to know for sure. But, there are reasons to believe that Jennifer might well have chosen to illustrate the idea of magnetic fields in a different way.

First of all, it is important to recognize the narrative force that assembling a large number of representations brings to bear on remembering an idea. I argue that Jennifer used hands-on activities for their motivational attributes. Activities are typically considered more interesting than reading a book or listening to a lecture. Allowing students to actually "see" magnetic fields is better than verbal description or illustration in books alone. Jennifer clearly endeavored to present her students with multiple opportunities to experience the ideas she wanted to teach. She did this in a nearly perfectly competent fashion. However, the primary element of student activity and demonstration, the magnets themselves, failed to perform to expectation. Jennifer therefore utilized a number of strategies to minimize their distraction. I will go through each of these in turn.

First, Jennifer made her way around the room to assist students in making correct compass notations. When students observed arrow directions that were opposite the canonical direction, Jennifer reassured them that those arrows were "tricky ones" and that it was ok to ignore them. Second, Jennifer had the students focus their observations at the ends of the magnets. Here the arrow directions are more sensitive to minute changes in position due to the concentration of field lines and thus, it was easier to interpret observed arrow directions as indications of the canonical depiction. Third, Jennifer did a demonstration on the overhead projector that actually was so different from the canonical view, that perhaps students viewed it as non-sensical. No students verbally challenged Jennifer's assertion that there were actually field lines coming from one short end of the magnet to the other -- when there clearly were not. I often have wondered why no students challenged her interpretation. It was not because the students were intimidated to venture questions or to express confusion. I observed many times in other situations, that these students were quite vocal and not hesitant to ask questions or state opinions.

Recall that one student wondered aloud what Jennifer meant by simple machines. Why then might it make sense for a class of students to effectively nod their heads in agreement in this instance? A possibility is that these students understood, at least intuitively, the role of demonstrations in Jennifer's school science classroom. Demonstrations were supposed to demonstrate something. If the teacher claimed that a demonstration failed to succeed, it was likely due to the nefarious and ubiquitous "human error" rather than something inherent to the phenomena itself. Therefore, students were positioned by their role in this classroom to observe the demonstration not as a test of the relationship between ideas and phenomena, but to see a "real" or "actual" illustration of an idea otherwise accessible only vicariously via lecture or textbook.

The following is from our post-observation conversation about the magnet lesson. I asked Jennifer about the demonstration and what was happening there. She explained why it was difficult to see the pattern in the filings. I had drawn a picture of a rectangular bar magnet about which we discussed why the field lines were hard to identify:

Jennifer: Actually, it's hard. It'd be nice if the school had real bar magnets but we don't. So you get these curves. And these ones that the kids pick up, and they pick them up going like this. [Jennifer used her pen to indicate field lines going in small circles at the ends of the magnet].

Mark: What do you mean 'they pick them up going like this'?

Jennifer: They'll see arrows like, they'll see one arrow going this way, and they'll see this arrow kinda go this way. This is what they'll observe. They'll see this one but it's fainter. Like this is the one that I want them to draw, and this is the one I point out when I go around to them. But this one is in there too—these round circles. Hard to differentiate between them.

Mark: See the part that was hard for me to get. Ok, is like, is this one even there? [I used my pencil to indicate a field line going from one end to the other]

Jennifer: Uh-huh. It should be. A lot of times—sometimes it's hard [to see]

Mark: Well, I know it *should be* in a bar magnet.

Jennifer: It *is* there! I *believe*[2] it's there.

What is important about this instance of Jennifer's reflection on her teaching is that she was frustrated that these were not "good" bar magnets, but not because they did not have magnetic fields. Because these magnets did not help her to tell the story of magnetic field lines -- she disregarded what they did do. Instead of seeing this as a challenge to her understanding of magnets, she choose to stay true to the story which she knew she wanted to tell. Instead of being able to use actual phenomena to support this story, she was required to draw a diagram of "what they should have seen." Jennifer was frustrated with the magnets because they did not play their intended role in the story she wanted to tell—a stance that differed dramatically from an effort to understand the behavior of this magnet and why it was strange.

In this narrative way, Jennifer used the theme magnetic fields to provide a series of experiences upon which an understanding of magnets could be formed. However, the way that Jennifer structured her lessons was more like chapters in a book than it was

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[2] *Italicized text* in the transcript denotes actual strong tonal speech emphases.

about some kind of conceptual understanding of magnetic fields. She was not compelled to look for the nature of the parallels across examples of phenomena. As such, the opportunity for students to see the examples as evidence for a deeper pattern was largely lost.

Commentary on the Case of Jennifer

Jennifer is an example of a pre-service teacher who understands science primarily along the narrative dimension. Her efforts establish connections across the examples of bar magnets were effective as *thematic illustrations* of the idea of magnetic fields. That is, that every magnet has an associated magnetic field. Though each of the activities and opportunities to engage in physical phenomena were narratively rich, the lack of a parallel structure across these examples and activities failed to provide authentic opportunities for paradigmatic pattern finding. The lack of a paradigmatic structure within which to organize these experiences and to create a set of activities that would encourage such pattern finding is absent from Jennifer's teaching. Jennifer saw her improvement as a teacher to be founded on her ability to find ever more interesting subject matter examples so that her teaching wouldn't get boring. Such boredom would result from getting stuck in the rut of an overly familiar story that in this case, was another chapter in the story of school science.

Considering the way that Jennifer viewed scientific knowledge to be largely narrative helps us better understand how her teaching made sense to her. Using the characteristics of narrative ways of knowing introduced earlier allows me to classify salient features of this analysis. First, Jennifer saw her planned activities as tied together by the theme of magnetic field lines. She wanted her students to have reason to accept the notion that magnets have field lines.[3] When these particular magnets did not conform to expectation, she deftly disregarded those aspects which detracted and stayed true to the storyline. She expressed frustration that the particular bar magnet failed to generate the clear representation of magnetic field lines she wanted to illustrate. Second, despite the recognition that the iron filings did not show the anticipated pattern, Jennifer remained convinced that the magnetic field lines were *still there*. For the given context of bar magnets, Jennifer accepted only the canonical version of the field line pattern. The third and final characteristic of narrative understanding is that the elements of the story must meet standards of internal consistency. Because the field lines shown in the text of a imaginary bar magnet through the center of the earth had lines emanating from the short end of the bar magnet, it was assumed that her demonstration do the same. When the bar magnet did not "perform" as expected, Jennifer chose to disregard the demonstration.

Interpreting Jennifer's teaching practice

In this section, I will examine both the content and ways in which this content are presented—I claim that together this constitutes how the subject matter is *represented*—to students to show that Jennifer relies on a narrative way of knowing science. I will draw upon the description of Jennifer's teaching already presented as well as instances

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[3] Notice the difference in phrasing between the previous sentence and the sentence "field lines are used to explain magnets. In the first, magnets are the main character and field lines are attributes. This is a narrative construal. In the second, field lines are a conceptual tool used to explain a range of phenomena, which is typical of a paradigmatic construal.

from across my observations and interactions with Jennifer over the 2002-2003 school year.

In doing so, I argue that Jennifer, like Sam, utilized a largely narrative way of knowing science in her teaching practices. However, there are at least two interesting differences between Sam and Jennifer. I claim that Sam might be characterized as helping his students learn to be successful in the narrative of chemistry as what chemists do and have done, with a particular emphasis on procedural competence. Jennifer also aimed to develop successful students in the narrative of school science, but she included a much greater emphasis on hands-on activities. These hands-on activities played a similar role to the procedural elements in Sam's teaching. Getting the right answer in Sam's class, was parallel to seeing the right illustration of a demonstration. In each case, there was a canonical procedure/illustration that was to be learned. Both interns accepted the knowledge in textbooks to be a goal of science learning. But Jennifer, due to her affinity for creating hands-on activities opened herself up to additional challenges as we saw in the magnets lesson. Therefore, Jennifer helps us understand how a narrative way of knowing science can generate difficulties by failing to provide the resources necessary to make explanations of natural phenomena.

Knowledge Representation in Practice: Questions posed and asked

Jennifer enjoyed quizzing her students on their knowledge. She often asked the whole class a number of questions to make sure that everyone was "getting it ok." She often reminded students that if they paid attention in class, and if they studied for the test, they would have no problems. Jennifer used praise often when students responded to her questions successfully. However, few of these questions required more than a single word or more than a correct association of response with phenomena. Seldom did Jennifer inquire about why a student responded one way or another. If a student responded incorrectly, Jennifer would typically say, "uhhmm, that's not quite right, can someone else help him out?" Though Jennifer worked very hard to prepare interesting activities and set for herself very high standards for the amount of knowledge she needed in order to teach something, her tests and quizzes often required only surface recognition of the situation for full credit. Even essay response questions were evaluated for the number of correct ideas embedded within the paragraph instead of for the ways in which those ideas were used to explain, or even illustrate, the phenomenon.

Interactions around Student Thinking

I was struck by the way that Jennifer looked at student's understanding as either "got it," or "not yet." In the lesson I observed where she taught about Lewis Dot Structures (LDS), she would give the students a molecule to express using LDS, and then walk quickly around the room to assess if students had it correct. She would typically just glance at a students paper, and then say, "not yet," "nope," "close," and the like. She did not try to explain what it was that a student had done incorrectly or correctly.

I also observed this interaction around other questions, when a student would respond in a way that was incorrect, Jennifer would say something like, "well, that's close…" or "not exactly." Or, she would just wait until another student said something that was close enough for her to continue. In effect, Jennifer employed a version of "verbal fill-in-the-blanks." For example, in the magnets lesson, Jennifer asked the class what also might have a magnetic field. A student said "refrigerator" and Jennifer just waited until another student offered, "a magnet" a comment that Jennifer repeated and allowed her to continue with her discussion.

I did not observe Jennifer asking students anything to the effect of how something made sense. Sometimes, she would ask if students were confused, but this was not to understand how students' might be confused from the student's perspective, but instead to identify exactly what, if anything, needed to be re-explained.

Knowledge Representation in Practice – Intern Reflections on Subject Matter

What do interns need to know? Jennifer had a very future-looking perspective on teaching. She was always excited about what she was learning for the next lesson, and less interested in thinking about lessons she already had taught. Jennifer was generally not interested in looking at the video tape of her lessons. When we did so, she focused almost entirely on her presentation style such as the way in which she spoke or what she was doing with her hands. When I asked what she might have done to improve a particular lesson, she responded typically with a variation of "I think I could probably have explained [some topic] more clearly, or done a few more activities."

She did have difficulty thinking of anything that she learned during the first part of the internship, with the possible exception of some management issues. Jennifer felt that she planned the same way she did during her senior-year placement. She would typically consult up to five textbooks and the internet in search of activities and ideas that would be interesting for students. She would then decide based on available time and school resources, which of the activities she would do and in what order to do them.

What is hard/easy about their subject matter? Jennifer felt that subject matter preparation was exceptionally important. She prepared extensively for the lessons that she was going to teach. As for the subject matter knowledge needed to teach middle school, Jennifer did not see it as being very difficult, and that the larger problem was how to present ideas so students would find them interesting and educational.

Knowledge Representation in Practice – Planning for instruction

Objectives for student learning. Jennifer was very concerned that her students have the kinds of experiences in middle school that would facilitate learning later in high school and college. She prepared a rich set of experiences in the form of hands-on activities for her students. Jennifer believed that school should be fun but only if there was an educational purpose as well for each activity. To find and develop fun and educational activities was a top priority. Typically, the first step in this effort was to consult the textbook adopted by the school. And because Jennifer worked very hard to create interesting lessons, it was not uncommon for her to also consult up to five additional textbooks (ranging from other middle school books through her own college level texts) as well as to routinely search the internet for more innovative ideas. Along with ideas suggested by her mentor, these resources provided the basis for assembling activities that would interest and engage students in the ideas she wanted to teach.

Jennifer identified her own views on science teaching as resonating with a view of inquiry teaching espoused in her teacher education program. More specifically, Jennifer readily acknowledged the desirability of engaging students with "examples from the real-world." She believed that students learned best when they had chances to do hands-on, exploratory activities. Jennifer therefore sought to utilize a large number of activities as well as examples for the topics she aimed to teach.

From her curricular resources, Jennifer looked to identify a theme or common idea that could be woven through a set of activities. In the earlier lesson, Jennifer focused on "magnetic field lines" as the theme that might suitably connect the series of activities. She organized a set of hands-on experiences that allowed students to connect the representations in their books with actual interactions with the phenomena. It is interesting that in her plans for these lessons, in addition to descriptions of the activities, she included a large amount of information about magnetic domains, un-paired electron spins, and para- and dia- magnetic effects. Such information is typically considered to be too advanced for 8th grade students and was not explicitly a part of any of the activities she had previously noted. When I asked her if perhaps she included that information because she had to turn in her plan for a teacher education course—she said, "no, I don't have to turn in this plan—it's just for my own information. Like if a kid asks me a question then I'd have this to fall back on."

University teacher education assignments. Though Jennifer used the lesson plan template provided by her teacher education program, she adapted its use for her own needs. For instance, the section where objectives were to be stated remained blank. This was not surprising, Jennifer often struggled to meet the expectations of her program for generating learning objectives. The teacher education program placed a strong emphasis on thinking about objectives and their relationship to the design of educational activities. Jennifer noted late in the internship that she never really understood the differences between the types of objectives, and that she always referred back to the TE handout to make sure she submitted objectives of the correct form. Often, for Jennifer, this required making simple verb substitutions from her intended objective to one more likely to meet the favor of her instructor. For example, changing her initial objective from "the student will understand how magnets work" to "the student will explain how magnets work." The first phrasing did not indicate how "understand" was to be measured and is therefore problematic from an assessment standing as well as from a theoretical stance that pushed for clarity of learning goals. Jennifer often would submit lesson plans for instructor evaluation with the initial expectation that she'd not do well. She then chose to re-work and re-submit coursework in an effort to improve her grade. She often directly incorportated the feedback regarding the wording of objectives (and other aspects) in her re-submission. The important point being that for Jennifer, this was largely a game of form, rather than of substance. For her, the differences in objectives did not map onto meaningful distinctions for what it meant for her to design activities and prepare plans. Unsurprisingly, teacher education assignments such as lesson and unit planning were generally seen by Jennifer to be overly time-consuming and poorly aligned with the actual work of learning to teach science.

Conclusion

I have argued here that Jennifer like Sam before her construed science narratively. Evidence for this has been drawn from throughout her practice and in the ways in which she engaged with examples. The larger narrative of science that she constructed with her students is that science is connected to personal experiences. The role of hands-on activities played a similar role to the role of procedures in the case of Sam. Each served to illustrate the central theme of their teaching. For Sam, this was that chemistry is learning to do what chemists have done. For Jennifer, this was that science is something that is all around you if you know where to look. The third and final case, the case of

Carol, shows how knowing science paradigmatically played out quite differently in her teaching practice.

Chapter 5

The Case of Carol

Overview

This is the final of the three case studies. The first two cases showed how interns' narrative ways of knowing science shaped their teaching practices. This final case, the case of Carol, differs from the others in important and interesting ways. Carol's teaching practice evidences a blend of narrative and paradigmatic ways of knowing science. It details the ways in which Carol developed students' abilities to use conceptual tools to make explanations of experiences in paradigmatic ways, and doing so using by embedding experiences in narrative structures. It is important to keep in mind that the description of the lesson that follows is not intended to demonstrate "student-centered," "inquiry," or other reformist visions of pedagogy. In fact, it is perhaps none of these. Rather, the lesson and analysis that follows highlights what is distinctive about Carol's way of knowing science and how her blend of narrative and paradigmatic ways of knowing science shaped the opportunities for learning in her classroom.

Carol

Carol interned at suburban Northridge Middle School and taught 7th grade science. The students at Northridge typically lived nearby in the growing neighborhoods surrounding the school. Built in the last 5 years, Northridge was spacious; yet designed to allow grade level teams of teachers to work in close proximity to each other. Each wing of the building was designated to such a team and these teachers taught the same subset of students. Carol majored in biological sciences and minored in chemistry and earth science. She was a strong student and considered a number of options, including application to medical school, before deciding to become a teacher. Because of her interest and ability in science, Carol initially was concerned that middle school science would not have "enough science" in the curriculum for her to remain interested. Carol wanted to be a positive influence on her students affectively as well as intellectually, but her primary reason for teaching was centered on science content . Carol's mentor came to middle school initially as a 6th grade teacher, and over the course of her 10 year career moved into 7th grade science. Carol and her mentor, Susan Karnofski, had a strong mutual respect for each other, and Carol found her mentor to be especially helpful for non-content related instructional issues. With respect to science however, Carol found it more useful to consult other resources, primarily her teacher education course instructors and classmates as well as a close personal friend who was an experienced science teacher.

Carol had a tremendous amount of autonomy to teach what and how she wanted to. Because of her strong interpersonal and classroom management skills, Carol did not often struggle with student discipline. By and large, Carol was able to count on the cooperation and enthusiasm of her students to engage in her lessons. Therefore, Carol was able to devote considerable time and effort directed toward the challenges of teaching subject matter.

Carol and her Teaching Practice

The lesson that follows shows important elements of Carol's teaching practice. The lesson is from the fourth week of a five-week unit on heredity & natural selection, and is the second day that natural selection is engaged. The students had previously read a section of their textbook and defined some of the central terms used to describe natural selection. This lesson extends that work to begin developing an understanding for how natural works and how to make good explanations in terms of the natural selection model Carol developed.

Lesson on traits, variation, and natural selection. "All right fifth hour. It's time to be in your seats please," announced Carol as the streamed into class. Her students were seated at their desks arranged into groups of four. Carol asked the students to get their homework out so she could check it for completion. She went quickly to each group and said something to each student such as, "Good job, Kyle" "Thank you, Benji" "Good work, Jake" as she recorded their homework performance on her clipboard. One student, Sean didn't have his homework done, and Carol told him that he would therefore get a zero for completion, but to get the handout out anyway so he could record what they were going to do in class today. Another student received half credit for partial work. After Carol finished checking student work (this took just over two minutes), she pulled down the projector screen and said to the class, "Ok, we're going to go over this together. This is your opportunity to make changes. You are going to look over your tool, and see if you need to add things or change things. You're also going to use this time -- if you weren't here -- you can use this time to copy the information down."

The handout that students are referred to while Carol spoke was called the "Change over Time Tool." This "tool" was a paper handout, and is reproduced in Figure 5.1 below. Carol designed it as an aide to help her students learn natural selection. A detailed analysis of this tool and its use in Carol's class will follow the description of her teaching. The lesson preceding this one introduced this tool to the students and the class was ready to continue where they left off previously.

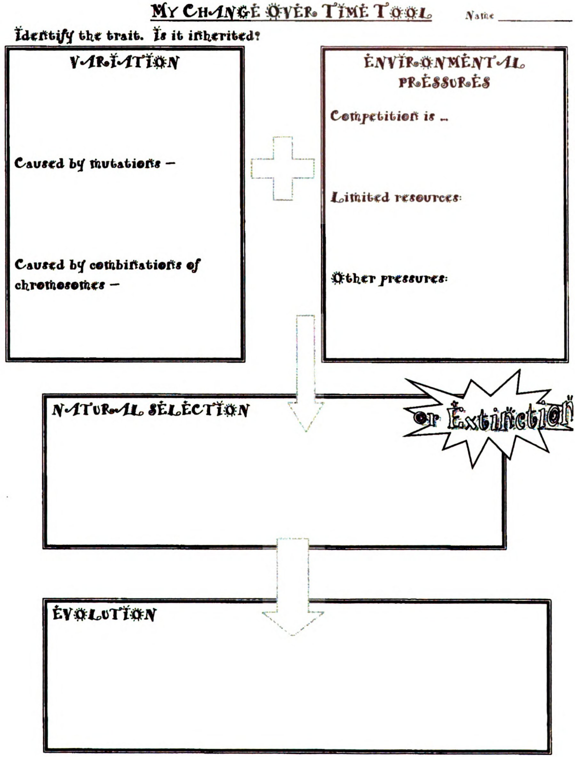

Figure 5.1. The Change Over Time Tool.

The PowerPoint slide Carol prepared was projected onto the screen. The first slide showed this:

VARIATION

Differences in quality of a trait among organisms

Only genetic variation can be passed to next generation

Caused by mutations--

Changes in DNA – these chance occurrences create NEW traits

Caused by combinations of chromosomes --

Different combinations of chromosomes in egg and sperm cell -- this causes each organism to have unique genes, and therefore unique proteins, and therefore unique traits!

Figure 5.2. PowerPoint slide: Variation.

As Figure 5.2 was projected on the screen, Carol explained the following as she helped students to coordinate this PowerPoint slide with the *Change Over Time Tool.* "So this is the first box, the one up here on the left -- the one about variation. And you can see that I've put down the definition of variation that we've been using all throughout this unit." She read what was on the screen below "variation" and pointed out that she also included a more specific note about "genetic variation." She continued, "We've talked about genetic variation being caused by mutations, where mutations are changes in DNA. It also says up here that these changes are chance occurrences that create new traits." She walked to the screen and pointed to the words "chance occurrences" as she said, "This phrase, 'chance occurrences' means that it happens. And occurrences means it happens, that it happens by chance. It doesn't happen on purpose, and we can't predict when it will happen, but these changes in DNA just happen by chance and they create new traits." Carol paused for a moment to let students write their notes and then continued. "We've also talked a lot about how variation is caused by combination of chromosomes. And we did that paper creature project where we pulled different chromosomes from the different bins, and we saw how chromosomes that end up in an egg cell or that end up in a sperm cell, create variation in all the offspring that are born." She paused again while students continued writing.

"Let's talk about variation that might not be genetic. What would be variation that would not be passed on to offspring. Because we said that variations are differences in the quality of a trait. And some traits are not inherited, some traits we've talked about are acquired. So let's give ourselves an example of a trait where there would be variation, but that could not be passed on to the next generation. Just to be sure that we're clear. What might be an example?" A student suggested, "What if you poured a can of paint in your hair?" Carol said, "Ok, if you poured a can of paint in your hair? So, let's say that there were lots of people in town who painted or dyed their hair. So this is a trait -- dyed hair -- and there are lots of people in town that have done this. So there's variation. Maybe some people have dyed it all black, maybe some put stripes in, some maybe dyed it green. So there's variation in this trait, but none of those people would have children that have the dyed hair color. So Kevin, that is a really good example. Variation can exist, but cannot be passed down to offspring. Good. Raise your hand if you (still) need this slide up?" A couple of students raised their hand, and Carol said, "Ok, another second."

"Ok? Good. Our next box is about environmental pressures. Yesterday when we looked at the cartoon with the four different flowers, we talked about competition as being the struggle of organisms for limited resources." Carol changed to the next slide that looked like Figure 5.3.

Environmental

Pressures

Competition is --

The struggle of organisms for limited resources

Limited resources:

Food, water, space, territory, mates, sunlight

Other pressures:

Changing climate

Figure 5.3. PowerPoint slide: Environmental pressures.

She continued, "And we said that in plants and animals, competition isn't necessarily like, hand-to-hand combat, and it's not mental like we might compete with other people to do well at something like a chess game. But competition among organisms is just a struggle for the limited resources that are available. We also talked about the different kinds of resources. We said that food was a resource that there was only so much of. Water is another limited resource. Space -- like when we talked about the seedlings that were growing, and that they need space. Another would be territory. Territory, specifically for animals is the space used either to hunt or raise offspring. And territory is very important for organisms. We also talked yesterday that mates are a limited resource because in some populations there aren't enough males for every female or vice versa. So there is competition among the organism to find a mate, or to find another organism to have offspring with. And we also talked about sunlight for plants being a limited resource. Besides limited resources, there are other types of environmental pressures. One would be a changing climate. So for instance, things like a drought or a very, very cold spell for a long time. That would be an environmental pressure. We also talked about chemicals. Chemicals that kill insects are called insecticides, and chemicals that kill plants are called herbicides. So that's what those two words mean. Antibiotics are really chemicals that kill bacteria. Kevin, you had a question?"

Kevin asked, "For limited resources, how can sunlight be a limited resource -- because there is only so much sunlight that is raining down on us? Are you talking about like how in forests, plants try to move to those spots where the sun goes the most?" Carol affirmed this and expanded on it. "That's exactly it, that's exactly what we're talking about -- and if you think about the bottom of a forest floor there's a lot of shady areas, a lot of places with not a lot of sun. If a seedling is trying to grow, it would be limited in the amount of sunlight that it gets. So that's a situation where sunlight is a limited resource. Ok? Will?"

Will asked the following question, "Couldn't predators be another one?" "Yes!" replied Carol, "And I was just about to ask if you could think of the one I forgot. Predators are definitely an 'other pressure' and you should add that to your list. And we were talking about predators yesterday when we were talking about those flowers with the hungry caterpillars. Predators are definitely an environmental pressure. Thanks Will."

Then Sean asked, "What about people?" Carol said, "Uhm, I think that people -- well, why don't you tell me what you mean about people." He replied, "Well, say like, people walking in the [inaudible] rain forest" Carol affirmed this, and said, "Uh-huh, people could be considered predators." Then Milly commented, "And like Sean was saying about the rain forest, we're killing the rain forest, so we're like predators." "You know -- that's another really good point," Carol said, "That probably -- like Sean said that humans are predators, we can probably add something into this 'other pressures' area something about land use. That humans do put pressure on the environment by choosing and controlling how we use land. And Milly's example was humans taking down the rain forest, I think that would definitely qualify as another environmental pressure."

Carol put another slide on the screen, and discussed it. "This slide goes with this box, part way down the sheet about natural selection, and yesterday in the evolution book that you read, you saw that the definition of natural selection is the survival and reproduction of those organisms best suited to their surroundings. That's the definition in your book. What that means is that some organisms survive and pass their traits on to future generations." Carol paused briefly to let students catch up. "Not all organisms necessarily survive, and natural selection is the process where suited organisms to the environment do survive and they're the ones that do have offspring." A student asked, "What about the 'or extinction' part." Carol replied, "The 'or extinction' part goes underneath this little bubble [she pointed on the handout as she said this]. Your book didn't have a definition of extinction in it; and this is the definition of extinction. The species no longer exists. All of the organisms died. So the species no longer exists. That's what extinction means. And extinction can happen if there's not enough, or not the right, genetic variation. We're going to talk more about what that statement means probably later. But it's important to realize that extinction does happen, that there are species that no longer exist." Carol paused to allow students to complete their notes.

"Ok, the last box on your sheet. What is the definition of evolution from your book? What did you copy down yesterday? Jackie?" "A change in species over time," she said. "Exactly," confirmed Carol. "Evolution is a change in species over time."

"Now we're going to talk a little bit about what these boxes mean and how they're connected to each other, then we're going to use them to try to answer some questions about how new traits show up in a population. So, let's look at your sheet here -- your *Change Over Time Tool.* This box," said Carol as she held up the sheet and pointed, "says, 'variation' and we're talking about variation in genes or genetic variation. What are the two causes of variation? In this box, what does it say? The two causes of variation?" A number of students raised their hand. "Camille, what's one of them?" asked Carol. "Uhm, mutations," offered Camille. "Ok, mutations are changes in DNA. What's another one, Mark?" "Combinations of chromosomes," said Mark. "Yep," affirmed Carol, "The way the chromosomes combine in the organism from the egg cell and the sperm cell. Ok? What about environment? Is there anything in this box, the box about variation, that tells you that the environment causes variation? Is there anything in this box that tells you that variation that can be caused by the environment? Right now -- is there anything in there?" Several students say "No." "No -- ok? There's nothing in there. Instead, we have a whole separate box that talks about environment pressures. And you can see in between we have the addition sign. That means 'and.' So genetic variation -- and or plus -- environmental pressures causes or allows natural selection. So in that plus sign at the top, you might want to write to yourself the word 'and' a note that means these two things have to work together. Genetic variation *and* environmental pressures work together to cause or allow natural selection to happen. So this first arrow that connects the top two boxes with the box about natural selection -- you might want to write 'causes or allows' in that arrow -- because genetic variation *and* environmental pressures work together to cause or allow natural selection to happen. If natural selection doesn't happen, or if there aren't any best-suited organisms to survive -- what's the other option? If natural selection isn't happening or the best-suited organisms aren't surviving -- there are no best-suited organisms -- what's the next option? Jackson?" "Extinction," he replied. "Extinction -- exactly" confirmed Carol, "These two things work together to cause or allow natural selection or extinction might happen instead. Ok? Over time, natural selection can lead to evolution. And that's what this bottom arrow means. It means 'can lead to.'" Carol indicated on the Change Over Time Tool which box she referred to. "And we're going to use this the same way we used the window pane in photosynthesis to help us figure out answers to problems about how new traits become established in the population. So leave these tools out. And I'm passing out an assignment called 'Ants and Moths' and we're going to work on it during the hour today, and then it will be your homework for tonight. You should add this as the next entry in your table of contents. Ok. Ants and Moths in the table of contents." Carol handed out the assignment and students recorded the assignment in their assignment journals, and then began reading it.

The invasion of the ants. Next, Carol put a new PowerPoint slide of a cartoon she made called "The invasion of the ants" (see Figure 5.4).

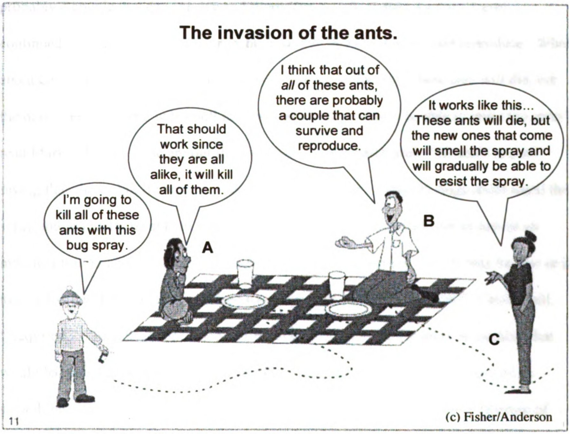

Figure 5.4. Invasion of the ants PowerPoint slide.

"All right, this is another evolution cartoon, and we're going to use it along with your *Change Over Time Tool* to help us answer all these questions about the ants. So, the cartoon says, 'The invasion of the ants' -- and it's also on your sheet -- this man with the hat and the bug spray can says 'I'm going to kill all of these ants with this bug spray.' What does the man with choice A say? What is his thought? Who would like to read that? Jackie?" Jackie read, "That should work since they are all alike, it will kill all of them." "Ok," continued Carol, "This person thinks that all the ants are exactly the same and the bug spray will kill all of them. What about choice B? What does the guy in choice B say? Taylor?" Taylor read, "I think that out of all of these ants, there are probably a couple that can survive and reproduce." "Ok, thanks Taylor," Carol continued, "So he says there are probably a couple that can survive and reproduce. What about choice C, what does she say? Mark?" "It works like this, these ants will die, but the new ones that come will smell the spray and will gradually be able to resist the spray" read Mark. "Ok, so these are our three choices," continued Carol. "If, and I'm not saying that she is, but if choice C is correct, if she is right -- that the bugs could smell the spray and gradually be able to resist it -- would that be an acquired trait in ants or an inherited trait in ants? Which one would it be *if* her statement is true. It may be true or it may not -- but if it is, is it an acquired trait or an inherited trait? Calvin?" Calvin said, "Acquired." "Exactly," confirmed Carol, "Because she's talking about something that would happen during that ants lifetime, after it was born, because it was exposed to something. And we said that acquired traits happened after you were born because of something that might happen to you. So what do you think is the right answer? A, B or C? What do you think Jackie?" "I think B," she stated. "You think B?" continued Carol, "That some ants will probably survive and reproduce. Ok -- Sean?" "I don't get this," said Sean. "Ok, what part?" inquired Carol. Sean asked a question about the "second big square" on his Change Over Time Tool. Carol told him that they were first going to work with the cartoon, and then they would work with the tool to explain what happened. So, they would address his question later. "So right now, just focus on the cartoon," she assured him, "And see if you agree with A, B or C. Chuck?" Chuck said, "C." "Tell us why you agree with C," beckoned Carol. "Because mosquito's adapt to those sprays, and you have to make them stronger," he explained. "Ok, so Chuck has information about mosquitoes -- a different kind of insect -- when they are exposed to bug spray that they adapt. Ok, Mark?" said Carol.

Mark said, "Like cockroaches, like whenever you spray for cockroaches and they adapt, then they come back and you can't spray them with the same thing," Carol replied, "Ok, that would be like in choice C, an acquired trait, where cockroaches acquire that over their lifetime? Ok. What do you think Tami?" This student replied, "Uhm, I feel that there are some bacteria that are getting stronger because they have to change the antibiotics because they are getting resistant." Carol explained in reply, "There *are* bacteria that are resistant to antibiotics, and actually we're going to talk about that situation probably tomorrow. So we're definitely going to talk about bacteria and antibiotics. Right now, when we're talking about the insects and whether or not resistance is an acquired trait, it's actually not. Resistance is actually not an acquired trait. Resistance is inherited. So bugs that are exposed to the bug spray; what's going to happen to them? If you're an ant and you're exposed to bug spray? Calvin?" "You're going to die," answered Calvin. Carol continued, "So over their lifetime, they don't acquire resistance. They actually inherit it. So, when we look at our sheet. What trait are we talking about? Camille?" "Resistance to bug spray?" offered Camille. "Exactly," confirmed Carol, "Resistance to bug spray. That's the trait that we're talking about. Resistance to bug spray. And that's what you can write in about this question, 'Identify the trait.' Sean, is this trait inherited?" "No," said Sean. "Uhm," Carol replied hesitantly, and another student said "Yes," which Carol picked up on to confirm, "Yes, this trait *is* inherited. Resistance is inherited. It is not an acquired trait. It is definitely inherited. And we'll come back to Tami's question about bacteria, and Chuck's comment about mosquitoes, but let's work through these questions together and see if we can come back to both the mosquitoes and cockroaches and *explain* [emphasized by Carol] what is happening with the mosquitoes and the cockroaches."

Variation in the trait. Calvin asked, "How can you inherit it if the ants die?" Carol confirmed this as a good question, "Ahh, this is a good question that Calvin has about how could inherit it, if all the bugs exposed to bug spray, die? Let's come right back to this question right after we do the next two on the sheet. So let's talk about the variation in this trait among the different ants. We said that the trait is 'resistance to bug spray' -- what could the variation be -- or how could we describe the variation among different ants? Any ideas? Will?" Will said, "like, some ants -- they are like more resistant to it, but the one's that are less resistant to it, they die?" "Ok," said Carol, "Good, so some ants have no resistance to bug spray. So that means, Will says, if they are exposed to bug spray -- they'll die. Is that the only option? What would be another option. If there is variation in this trait, Will says that some ants have no resistance. What might be some other options? Kevin?" Kevin said, "Some ants might have some resistance, and other ants might have just small amounts of it." Carol then said, "ok, another option that Kevin says is that some ants have some resistance. Or ants could have, maybe, complete resistance. And we don't really know, but we do know that there could be variation. So ants could be not resistant, they could be resistant or like Kevin says, they might be in between. They could survive a little bit of bug spray, but not a lot; we're not really sure. But this would be the variation in that trait."

Carol continued, "Now let's talk about what the variation is caused by. Now would be a good time to look back at that tool, and the box about variation to think about the possible causes of this variation. That the ants might, or might not, be resistant. What might be a cause? Jackson?" Jackson said, "uh, like it might be a mutation." "Good," said Carol, "Jackson says that a cause might be a mutation. And let's walk through how this would work. So, let's say that we have a mutation. What is a mutation? Tami?" Tami said, "The changes in DNA?" "Ok," said Carol, "Good. So changes in DNA. If there are changes in DNA, what would that mean for that small section of DNA on a chromosome? What do we call that small section of DNA that has a specific job? What's the name of that small section? Rick?" "Protein," said Rick. "It's not a protein. What is it -- Will?" Will said, "A gene." "A gene -- exactly," confirmed Carol, "So changes in DNA, if there's a change in that gene, we could get a new gene. What is that new gene in the ants body, going to tell that body to make? What is the new gene going to tell the ants body to make? Camille?" Camille said, "A new protein." Carol repeated this, and asked "So how will this new protein show up in the ant? Julie?" Julie said, "Maybe it can repel, I mean resist the bug spray?" "Ok," said Carol, "What is the word we use for that -- resistance to bug spray? Camille?" Camille said, "A trait." Carol repeated this and then said, "And that new trait is 'resistance to bug spray.'" Carol had written each of these parts on the whiteboard as shown below, in Figure 5.5:

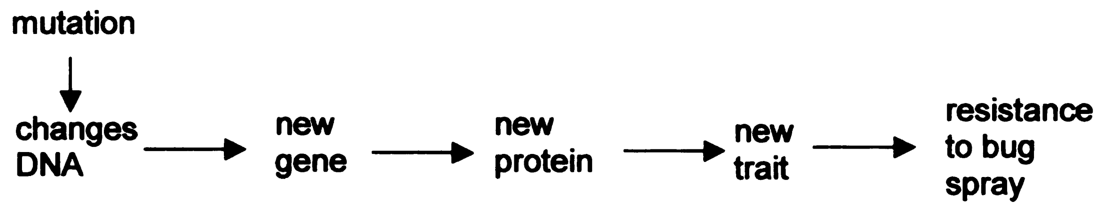

Figure 5.5. Whiteboard diagram for sequence from mutation to trait.

Carol continued, "And this is the sequence for how genetic information produces traits. So, if we have a mutation, we'll have a change in the DNA so we'll get a new gene in those ants. And those ants' bodies will produce new proteins that we will see as a new trait which is the resistance to bug spray. So if there's a mutation in the DNA it might lead to this trait of resistance to bug spray." A student asked, "Should we draw that timeline?" "Yeah," replied Carol, "I would draw this in the box where it says, 'what is this variation caused by' to remind you about all the steps that go through in between a mutation happening, or a change in the DNA, and finally the ants having resistance to bug spray. This is how it works inside the ants' bodies."

How traits in future generations get established. Carol paused for about a minute while students wrote on their notes. Carol said, "Now let's go back to Calvin's question. His question was, 'If bug spray kills all of the ants that aren't resistant, how would any of them survive?' So, how are ants going to survive if the ants that are exposed to bug spray die? How does this information in these two questions about the variation of the trait and then what the variation is caused by? How can we answer Calvin's question now? What do you think? Mark?" Mark said, "All those ants died, and then some other ants come and like, the bug spray is still in the air and so it's not that big of a dose to survive?"

"Ok," said Carol, "Mark says that maybe the second group that would come is exposed to less bug spray. This might be possible. But, uhm, remember that we said, that choice C in this cartoon is not correct. It's not the way it works. That choice C, that bugs that are exposed to bug spray could get resistance by "being around it" that that's actually not true. And we have to convince ourselves that that's not true, and the true answer is B. That there are a couple of ants that probably could survive. So if we look at choice B, and look at how we answered these (other) questions about variation, how can we answer Calvin's question about how does the ant population continue? Camille?"

Camille said, "Some ants have no resistance so they die. But some ants have some resistance so they survive a little and some have more resistance and they will survive. The one's that survive had a mutation and so they were resistant to bug spray so they will pass their genes on to their offspring." "Exactly!" said Carol, "That's exactly how it works. All the bugs that don't have this gene, they die, because they're not resistant to the bug spray. But some ants, just like it says in B, that there are probably a couple that can survive and reproduce, some ants -- just by chance -- have this gene, that tells their body to make this protein that makes them not sensitive to the bug spray. So Calvin's right about all the ants that aren't resistant to bug spray. They die. But out of a zillion ants, there's probably a few that just by chance, have this gene which tells their bodies to make a protein makes them resistant. And it would be those ants that would surive. Brian?"

Brian said, "What if all the ants that survived were male?" Carol said, "That's a really good question. What if all the ants that survived were male? And there were no females. What do you think would happen? Camille?" "Uhm, outside their colony, they might breed with others," said Camille. "Ok," affirmed Carol, "So one option might be that if there are other ant populations around that they could intermix and then breed with another colony. What might happen if that didn't happen? Tami?" Tami said, "They would probably die out because they couldn't reproduce." "Exactly," said Carol, "If there were no other females, and no other colonies that the males could get to -- maybe they're on an island of something -- if Brian's situation was true and the only ants to survive were male -- those ants would become extinct. Good question!" Tami asked another question, "Isn't it possible for certain traits and genes to show up in only one gender and not the other?" Carol replied, "Yes it is possible. And that has to do with the chromosomes that make us male or female, and sometimes, the information is just on a single gene -- there isn't a copy. And we call these 'sex-linked' traits."

"All right, let's return to our insect situation," continued Carol, "As we've been talking about these ants at the picnic -- what is the environmental pressure they've been under? The environmental pressure that is working with the genetic variation? Will?" "Chemicals?" said Will. "Yep! Chemicals," said Carol, "Specifically the bug spray."

"Let's look at this last bullet now. It says describe the natural selection that is occurring. What organisms are surviving to reproduce? So, we looked at different ants, and there are different varieties of this trait -- resistance to bug spray -- some are resistant, some aren't resistant, some maybe are in the middle -- we're not really sure. So how does this environmental pressure of bug spray combine with the variation so that only some of the organisms survive? We're looking at which organisms would survive? Camille?" Camille said, "Only those that are resistant to bug spray." "Exactly," said

Carol, "the ants that would survive are all resistant to bug spray." Carol paused as students wrote in their notes.

"I want to go back to something that Mark said earlier when we're talking about how some ants would survive and some would not. Is resistance to bug spray an inherited trait?" Some students say 'yes,' and Carol repeats this. "Ok, if it is an inherited trait, do you think that it would matter during the lifetime of an ant whether or not it was exposed to the bug spray. My question is, if resistance to bug spray is inherited, does it matter how much bug spray an ant is exposed to in terms of its passing that trait on to its offspring? What do you think, Calvin?" Calvin said, "No, because inherited traits are with you when you're born." "Exactly," confirmed Carol, "Calvin's right. The answer is no. Inherited traits are with you when you're born. It doesn't matter how much bug spray an ant is exposed to, if it's resistant -- it will live. If it is not resistant, it will die. If it's sort of resistant, it might die or might live, but it's not going to affect the ants' offspring. If a 'sort of' resistant ant, went through a bug spray cloud and survived, it's still only going to pass what kind of trait on to its offspring? Camille?" "The 'sort of resistant' trait," said Camille. "Right -- the sort of resistant trait," confirmed Carol. "Even if it's exposed to bug spray and it lives, it's not more likely to pass on greater resistance to its offspring. Because this is a gene and what happens to us in our environment doesn't affect our genes. What do you think? Do you have questions about that? No? Good. Ok."

Carol continued, "Your homework tonight is to go ahead and finish this sheet, but we actually have time now in class to go through the next example with you together. Before we do that, let's look at the last thing you're supposed to do on this side (Carol holds up the handout). The instructions say to use this information and your change over time tool, to *explain* how resistance to bug spray gets established in the ant population. And if you look back up at the top, next to that cartoon, you'll see a statement with four bullets. And these are the four things that a good explanation will include. Just like we talked about how a good explanation of how we see includes, and how a good explanation for how plants make food includes, this is what you need to include for a good explanation on how traits become established in a population. One is to identify the trait, then you need to describe the variation in the trait among the organism, you need to describe the environmental pressures, and you need to describe the natural selection that's occurring. All of these things, we have just done as we answered these questions. So all you have to do is put that together in a paragraph. All right? Before you leave today, let's talk about the next cartoon and the next set of questions. That will be a really good start for you on your homework."

The peppered moths. Carol put a new PowerPoint cartoon on the screen and continued, "This is the moth situation that we're dealing with, and this cartoon takes place in England." (See Figure 5.6)

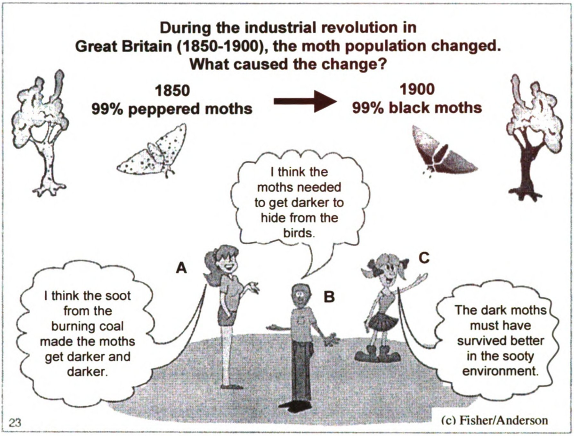

Figure 5.6. Peppered Moth PowerPoint slide.

"A long time ago, most of the moths were what we called 'peppered' and this was in the reading you did yesterday in class. Peppered means grayish. These moths were a peppered color or a grayish color. 50 years later, most of the moths were black. So what is the trait that we're looking at? What is the trait in this situation? Julie?"

"The color of the moth?" said Julie. "Exactly," said Carol, "The color of the moth or moth color. We've talked a lot about fur color, hair color, eye color, do you think that moth color is an inherited trait? [students replied yes] Yes! Yes it is. What would be the variation among moths? If you look at this cartoon on your sheet, what would be the variation in the moths, Julie?" Julie said, "The color -- like you could have peppered or black?" "Exactly," said Carol, "You could have peppered or black moths. So the variation is peppered or black. Before we answer the rest of the questions in this sequence, let's look at the cartoon and figure out if we agree with A, B or C. Who would like to read choice A for us? Benji?" Benji read from the handout, "I think the soot from burning coal made the moths get darker and darker." "Ok," said Carol, "She [in the cartoon] thinks that the soot from the coal -- soot is kinda like ash -- so that the soot from the coal made the moths get darker. What about B? Can you read B Jackie?" Jackie read, "I think that the moths needed to get darker to hide from the birds." "Ok," said Carol, "So this man thinks that the moths needed to get darker to hide from the birds. What about choice C, what does that woman think? Brian?" Brian read, "The dark moths must have survived better in the sooty environment." "Ok," said Carol, "she thinks that the dark moths survived better in this environment where there is a lot of soot. What do you think? Which answer do you agree with? Maria?" Maria said, "C." "Ok," asked Carol, "How many of you agree with Maria? (students raised their hands) Ok, the majority of you agree. Maria is right. C is the correct answer because the dark moths must have survived better in the sooty environment. Jackie?" Jackie asked, "Ok, for the other PowerPoint cartoon, what was the answer?" Carol said, "Ok, for the ants, the correct answer was B." Carol asked, referring to the moth cartoon, "What makes A or B, not correct? Tami?" Tami replied, "For A, for the moths to get darker and darker that would be an acquired trait, and this is an inherited trait." "Ok, good," said Carol, "So Tami says that A can't be true. Because if the moths did get darker because of the soot then that would be an acquired trait and we already know this is inherited. What makes B not true? Will?" "Uhm," said Will, "They do need to get darker, but they can't because that would be an acquired trait." "Exactly," said Carol, "Will says that the do need to get darker to hide from birds, but they can't do it just because they need to; that would make it an acquired trait. Kind of like if we could 'think' our hair darker. Or another example would be to get bigger muscles because we worked out. The moths can't get darker just because they need to. So, what would happen so that dark moths did appear? Where did the variation come from so that there were dark and peppered moths? Where's the variation coming from? Trevor?" Trevor said, "Well on the thing it said that 99% were peppered, so maybe that last 1% were black and maybe that was enough for them when the trees got darker, to start producing more black moths?" "Exactly," said Carol, "You got it. That's exactly how it worked. He said, that in 1850, about 1% of the moths were black, so there was variation in the trait all along. Just like for us there is variation in hair color. Then he said, that when the trees got darker, black moths survived better. Where did the variation, say in 1850, where did most of the variation come from? There's mostly gray or peppered moths, but there were also black moths. Think about variation in other traits that we've been looking at -- variation in flowers and in people. Where does the majority of variation come from? And if you need to, look on the tool to see what your choices are -- or what's causing it?" A student said, "Mutations." Carol said, "Mutations might have caused it. What might be another choice? Camille?" Camille said, "Combinations of chromosomes?" "Exactly," said Carol, "Combinations of chromosomes. Either one is likely in this situation, that the combination of chromosomes that comes from an egg cell or a sperm cell, causes some moths to be black, whereas others are peppered. Or it might have been a mutation that caused a new gene. Either way, there are genes that produce proteins that cause the color in these moths. What about the environmental pressure? What is the environmental pressure in this situation? Camille? "I would say pollution or the industrial revolution." "Yeah," said Carol, "Maybe pollution would be a good explanation. The environmental pressure would be the pollution, or the soot in the air. All right, the rest of this will be for homework tonight and we'll talk about it tomorrow. So we have about one minute left in class, so right now think about if have any questions. Think about if you have any questions before you go."

The students started to get their books in order, and soon thereafter Carol told them "Ok, you can go."

Commentary on the Case of Carol

I am struck by a number of things in reading this accounting of Carol's teaching. First of all, Carol talks a lot. She also has a very authoritative view of knowledge and she definitely asserts that something is true. One of the things that's interesting to note is that in our conversations about the lesson, Carol was worried that she didn't have any proof that resistance in bug spray is an inherited trait. And in fact, it would depend on the type of bug spray and ant in order to know for sure. What does this discomfort indicate about the way in which Carol thought about her teaching? I think that she has a strong evidence-based need to understand why things are the way they are.

What role do examples play in Carol's teaching? Examples, first of all, provide illustration of both ideas and contexts, but they are also used by Carol as something that is in need of explanation. Examples, for Carol, seldom speak for themselves. Also the nature of a good explanation is quite different for Carol than it is for Jennifer and Sam. So too is the tentative nature of the state of student understanding. Carol was always uncertain if the assessment information that students gave her was sufficient to make the case that they "understood." Sam and Jennifer had a very different standard. Their lack of interest in how students "make sense" I claim is an artifact of the way they think about the subject matter. Each of these interns thinks that there are right answers. It's in the way that they approach getting their students to demonstrate that knowledge as well as what the knowledge is in the first place, that they differ.

These interns demonstrate that having control of a class is not simply a matter of having control and not having control -- but in the way that control is exercised. Sam used incomplete information as a strategy and expected students to be able to engage the narratives/procedures with his help. Jennifer used clear expectations about exams, to provide a rich set of experiences that illustrated the ideas she tried to teach. Actually, Sam used examples with little or no expectation that what students learned would help them understand them. Jennifer used examples as a way to connect the ideas to the students' experiences, but didn't use the examples as phenomena to explain, rather they were phenomena that illustrated. Carol used examples as phenomena that both illustrated and explained.

Interpreting Carol's Teaching Practice.

The ways in which knowledge is represented to students is part of the enacted curriculum and is as much a part of the subject matter as what is more typically considered the content. Schwab discusses this distinction succinctly when he claims that how a subject is taught is as much a part of what is learned as is the object of that teaching (Schwab, 1978). In this section, I will examine both the content and ways in which this content are presented -- I claim that together this constitutes how the subject matter is represented. I organize my analysis by examining how knowledge is represented in four contexts: intern-directed situations, intern-pupil interactions, intern reflections on subject matter, and in planning for instruction. I will draw upon the description of Carol's teaching already presented as well as instances from across my observations and interactions with Carol over the 2002-2003 school year.

Knowledge Representation in Practice -- Intern-directed Situations

Teacher-directed situations are those in which the teacher uses assignments, activities, demonstrations and lectures to present subject matter. In this section I will address the following questions and examine their interactions with ways of knowing science: What are the routines in Carol's teaching practice? How does Carol sustain the lesson's momentum? And how are classroom activities and assignments used?

Classroom routines. Carol emphasized the goal of making explanations throughout her teaching. As it was the case for the described lesson, it was also characteristic of the lessons I observed, that lessons built upon previous sessions. The lesson described, started with a check of the previous nights homework for completion. By focusing completion or effort, Carol demonstrated that she valued persistent effort on the part of students. Also, by expecting students to work on homework, and then to intensively work through the same ideas, Carol explicitly worked to model the ways of thinking that she wanted her students to adopt. Further, by working on similar ideas over time, Carol ensured there would be multiple opportunities for students to engage the ideas.

As is also readily apparent from the natural selection lesson, Carol used the names of individual students often. She referred to ideas with reference to who said them, and she remembered what students said, and came back to those ideas at a later time. This was routine behavior for Carol across my observations. It had the effect, I believe, in personalizing the observations of students and improving the motivation of students to participate. It also demonstrated Carol's respect for student ideas and thinking which Carol noted were part of being a role-model in her work with middle school students. However, the most important part of teaching for Carol was to teach students how to make what she called, "good explanations." Her routines were aligned with this goal and her lessons consistently aimed to support students' learning to explain.

Sustaining lesson momentum. I observed Carol using three main strategies for maintaining lesson momentum relevant to knowledge representation practices: variety of instructional strategies, well defined-assignments and engaging examples. The first, using variety, was not well demonstrated by the natural selection lesson. However, across many of my other observations, Carol kept a lively pace in class and students often engaged in a number of different activities. For instance, for a lesson on light, Carol had students engage in a short lab activity to make some observations about the reflection of light in different materials. The students classified their observations and tried to identify patterns in their data. These patterns were shared with the class, and student explanations of these patterns were drawn on the board. Students participated in demonstrations of light reflection.

Having well-defined assignments was illustrated in the natural selection lesson. Having the *Change Over Time Tool* served as a map of the conceptual territory that students would become familiar with. While I will discuss the details of this tool later, the role that it served in class was to help students organize and keep track of the ideas that were engaged. Carol spent considerable time developing such resources across her teaching. Many times these resources took the form of a simple conceptual model. For lessons on density, she used explanations based upon the relationship density = mass/volume. For light, explanations were based upon identifying the relationships between the light source, the object and the observer. For photosynthesis, explanations were based upon identifying the relationships in a model Carol devised consisting of "raw materials, (the) process of photosynthesis, final products, and movement/storage." Because students knew that they would have to know the parts of a model and the relationships between these parts in order to explain phenomena, momentum was sustained throughout the lessons.

Third, Carol utilized problems and scenarios that required explanation. Often times, these problems were likely interesting to students, such as the "invasion of the ants." At other times, Carol would make use of timely connections to produce examples. For instance, near Halloween, Carol had students determine the densities of small pumpkins. They also had to explain why some of the pumpkins -- though larger -- had lesser densities than others. Across my observations, Carol endeavored to find contexts, examples and scenarios that would engage students' interests and provide opportunities to develop abilities to make good explanations.

Assignments and classroom activities. Carol taught in a highly controlled fashion. She constructed her own curricular materials with an emphasis on helping students to organize their observations and use those observations to make explanations of phenomena. These explanations were in terms of an explicit model that Carol gave to the students.

For example, there are several key elements of the *Change Over Time Tool* that are worth noting specifically. First, Carol called this scaffolding device a "tool" and referred to it consistently as a tool with her students. This was a way of emphasizing to the students that this was something used to make or create something else. In this case, Carol's goal was for students to make good explanations of natural selection. Second, the name of the tool -- *Change Over Time* -- emphasizes another hard-to -- appreciate facet of natural selection. That changes happen over the course of many generations is a crucial construct for understanding natural selection. And third, Carol looked at this tool as a way to make a topic that is often highly abstract and verbal, to be more -- as she called it -- "concrete." She was not concerned that her students would internalize the model of natural selection. She frequently reminded students that they would be able to use the tool on their assignments and quizzes. In doing so, she demonstrated her interest in building her students' capacities to use the *Change Over Time Tool* as a conceptual scaffolding with which to make robust explanations.

The classroom activities in Carol's practice do two things with respect to knowledge representation. They provide a rich set of narrative contexts that provide students' with opportunities to explore and explain in terms of paradigmatic connections. They also demonstrate that the models Carol introduced were powerful. Powerful, because they were taken to account for all relevant phenomena, and discussion in class was at times devoted to pushing the limits of the models' applicability. For instance, in the natural selection lesson, the question came up regarding the level of bug spray dosage. Dosage was not a part of the given model -- which allowed only for the death or survival of ants. The "kind-of resistant" trait was entertained but only for perhaps rhetorical purposes, and was not formally shown to be outside the constraints of the model.

I do not have any evidence to suggest that Carol helped her students find limitations in the models she used. Rather, the models Carol introduced were largely taken as given by the students and the learning activities centered on employing them appropriately. Again, however, the point of this analysis is not to defend or evaluate particular curricular representations for effectiveness, but to examine the way in which such representations were used. The activities and assignments designed by Carol consistently focused and developed students' abilities to make good model-based explanations of natural phenomena.

Knowledge Representation in Practice – Teacher/pupil Interactions

The role of examples. To say that teachers need to use examples in teaching is to do little more than state the obvious. However, the ways in which teachers use examples is perhaps less so. Examples are widely used by teachers to connect the subject matter with student experience. An example might illustrate something already experienced by the student or it may be itself an example of an experience relevant to the subject matter. Carol, like most teachers, certainly did this. She used situations with which students were familiar such as using bug spray, and she also used lab activities and demonstrations to create experiences for students that could serve as examples. But Carol also used examples in a way quite different from this as well.

The examples above can be considered illustrations of an idea. An image can be seen in the mirror and identified as an image. Various samples of hair can be used to show variation in the "hair color" trait. But Carol used examples in a different way as well. Carol also used examples as phenomena that needed to be explained. The examples were not simply illustrations of an idea, but rather they were instances of a broader phenomenon that could be connected via explanations based on models. Thus, Carol aimed to help students explain the example of "pumpkins" using the idea of density, and she aimed to develop her students' ability to explain how peppered moths evolved using natural selection.

Questions posed and asked. There was a policy -- established by Carol's mentor Susan -- that only those students' who volunteered would be called on by the teacher. Carol was surprised in fact, at the number of parents who told her during conferences that they appreciated this stance. While Carol recognized some positive aspects of such a policy, she also felt that being able to articulate your thinking was a valuable skill and that some of her students may miss opportunities to develop this ability. Regardless, Carol asked her students many questions. These questions ranged from the highly procedural and factual through the very abstract. Question formats ranged from multiple choice & whole-class votes to paragraph-length responses and drawings. The type of question would depend upon the stage in the conceptual development of the lesson. For the natural selection lesson, Carol asked many identification questions, such as "what is the trait?" and "what is an environmental pressure?" Carol scaffolded her student's abilities to respond to more challenging questions through the use of the handouts as in Figures 4 & 6.

The day after the natural selection lesson described previously, Carol asked the class to respond to several "evolution challenge" questions. These questions, Carol explained, were not going to be graded, instead, they were simply for practice in making good explanations about natural selection, and they would give students a chance to assess their own abilities to make such explanations. Carol encouraged students to use their *Change Over Time Tools* to help them think about each of the questions. An example question is described in Figure 5.7.

3. Dark colored skin is a trait that protects humans from the Sun. This trait is especially helpful in areas of the world where there is a lot of direct Sunlight. (ex: in the Saharan Desert in Africa)
    a. Exposed to Sun, people's skin gets darker. Gradually, over many, many generations, people living in places like the Sahara got darker skin in order to protect themselves in their environment.
    b. People of Swedish descent typically have very light skin. If the Swedish family moved to Africa, over many, many generations, their offspring would have dark skin because of the exposure to the Sun.
    c. Skin color is an inherited trait. This means that no matter how much Sun you are exposed to during your lifetime, you will still pass on your original skin color to your offspring.

Figure 5.7. Evolution challenge question example.

These particular questions were designed to address distinctions between acquired and inherited traits. This is a crucial distinction to make in the process of making a good explanation of natural selection. It was about this distinction that several students asked questions in the natural selection lesson. These questions, such as the question asked by Calvin, "how can you inherit it if the ants die?" evidence a serious effort on the student to make sense of the model and its components. Carol routinely entertained questions asked by students that showed they were trying to think through the model and how it related to a particular scenario or example. The distinctive aspect of this type of question was its purpose. Instead of a request for the definition of inherited traits, this question showed that Calvin was trying to understand how inheritance could work if the ants in question died. In short, Calvin was working through a paradigmatic coordination of the model with the scenario. Inspection of the natural selection lesson finds students ask to clarify definitions, test relationships between model components, relate situations to others that may be similar, and extend the model to other situations.

Carol aimed to build on student responses, and depending on the development of the model and students' thinking -- responds either directly or waits and turns the question back to the class. For the vast majority of student questions, Carol attempted to respond with respect to the model or some evidence based on student experiences. However, as was evident in the natural selection lesson, Carol asserted that resistance to bug spray was an inherited trait. She noted in our conversations that it troubled her that she didn't have any evidence for that. When students made statements that suggested they thought the resistance to bug spray trait to be an acquired trait, Carol said, "Remember that we said, that choice C in this cartoon is not correct. It's not the way it works." This is an interesting response for two reasons. First, by directing students to examine "previous evidence" which was a determination that choice C was not correct, Carol helped students to see that they had the resources to answer that question themselves. Second, by adding, "it's not the way it works" Carol is indicating that what is in question is not the model, but that particular detail. The model is taken as something that works -- that it does a good job explaining the phenomenon. The model is, itself, not in question. How to use the model to make good explanations, is.

Knowledge Representation in Practice – Intern Reflections on Subject Matter

What do interns need to know? Carol spent a lot of time planning and developing lessons. Though she felt that she "knew" the material very well because of her strong science background, she had less background in understanding how middle school students responded to instruction. This, of course, was much more complex than addressing subject matter questions by themselves. Susan, Carol's mentor, though not a science specialist herself, had excellent rapport, and skills working, with middle school students. Carol felt that she learned a lot about how to help students develop a sense of responsibility for their actions as well as, organizational strategies for managing the work of teaching from Susan. Carol considered expert teachers to have the ability to have "four sets of eyes" and to be able to talk to "five students at once." This ability to multi-task, she felt, was improving over the course of the year.

What is hard/easy about their subject matter? The central challenge that Carol faced in teaching subject matter with her students, was to find a model that adequately addressed the content, yet remained accessible for middle school students. To develop these models, in addition to sheer effort and her own content understanding, Carol relied on her university teacher education professors and a good friend who was an experienced high school science teacher for additional ideas and resources. From these Carol learned what common misconceptions students have for particular topics and concepts. In the case of natural selection, the idea of adaptation is particularly troublesome. With a common-sense definition of the word adaptation, the Lamarckian view of evolution becomes the default understanding. To use a previous example, skin color "adapts" to the environment, because skin color changes because it needs to. However, because skin color is an inherited trait, rather than an acquired trait -- it is unable to be passed on to future generations. Such precision in language use required Carol to be both clear in her own thinking about such distinctions, but also to design activities that would directly address these ideas her students would likely have. Carol also noted that she avoided using the term adaptation to avoid invoking these ideas until she had firmly established the distinctions between acquired and inherited traits.

Carol believed that each of her students could improve in their ability to make explanations of natural phenomena. She developed scaffolding, conceptual tools such as the *Change Over Time Tool* as well as a similar tool for explaining photosynthesis. These tools arose from her own challenges in organizing and keeping track of the complexity of the models. She found that in her own thinking, that having an explicit model to refer to not only helped her organize information, but helped her to clearly distinguish and emphasize the connections between parts. She explained to me that initially, she felt that by listing explicit criteria for what made a good explanation, would make it "too easy" for students to answer questions without really understanding. Though she maintained a healthy suspicion of the validity of her assessments, she did find that students needed such scaffolding in order to improve their abilities to make explanations.

Knowledge Representation in Practice – Planning for Instruction

Objectives for student learning. Carol deeply appreciated the distinctions made in classroom objectives. Her instruction was designed to enable students to meet ambitious learning goals. Many of Carol's objectives were in the form of "using" objectives. An example of this type of objective is: "explain how new traits might become established in a population and how species become extinct." This objective requires that students make an explanation, and such an explanation is going to be with respect to a model of natural selection.

Carol sought to help her students improve in their ability to make "good explanations." This over-arching concern was central to her planning. After determining what the objectives were for the course -- in this case the state published objectives for middle school science, she first aimed to devise a simple model of the phenomena in question. For the lessons described on natural selection, Carol created a model that was both appropriate for her middle school students, and importantly, it was a model that did a reasonable job for accounting for a range of examples. The model for natural selection that she developed can be generally represented as in Figure 5.8.

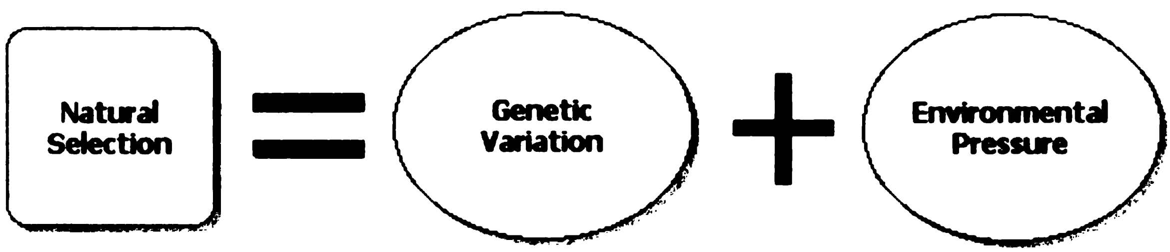

Figure 5.8. Carol's model of natural selection.

This model constrained explanations of natural selection as the result of two parts: a source of genetic variation and an environmental pressure. Carol then considered a range of examples that could be used to illustrate the model. These examples were then used to create a set of scaffolded activities that would help students develop the ability to explain each example with respect to the given model. Particularly important for Carol was that her model be able to address the common student misconception that evolution and adaptation are "need-based processes: that traits evolve because organisms need them."

One of the examples that Carol considered in her initally planning of the lesson was how a camel got its hump. Carol wrote in her plans that camels have humps to store water and that this trait helps them to survive desert conditions. Her idea was that this example would require students to confront their "need-based" understandings and instead learn to think about how camels got their humps with respect to ner natural selection model. When Carol talked about this example with her university instructor -- she found out of course that camels don't store water in their humps! To Carol, this was but a minor set-back to her planning. Her conceptual model remained intact, she simply had to find examples that could be explained with it. So, Carol investigated and developed additional examples such as how ants become resistent to pesticides and how the pepper moths adapted to industrialization in England. Carol was satisfied with her preparation when she was convinced that she had a model of the phenomena in question and a series of examples that were explainable by that model.

Ordering classroom activities. In her teaching of natural selection, Carol helped her students learn potential sources of genetic variation and then they looked at potential environmental pressures. Though the earlier description of instruction may have looked like students were "filling in the boxes" as to whether a particular example contained evidence for an environmental pressure or for a source of genetic variation -- there was a powerful and important structure behind Carol's teaching. She was building her students' capacity for interpreting and organizing experiences with respect to a conceptual model. Subsequent lessons extended this lesson to provide opportunities for students to use the model to make explanations in a progressively less structured fashion.

This structure was designed to provide scaffolding for her students to create paradigmatic understandings of natural selection. First, the conceptual categories were introduced and students were provided with many opportunities to engage these concepts. As the students gained in their ability to use the model, additional examples were introduced that served as opportunities for students to test and improve their abilities to make appropriate explanations.

What was important for Carol was that the structure of each of her examples provided the bases for rich pattern-finding opportunities for students and that they be able to turn these patterns into scientific explanations. Whether it be ants, moths or polar bears, she helped her students distinguish the deeper conceptual structures for which each of these topics can be made an example. The parallel purpose for each of the examples represented in Carol's teaching was characteristic of her approach across observed lessons.

Conclusion

I argue that Carol coordinated between both narrative and paradigmatic ways of knowing science. I have drawn upon a broad range of evidence from her teaching practice to do so. These practices ranged from planning, through instruction, and in her reflections on teaching science. Because Carol construed science differently than did Sam and Jennifer, and because these differences were found throughout each of their teaching practices, it is reasonable to suspect that the opportunities to learn science might also be different, in each of their classrooms. Because a students' opportunity to learn science depends, in part, on the knowledge representations created and used by the teacher—how a teacher construes science influences directly a students' opportunity to learn. In chapter six, I next examine the ways in which the differences in how these three interns construed science manifest different opportunities for students to learn science.

Chapter 6

Teaching Practices Shape Opportunities for Student Learning.

Overview

The preceding cases developed the argument that the interns' ways of knowing science were evidenced in their teaching practices. Sam and Jennifer tended to construe science as a narrative enterprise and Carol tended to blend narrative and paradigmatic ways of knowing. I now argue that the knowledge representations used by the interns shaped their students' opportunities to learn science. I will show how the ways interns know science shaped the opportunities to learn science in these interns' classrooms and that these opportunities differ in ways central to learning science for understanding (Anderson, 2003).

I begin with a point of clarification. The argument I am making in this chapter is not that knowledge representations are the *sole* determiner of opportunities to learn science for understanding. Teaching is an incredibly complex endeavor. The actual opportunities to learn in a classroom are doubtless the product of a host of pedagogical and contextual factors. My project here is not to try to define or describe actual opportunities to learn or whether any such opportunities to learn were realized. Instead, I aim to examine the interns' knowledge representations in practice and show how they shaped the potential opportunities for students to learn science for understanding. I do so based upon the recognition that an opportunity must first exist if it is to have the chance to be actualized. I consider this analysis to be a central, rather than complete, part of the effort to gain insights into the core of practices needed to successfully teach students science for understanding.

Despite the obvious interest in establishing standards for what teachers need to know about the subjects they teach, little progress has been made in achieving agreement for what that subject matter knowledge might look like. Currently in many states, new teachers are required to achieve a passing score on content-specific subject matter test. In fact, each of these interns passed their state's test prior to their internship year. The exam taken by these interns was called the State Test for Teacher Certification (STTC). Nationally, the Educational Testing Service markets the PRAXIS examinations that have been popular choices for districts attempting to ensure that teachers have appropriate subject matter understandings. Evidence that such tests impact the quality of instruction is sparse. Instead, such tests are justified by common sense—if a teacher can't pass a test of basic knowledge, then how would they be effective in the classroom? While this may well be persuasive, there is little empirical support offered by the research community beyond recommendations that teachers essentially need deep, coherent, and rich understandings of disciplinary knowledge (Wilson, et al. 2001).

It is perhaps surprising that specification of the subject matter knowledge that teachers either should know or actually do know has been largely absent from the research literature. Reasons for this include the lack of reliable assessments of subject matter knowledge, the invasive nature of researchers asking teachers to explain the limits of their understanding, and ultimately the lack of articulation for what constitutes subject matter understanding. Efforts to produce explicit content standards such as the Benchmarks for Scientific Literacy (AAAS, 1993) and to map their relationships (AAAS, 2001) have been helpful but their sheer size and scope are beyond what could reasonably be expected for interns (and many teachers) to know.

What researchers and others have used are proxies for subject matter understanding that include self-assessments of knowledge (e.g. along the dimension of high/low "familiarity" with content, e.g. Carlsen 1992, 1993), the number of courses in the subject area at university or simply having an academic major in the discipline (Lanier & Little, 1984). I approach intern's subject matter understanding not from the perspective of attempting to ascertain precisely what an interns' knowledge of science is—but rather I infer *how* it is structured based upon the instructional representations that interns generated for their students. I claim that the distinctions between their instructional representations and interns' so-called "true" understanding are moot when one considers the perspective of a student. The opportunities to learn science created by the intern are the pragmatic resources available for students to learn science. Whether the representations used in class match precisely the representations somewhere in the interns' head are for these purposes not important.

Comparison of Opportunities to Learn

An examination of these representations for Sam, Jennifer and Carol, will show that the ways in representations were structured resulted in vivid differences in the opportunities students had to learn science for understanding.

To preface my later focus of explicating the differences between the three interns and the ways in which their knowledge representations in practice differ, it is important to note a number of ways in which these interns were similar.

Commonalities of Background and General Teaching Ability

Each of the three interns majored in a disciplinary science, Sam and Jennifer in chemistry, and Carol in biology. And because their teacher education program was a five-year program, they were already university graduates at the time of their internship year. As well, each had passed the State Test for Teacher Certification in their subject matters. From a policy perspective, each of these teachers was a well-qualified teacher in their subject matter. And each of these interns experienced the same intensive teacher education program whose centerpiece was a 4 semester sequence of science-specific education courses.

Accounts of student teaching/new teacher learning often focus on the challenges faced by these teachers and their efforts to address them (Segall, 2002, Carlsen,1991). Other accounts portray student teachers who were unable to successfully navigate the perils of student teaching without significant difficulty (Britzman, 1991). However, the three interns that I portray in this study, though not without a lot of hard work, had remarkably successful student teaching experiences. Each taught in schools that had norms of academic achievement. Their students were, though not always enthusiastic, generally receptive to participating in school. Each intern felt affirmed by their student teaching experience and felt that teaching was a great fit as a career. They each believed that the internship prepared them well for teaching. They believed that they were having a positive effect on their students and they each were looking forward to a career in education. Reinforcing this view were their mentor teachers. Each mentor considered their intern to be strong student teachers, and felt fortunate to work with such fine young teachers. The university field supervisors held these three interns in similar regard. In fact a common sentiment expressed by each of the interns was that by the midpoint of the year, the field supervisors apparently felt that they were doing well enough to not need feedback critical of their practice. Instead the field supervisors tended to reinforce and encourage the continued good work that each was doing.

My own sense for how these interns compared to the many student teachers I have worked with is that they each would be "well-started beginners" who in many ways have a level of teaching acumen and instructional flair that would be envied by many more experienced teachers. As evidenced in the case study lessons, each of the interns made productive and efficient use of class time. Each maintained high standards for both academic and social behavior. Each teacher was respectful of students and had clearly established rapport with them. Their classroom management ability enabled each to teach in ways that they desired. I did not hear, as I have heard many times in work with other interns, "well, next year when I get my own class, I'll be able to teach the way I wanted to." These three interns had the management skills, the interpersonal abilities to work with students, and the work ethic to come to class each day prepared to achieve their goals as teachers of science.

Commonalities of Teaching Practice

There were many points of commonality in the practices of each of the interns. Though Jennifer was the most adept at providing students with hands-on activities, for each of the interns including activities was a priority. As well, each intern recognized the need to connect academic content with the experiences of their students. For Sam, this was often to refer to things that he knew they had studied previously or as in the case of the lesson I observed on pH scales he centered the lesson on an acid rain activity—a topic that students had all heard about. For a lesson on density before Halloween, Carol provided individual pumpkins for each student.

In general the repertoire of instructional strategies for each intern was quite impressive. I personally observed the interns utilize whole and small groups, demonstrations, lecture, hands-on labs and activities, individual and partnered assignments, homework, and tests & quizzes. In addition, Sam used formal laboratories, and Jennifer & Carol used group projects and presentations as additional instructional strategies. Carol also managed field trips, and Jennifer coordinated a school-wide career day. These were interns who worked hard to provide a variety of experiences for their students. Each wanted science to be fun but yet educational. Varying activities was one strategy for addressing this.

A final point of commonality was the relatively firm control and active presence that each exercised with their classes. Regardless of the type of lesson, each of these interns was actively engaged with students. During labs and seatwork Sam was constantly interacting with students and assisting them with questions. Jennifer too, closely monitored the activities of students whether working in groups or individually. While videotaping a lab in Carol's class on light, I asked her if she would mind if I followed her around to record her interactions with students. She said it'd likely be boring because she wasn't going to be talking much. Well, for the next thirty minutes she did nothing but talk and interact with students around their observations.

Summary of Intern Commonalities

From the perspectives of their students, mentors, university field supervisors; Sam, Jennifer and Carol were considered to be strong interns. And from my perspective too, I would say that each was a well-started beginner, and even that they were "better" teachers than many more experienced teachers with whom I've worked. I establish this because the bulk of the subsequent analysis regards distinctions that I make in the practices of these interns. While I will be careful to qualify these distinctions where necessary, it is important to recognize that along important dimensions of learning to teach there are many similarities amongst these three interns.

In summary these similarities are that each intern was a university graduate who majored in a science discipline and had passed the state subject matter competency test. Their teacher education program was nationally regarded and subject-matter intensive with extensive field-based experiences including a full-year teaching internship. They were highly thought of by university field-supervisors, their mentors and their students, and they used a variety of instructional strategies and had strong management skills.

Contrasts in Opportunities to Learn

Next I develop the contrasts between the three interns in order to flesh out how differences in the ways the interns know science narratively or paradigmatically affected the opportunities to learn science in their classrooms. As I did in each of the cases, I will examine the instructional representations (Leinhardt, 2001) for ways in which the subject matter of science is represented. In particular, I will look at instances of practice for intern directed representations and intern-student interactions to provide evidence of contrast in the opportunities to learn science.

Knowledge Representation Contrasts—Intern Directed Representations

I will examine three intern-directed knowledge representations in light of the opportunities they create for students to learn science for understanding: classroom routines, assignments and lecture. In each section I will briefly describe how each intern used the particular context to represent knowledge about science. I will also summarize how these representations as a whole develop and impact the opportunities to learn science for students. Though evidence for ways of knowing in routines might be less striking than in other, perhaps more obvious places (such as assignments), I choose to start there to underscore what I argue is the pervasive influence of subject matter on the practices of these interns.

Routines. In what ways did the routines observed in the interns' practice serve as knowledge representations and how did they affect the opportunities to learn?

For Sam, it was very important that students paid careful attention so that they did not miss out on instruction. Sam did a number of things to keep students attention. He noted in conversation with me that he tried to vary his vocal inflections to make explanations more interesting. He also used verbal cues in his lectures to signal what was important for students to record in their notes, by pausing after a salient phrase, or by re-stating a phrase with pronounced elocution, as in the case where he wrote and said, "an atom is mostly empty space," and "nucleus is very small." This routine way of speaking to students was intended to signal that they were to record the information exactly as Sam indicated. Further this information, though embedded in a larger context, was clearly the most important thing to remember about that context. The effect of these routines were to reinforce the stance that Sam was helping students take a complex subject—the subject matter of chemistry—and reduce that complexity to what was most important and essential. This is an example of the way in which routines worked to simplify the subject matter of chemistry for the students. For Sam, routines largely served to influence knowledge representations by providing opportunities to learn "simplified science."

For Jennifer, it was very important that students participated in activities. Jennifer did a number of things so that students would have multiple opportunities to have experiences with the subject matter of science. She routinely consulted a number of textbooks and the internet in order to find a set of activities that would illustrate the topics. Students were to engage these materials and then often record in their notebooks what they observed. As we saw earlier in the lesson on magnetic fields, Jennifer even had the students record in their notebooks that which they didn't see! Jennifer established the classroom routine that demonstrations were to accurately illustrate science knowledge. Because this knowledge was likely to show up as the answer to a future exam question, it is perhaps unsurprising that not a single student suggested that the asserted pattern for magnetic field lines was actually not the pattern they observed. This routine of considering *phenomena as illustration*, served to simplify the subject matter. In providing multiple activities that illustrated the subject matter, Jennifer made it simpler for students to remember what they were supposed to learn.

For Carol, and like Jennifer, it was very important that students participated in activities. And like Jennifer, Carol had students record in their notes what it was that they observed. However, for Carol these notes were to be used as evidence in making explanations of the phenomena rather than just accounts to be committed to memory. Notes also served an additional purpose for Carol. It was routine for Carol to emphasize that students "write to yourself" in their notes about how they were supposed to think about a particular piece of information. While the routine of note-taking in Carol's teaching was similar to that of Sam and Jennifer in that notes were accounts of information, they differed in that for Carol, notes were also a place to record how you were supposed to think about that information. It was also routine that Carol generated a representation that would help to manage the complexity of the subject matter. For example, she created as previously examined, the *Change Over Time Tool*, and she also created a tool for use in thinking about photosynthesis that she called the *Window Pane*. The routine of note-taking, then participating in activities while building and exercising the capacity to make scientific explanations was common across my observations of her teaching. These routines did not aim to simplify the subject matter. Instead they aimed to support and manage the complexity of making explanations in science.

In each case, routines established and sustained norms of relationship between how class-time was used and what was important to learn. For Sam and Jennifer, routines served to *simplify* the cognitive complexity of the subject matter. They also reinforced the notion that the teacher would provide simple illustrations of the ideas otherwise found in textbooks. For Carol, routines served to help her *manage* the complexity of subject matter and to create knowledge representations that her students would use to do so as well. They also reinforced the notion that Carol would help students learn how to think about phenomena so that they could make explanations themselves.

The opportunities to learn in each class were likewise differentiated. In Sam's class, the opportunities to learn were based upon the simplified versions of chemistry that Sam provided. For Jennifer, having a rich experiential base gave students multiple opportunities to see ideas and concepts illustrated. However, opportunities to engage in the explanation of phenomena were not provided and were in fact largely avoided. Jennifer selected demonstrations and activities likely to produce illustrations of the subject matter. Both Sam and Jennifer used routines that simplified the subject matter and their students' opportunities to learn science were similarly simplified. Carol, however, worked to provide opportunities for her students to engage in phenomena more directly. She provided opportunities for students to learn how to manage and explain the complexity of science subject matter.

Assignments. In what ways did the assignments in the interns' practice serve as knowledge representations and how did they affect the opportunities to learn?

Sam endeavored for his students to succeed in his class, and a central part of succeeding was in doing and completing assignments. Sam felt that effort was a primary determinant of success in schools, and he justifiably wanted to prepare his students for what they were likely to face when taking future science classes. So, in his chemistry class there was a strong orientation to completing class work. The overt focus of activity was to *do*. And *doing* took the form of solving problems, performing calculations and completing labs and their associated "write-ups." As Sam said in the earlier case, students' would take just a few notes, because he really "wanted them to do the lab." Sam felt that the purpose of his class was to prepare students for college. By *doing* problems, calculations and labs, Sam was preparing students to do similar work when they took future science classes. The procedural competence of his students evidenced the success of this approach. Each assignment was another context in which problems were simply embedded and awaiting solution. The emphasis on *doing* shaped knowledge representations in chemistry to be about completion of class work.

Like Sam, Jennifer wanted her students to be successful in future science classes. Jennifer also emphasized that assignments should not only be completed, but also reviewed and studied for exams. Jennifer often had students prepare sets of flash-cards for the material covered in assignments and the process of preparing these cards required students to go back through their completed work. The emphasis in assignments was on recognizing and identifying examples and to then commit these to memory. Because the sets of examples were sometimes loosely connected -- for example, I observed a lesson on forensic science that was selected simply because it was interesting -- there was less a sense that the ideas were building toward something. The way that knowledge was represented in assignments created the sense that science was a set of examples that had to be learned and efficiently associated with scientific terminology.

Carol certainly also considered the doing and completing assignments to be important for her students. She recognized, as did Sam and Jennifer, that building norms of responsibility transcended disciplinary and academic boundaries in addition to being good preparation for future course work. And in many ways, Carol used assignments like they did. But the additional function that assignments played in Carol's teaching was the sense that each assignment built toward coherent goal. Carol used assignments to build the capacity of students to do something with the knowledge they were learning. This typically centered on the ability to make good explanations. The assignments impacted the representation of knowledge in this class by showing that understanding in science was built upon ideas that develop over time and many lessons.

In each intern's practice, assignments supported norms that related the work done by assignments to the subject matter to be learned. For Sam these assignments were the work of learning, and by doing problems, calculations and labs, he was preparing students to succeed in future science classes. These were also the knowledge representations of the subject matter of chemistry that his students engaged on a daily basis. For Jennifer the work of learning was to remember sets of examples of the science ideas and concepts she taught. The efficiency and habits she reinforced helped her students learn that the collection of experiences she presented would prepare them well for exams. Carol used assignments in ways that represented knowledge in science as the building of capacities for students to make explanations.

For Sam and Jennifer the net effect was that assignments played the role of episodes, like scenes in a chapter, to be completed and then assimilated into the larger set of experiences of the unit. For Carol, assignments served to build the capacity for students to make explanations with respect to a conceptual model in science. For each of the interns, assignments provided pieces of the whole. For Sam, assignments resulted in procedural competence in the problems that chemists solve and knowledge of what chemists have done. For Jennifer, assignments tended toward a view of science that was a coherent picture made up of many examples. For Carol, assignments developed the conceptual tools used to engage, interpret and organize science subject matter and natural phenomena more directly.

The opportunities to learn science in the classes of Sam, Jennifer and Carol differed in the ways science knowledge was represented. For Sam, students' opportunities to learn science were constrained to be largely procedural. Though Sam was very effective at equipping his students to *do* calculations and solve problems, assignments were not used to help students explain the phenomena represented by these calculations, problems or labs. For Jennifer, the rich set of examples and connections made to students' lives provided opportunities to learn that science was in fact, relevant to middle schoolers. However, the opportunities to learn that science is more than associating a collection of topically linked examples was not available to her students. For Carol, assignments shaped the ways in which students had opportunities to learn that science is concerned with making explanations that require sustained effort and attention.

Lecture. In what ways did lecture in the interns' practice serve as knowledge representations and how did they affect the opportunities to learn?

For Sam, the information that he shared during lecture was, as a student, well worth paying attention to. As noted earlier in the case, Sam employed several techniques for encouraging his students to pay attention. He encouraged students to listen carefully, and he frequently reminded students to ask questions if they were confused. Sam would often ask questions that required information that had not yet been revealed to the students. Student would none-the-less enthusiastically offer guesses, perhaps hoping that they would get lucky. When something of particular importance would be said, Sam would say it in a way that alerted the class that they should note carefully what was said in their notes and be sure to study it for the exam. Sam also spent considerable time modeling problem solutions as examples while providing helpful information for solving problems and doing calculations. As a knowledge representation, lecture reinforced the notion that science might appear complicated but it's also understandable if careful attention was paid.

Jennifer also used lecture to share information with her students. She emphasized careful listening and note-taking skills with her students. She also asked students to play what I call, "verbal fill-in-the-blanks." For example, in the earlier case when Jennifer introduced the compass, she asked questions such as, "what does a compass do?" a student replied, "says which way north is" and Jennifer continued, "points which way north is. How does it know which way north is?" Another student replied, "it follows magnetic north." This kind of dialogical interaction effectively serves as a lecture, but dispersed over several speakers. It gives the appearance that the students are explaining rather than the teacher telling. As a knowledge representation this method of lecturing portrayed science as something that lots of people know. The teacher was not the only provider of information. It also confirmed that the teacher is not the only person who could know the story. This representation of science portrayed the story of science to be something learnable—that already students in the class knew major pieces of the story. Successful learning was therefore based on careful attention to the telling of the story and subsequent effort on the part of each student to remember and re-tell that story.

Carol placed strong emphasis on lecture as a way of providing information. From the earlier case, it is clear that she did not shy away from telling students information. There are a couple of interesting features to note however in the way she represented knowledge in lecture. First, there was a strong emphasis on precision in both language usage and in making distinctions. Much of what Carol explained involved detailing the ways in which scientific models required careful attention to detail. The second feature to note has already been mentioned in the section on routines. It was Carol's attention during lecture, to not only impart information, but to guide how students should think about the information. Taken together, precision in language and distinctions coupled with attention to how students should think about the information, form a representation of the knowledge in science as again complex, but also as something that with care, can be understood in its complexity. It is important to note that ideas introduced in lecture by

Carol were typically then engaged more fully in activity; lecture was not a substitute for experiences.

For each intern, lecture was used to impart information to the students. For Sam and Jennifer, lecture was the default way of communicating material when there were no other convenient ways to illustrate ideas. For Carol, lecture was used to make precise distinctions and to provide the basis for making appropriate observations about phenomena. As knowledge representations both Sam and Jennifer would prefer to do more active kinds of instruction. Lectures ran the risk of being boring as well as easily forgotten -- a view reinforced by their emphasis on taking careful notes. For Carol, lecture added what could not be found in activity alone. Lecture provided the opportunity to model precision in language use and introduce students to relevant features of model-based reasoning.

The opportunities to learn provided by lecture again differentiate by the ways in which lecture was used. For Sam and Jennifer, lecture provided students with manageable chunks of information, prioritized for future recollection. For Carol, lecture provided students with modeling of precise language use and initial orientations toward using conceptual tools for making good explanations.

Summary of knowledge representations in practice—intern directed. The dimensions of intern-directed knowledge representations found in routines, assignments and lecture establish patterns in practice that align along narrative and/or paradigmatic dimensions of ways of knowing science.

The narrative practices of Sam and Jennifer emphasized routines that reinforced notions that the teacher would translate important scientific knowledge for ease of use by the students. Assignments were ways of exposing students to collections of experiences that were more or less loosely connected by theme or proximity in the textbook. Lectures were ways of filling in gaps in the story that could not be provided expediently via hands-on activity. Students' opportunities to learn science consisted of exposure to a rich collection of experiences that were narratively and thematically connected by the structure of the instructional unit.

The paradigmatic practices of Carol emphasized routines that reinforced notions that the teacher would provide a model with which students would evaluate phenomena to make explanations. Students' opportunities to learn consisted of capacities, built over time, to use conceptual tools such as the photosynthesis *Window Pane* and *Change Over Time Tool* in order to make good explanations of phenomena.

Each of the interns successfully helped their students to achieve important learning goals and provided opportunities to learn science. Sam and Jennifer provided their students with rich sets of experiences that well prepared them to reproduce narrative relationships as well as procedural competence. Carol likewise built a rich set of narrative experiences and procedural competence that was used in the service of reproducing narrative relationships, but additionally Carol facilitated students' abilities to make paradigmatic explanations of natural phenomena.

Knowledge Representation Contrasts—Intern/student Interactions

The following knowledge representations serve as locations to investigate the ways science was engaged in interaction between interns and their students. Analysis of interactions will focus on the use of examples, and the questions asked by both intern and students.

Examples. How did examples serve as knowledge representations and what opportunities did they provide for students to learn science?

Sam used two main types of examples in his practice. Examples were either problem-solving exercises he performed at the board for the whole class, or they served as motivational aides to support the continued efforts of students to participate in class. Due to the heavy emphasis on solving problems in chemistry, Sam was particularly intent on producing concise and clear explanations of problem solutions. By modeling correct solutions Sam provided students with an enactment of how they should *do* the problems. Sam also used examples to motivate students. By doing problems on the board, Sam also aimed to motivate student's efforts to work them as well. I observed Sam do many problems that included interactions with students that emphasized their abilities to successfully do them. Sam also noted that to motivate students he would love to be able to "blow things up" every day, but that wasn't often feasible. I did however, observe Sam blow up things up on one occasion.

Sam blew up several balloons near the end of class after showing students how to balance equations. These explosions were to serve as examples for a particular equation to demonstrate that the balanced equation was correct. The balanced equation on the whiteboard had to do with methane, CH_4, combusting with oxygen, O_2. Based on the balanced equation Sam asked what the proper ratio of oxygen to gas should be for the biggest explosion. As students suggested various combinations of the numbers in the equation, he filled a balloon with pure methane. Students predicted that this balloon would explode with a huge bang. When Sam ignited this balloon it only flared into a diffuse ball of flame with almost no bang at all. However, subsequent balloons that contained combinations of gas and oxygen each burst with a tremendous bang. These examples were to serve as confirmation that correctly balancing chemical equations had tangible results. However, the connection was left implicit. Sam did not explain how he was able to produce the correct ratio of gas to oxygen in the spherical balloon. Based on the students' voiced ratings of each explosions' "strength," there were real questions whether the asserted "correct" ratio balloon actually was the loudest. A number of students felt a balloon of a different ratio sounded louder. Also, students were perhaps as likely to attribute loudness of explosion to the total volume of the balloon rather than to the ratio of methane to oxygen[4]. These considerations were not important to Sam, I argue, because they were beside the point of the example. The demonstration was performed to serve as evidence that applications of chemistry have "real-world" implications. To explicitly connect this example to the subject matter would likely take the fun out of it, and reduce the motivational benefit that was the primary purpose to begin with. As a knowledge representation, examples of problem solution as well as phenomena illustration served similar purposes in Sam's class. Examples demonstrated to students that they were learning the correct information, and that Sam was able to help them also achieve the correct response.

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[4] Because the balloon is a roughly spherical container for the gas, its volume expands as the cube of its radius. Often, students are likely to consider a balloon that is twice as "big" to have twice as much gas, when actually it had eight times as much gas (2^3), it is not clear how they were making sense of the ratio's on the board which were to be two to one, oxygen to methane.

Jennifer used examples to provide tangible connections between subject matter content and students' experiences. She tried to provide as many hands-on illustrations as possible in her lessons. Having multiple experiences with phenomena made science real to her students. It also made it easier to remember what was done in class. As was shown in the magnets lesson and explained earlier about the use of dialogical lecturing, Jennifer attempted to draw from students' personal experiences as well as classroom experiences to illustrate that science was relevant to their lives. With respect to knowledge representations, examples served as illustrations of the ideas or concepts. "Seeing is believing" summarizes this stance toward examples. Sometimes however, it was hard to see what the example was supposed to illustrate.

In a lesson on digestion, Jennifer had students place a salt-free, saltine cracker in their mouths with the instructions to not chew the cracker. The students were then supposed to record what they tasted at one-minute intervals for five minutes. Students claimed that it tasted like saliva, or "sogginess." Several students expressed a sense of disgusting delight in having a soggy cracker in their mouths. Jennifer informed the class that what they were supposed to have noticed was a sweetening of the cracker due to digestive processes occurring in their mouths. She explained that starches in the cracker were being broken down into carbohydrates by the enzymes in saliva. These carbohydrates would then taste sweet. To confirm this, she had the students repeat the activity with another cracker for five minutes. Few students indicated that they observed this sweetness effect, and most continued to relish in the sogginess of their crackers.

Jennifer's expectation for this as an example was that it would illustrate the breakdown of starch into carbohydrates. However, despite the fact that many students were more interested in the textured sensation of soggy crackers, this example would have had a hard time illustrating this process. Because this process was not observable, the example could only provide evidence that the cracker tasted sweet. It was not possible to "see" the digestive processes at all. What it did provide was a memorable event that would remind students that a digestive process occurred in their mouths. This was consistent with the way Jennifer used examples; they were visual aides useful for remembering scientific ideas. As a knowledge representation though, the example was intended to illustrate a process that was not observable. It did demonstrate that if you know the correct story, that you could relate it to an appropriate example.

Carol used examples in ways similar to both Sam and Jennifer. She used examples as illustrations of ideas, as motivation aides and as tangible experiences that students could refer to. However, she also used examples very differently. What differentiates Carol's use of examples from Sam and Jennifer was that in addition to the aforementioned practices, Carol used examples as *instances to be explained* by scientific models. By treating examples as both illustration of phenomena and phenomena to be explained, Carol emphasized to students that science was more than knowing things in science. Science was also about making good explanations.

For example, previously mentioned was a lesson on density that utilized pumpkins. Students were asked to calculate the densities of their pumpkins and explain how a great big pumpkin might have a lower density than a tiny, little pumpkin. In the process of making these explanations it was not enough to simply calculate the density using the formula density= mass divided by volume. Students had to explain why, in fact, the little pumpkin had a greater density. Students eventually cut open the pumpkins in an effort to demonstrate and explain what the concept of density meant with respect to the distribution of mass within the volume of the pumpkin. This instance shows how an example, in this case pumpkins, can both be an illustration of density as well as the object of an explanation of what density means.

For Sam and Jennifer, examples served as illustrations of the subject matter that were justified by the examples' ability to adequately represent phenomena. For Carol, examples also served as illustrations of the subject matter, but they were justified as examples not by their representational nature. Instead, examples were justified as illustrations of subject matter if they could also be explained with respect to a scientific model. The opportunities to learn science for the students in Sam and Jennifer's classes were limited to knowing *instances of* scientific ideas and concepts. In Carol's teaching, the opportunities to learn included both knowing *that* examples were *instances of* scientific ideas and concepts as well as how to explain *why* examples were *instances of* scientific ideas and concepts with respect to a scientific model.

In summary, examples in Sam and Jennifer's teaching, served as narrative illustrations of subject matter ideas, while in Carols' teaching, examples served both narrative and paradigmatic ends.

Questions asked by intern and by students. What role did questions serve as knowledge representations and what opportunities to learn did they provide?

The questions asked by Sam tended to serve one of two purposes. Questions were intended to see if students knew what the story was, as in the questions he asked students about the Rutherford Gold Foil experiment, or questions were intended to determine if students knew what to do next in the context of problem solving. In either case, Sam asked questions as a means for diagnosing and correcting student misunderstandings. He explained to me that asking students questions (as well as having students ask him questions) helped him to unearth "misconceptions" so that he could "stamp them out" quickly. "Stamping out misconceptions" took the form of directly and clearly explaining how to do the problem correctly from the beginning. I rarely observed Sam ask any follow-up questions to the student responses to his questions. When Sam would ask a question that resulted in numerous responses, he would tend to ignore the incorrect offerings and wait until something more correct was said. This was well illustrated in the case by the set of questions he asked students about what Rutherford discovered from the gold foil experiment.

The questions that students asked of Sam were overwhelmingly short, procedural and confirmatory in nature. "Can you do number 12?" "Did I get this right?" "How do you balance this formula?" were typical. When students claimed that something "didn't make sense" this was operationally equivalent to "I don't know what to do next." When a student would tell Sam that something didn't make sense, he would quickly determine what the student didn't know how to do, and then he either told or showed the student exactly what to do next. Sam frequently announced to students that it was "their job to ask questions and [his] job to answer 'em!"

When considering questions as representations of knowledge, Sam used questions to monitor the performance status of students understanding. The students used questions for the same purposes, and ask questions to improve their ability to do problems and calculations. Because there were correct responses to the problems in this chemistry class, it was important that standards of accuracy were met and maintained. The frequent use of questions to evaluate and appraise these standards of accuracy reinforced the sense that chemistry was about solving problems. These problems were seldom explicitly about natural phenomena, rather, natural phenomena occasionally served as real-world contexts for the "actual" subject of the class, which for Sam was doing chemistry problems.

Though Jennifer, like Sam, asked questions that served the two purposes noted above, she also asked a third type of question. In addition to questions about how examples illustrated scientific ideas, and how to get correct answers, Jennifer would ask questions to elicit student examples and experiences. However, she often did so in the service of orchestrating a single storyline from multiple sources. Questions of this type created an explicit connection between the subject matter and the students' experiences. However the nature of that connection was seldom pursued. As with Sam, Jennifer rarely asked follow-up questions to students' responses. Jennifer often evaluated such responses with short statements such as, "yep," "nope," "not quite," "you're close," and "almost." This type of interaction was illustrated in the case when the student asked for clarification on his exam regarding his use of the correct symbols on a diagram and Jennifer simply informed him that his symbols were wrong.

Because Jennifer often asked students to think of relevant examples from their own experiences, they often would ask her questions such as "is that kinda like [x]?" to which Jennifer typically would reply, "yeah," or "not really." I did not observe Jennifer explain why something either was or wasn't an example. She either would state that it was or wasn't, or she would admit that she didn't really know but would look it up and get back to them. When a student said, "this doesn't make sense" it often meant that the student couldn't remember what came next. Jennifer would help the student reconstruct his or her memory by asking questions such as, "remember when we did that lab with the [x]?" or "What did we do on Monday?" These questions were intended to both support the student in answering the question for herself, but they also demonstrated to the student that if they had just been paying better attention they already had all the resources needed to answer that question.

For Jennifer, questions shaped the representations of knowledge in science to consist of examples that were to be ordered into a story, as in the dialogical lecture regarding how a compass knew which way to point. Also, the questions asked by students showed that their knowledge representations consisted of efforts to make connections between the subject matter and their own experiences. These connections were loosely organized into one of three possibilities—correct connections, incorrect connections and unknown connections.

In addition to using questions as checks for general comprehension, Carol was particularly cognizant of two additional purposes in asking questions. The first involved her listening carefully to students' responses to try to understand with what precision and accuracy students were using terminology correctly. This was bolstered by Carol's awareness (from her planning efforts) of typical misconceptions held by students. The second purpose was to ask students to clarify their explanations of phenomena. These kinds of follow-up questions were asked frequently during labs and other activities where the purpose would be to make explanations of phenomena.

The students as well, would ask questions ranging in length from short to very complicated. Carol would respond in a number of ways. She might respond directly or turn the question to the class. She also asked clarifying questions of student responses. Or she would defer and address the question later at a more appropriate time (which in my observations, she always successfully seemed to remember to do). When students would say, "this doesn't make sense," they were typically confused about details of the model itself, or how to use the model to make good explanations of the phenomena.

The ways in which questions shaped the representations of knowledge in Carol's teaching practices showed that science was about making sense of phenomena, and that making sense involved connecting relevant examples in terms of a scientific model. The questions asked by Carol were directed toward this effort as were the questions asked by students.

In summary, the questions commonly posed in both Sam and Jennifer's teaching practices engaged objects of narrative interest. The designation of proper instances of a scientific idea and the proper sequencing of those instances were the two main objects of questions asked both by Sam and Jennifer and of, Sam and Jennifer. Though Jennifer also sought to connect the subject matter ideas with her students' experiences, these connections served to strengthen and personalize the illustrations of the narrative. The questions that were engaged in Carol's practice also required the construction of a compelling narrative. What was different about the questions in Carol's practice was that questions also served to use that narrative as the object of analysis to make explanations with in terms of a scientific model in a paradigmatic fashion.

Summary of knowledge representations in practice—intern/student interactions. This section explored the ways in which knowledge representations were shaped by the practices of examples and questions. Each of the interns utilized rich sets of examples and multiple types of questions. And each of these practices helped the interns achieve their goals for student learning. The ways that each intern differed can be attributed to their either narrative or paradigmatic ways of knowing science.

The narrative practices of Sam and Jennifer emphasized examples that served as illustrations of phenomena. These illustrations were to be shaped into coherent narratives that mapped onto science learning objectives. For instance knowing that Rutherford discovered the neutron and that the atom is mostly empty space is a short narrative example of what Sam taught his students. Jennifer used bar magnets to teach the story of magnetic field lines. Examples were either helpful illustrations or less helpful. By providing multiple examples, the likelihood that an illustration would be helpful increased.

Questions were used in narrative practices to check the status of the story or its components. Sam asked questions about "what to do next" as a way to lead students through the steps of doing problems. Jennifer asked questions to provide opportunities to check students' stories against her own. In entertaining many student responses, and in evaluating them as correct or incorrect, the class as a whole benefited from hearing numerous responses both the correct, and incorrect. This combination of selecting correct elements and purging incorrect elements was a useful way to construct a narrative that matched Jennifer's.

Carol's teaching practices emphasized examples and questions that built the capacities of students to make good explanations of phenomena. In this sense, examples were both narrative illustrations of ideas as well as objects to be explained paradigmatically. Questions too were both opportunities to determine the accuracy and precision of interpretation as well as a means for engaging phenomena with respect to a scientific model.

Again, each of the interns was successful in helping their students meet important learning goals, and each intern provided opportunities to learn science. However, as in the previous section, Sam and Jennifer provided their students with opportunities to learn a narrative construal of science. Because Carol was able to develop opportunities to learn both narrative and paradigmatic construals of science, her students had the opportunity to both know and explain ideas in science and illustrate those ideas with rich sets of examples.

Summary of Comparisons Across Cases

This chapter demonstrated that the ways in which the Sam, Jennifer and Carol construed science narratively and/or paradigmatically had pervasive impact on the representations of science found in their teaching practices. From the pedantic routines of the classroom to the most direct engagement of subject matter as found in examples, the opportunities to learn science in these interns' classrooms were dramatically different.

Chapter 7

Conclusions and Implications

This final chapter briefly reviews the arguments made in the preceding chapters. I then draw three conclusions from these arguments about teaching science, learning to teach science and the role of the subject matter in science teacher education. I then examine several limitations of the present study and build from those limitations to a set of questions for future work.

Review of the Chapters

Chapter One: Situating the Study

The literature on the role of subject matter and learning to teach science is generally diffuse and emergent. The breadth of inquiry and range of conceptualizations does little to bring clarity to the field. This is due in large part to the complexity of the challenge. Learning to teach is difficult intellectual and emotional work embedded within cultural systems that defy simplistic analyses.

This study takes a different and more interpretive approach. It builds on the assertion made by Bruner (1985) that there are two fundamental modes of thought: narrative and paradigmatic. Also, I consider disciplinary science first of all to be a resource for science as subject matter. As such it provides a set of substantive and syntactical resources (Schwab, 1978). These resources serve not as standards to meet, but rather resources for the development of subject matter curriculum. I use Bruner then as a guide for making sense of these disciplinary resources, and engage the interpretive effort to understand how interns make sense of science. Coupled with Myers' (1990) analyses of scientific texts as narratives of nature or narratives of science, it is clear that there are multiple ways to construe scientific experience and in the construction of narrative, access to disciplinary resources is both provided and limited as a necessary part of representation.

This study asks the question: how do interns make sense of science as subject matter and how does this affect their teaching? It uses an interpretive framework to characterize the sense making of three science interns, and then explores the opportunities to learn science in their instructional representations of knowledge.

Chapter Two: Methods

Over the 2002-2003 school year, five interns completing their full-year internship at Midwestern State University were observed and interviewed about their teaching practice. Four sets of observations and interviews were completed for each intern, and three of the interns were selected for in-depth case study analysis. The case studies focused on interns' instructional representations of subject matter and were interpreted using the narrative and paradigmatic ways of knowing framework. Cases were developed using modified analytic induction (Bogdan & Bicklin, 1998), and the framework evolved in tandem with the cases as they were developed.

I argue that a close examination of teaching practice allows for exploration of the ways in which the norms and practices of learning to teach science can be used to interpret the ways in which knowledge is represented. These norms and practices have fundamental roles in shaping the opportunities to learn science in these interns' classrooms.

Chapter Three: The Case of Sam

In the third chapter, I argue that Sam construed chemistry as a largely narrative enterprise. Across my observations, Sam emphasized and embedded procedural knowledge and skill into the larger story of "what chemists do and have done." I show that narrative construals of chemistry are pervasive throughout his representations of subject matter. This by itself is interesting because of the inclination to suppose that a rigorous[5] treatment of chemistry would *require* a paradigmatic construal. Over the year of the study, Sam's learning to teach science remained along a largely narrative trajectory. The internship experience provided Sam with time-tested approaches for developing students' abilities to solve problems and efficiently do chemistry procedures.

Chapter Four: The Case of Jennifer

I argue that Jennifer, like Sam, construed science as a largely narrative enterprise. Jennifer emphasized the need to connect subject matter with the experiences of her students. She embedded numerous hands-on activities and demonstrations to illustrate science concepts into the larger story of "Science is all around us." I show that narrative construals of science were pervasive throughout her representations of subject matter. In particular, I show how a narrative construal of magnetic fields did not provide the knowledge resources necessary to explain the phenomena.

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[5] I claim that Sam teaches a *rigorous* class because he prepared students for college coursework. His students learned to solve many problems and his expectations for student performance were high. This was not an easy class, and students worked hard to do well.

Because Jennifer was committed to providing actual phenomena as illustrations of ideas, she actually increased the challenge of teaching by engaging phenomena that might not illustrate the intended concept. This could (and did) undermine her teaching and the use of actual examples to illustrate ideas. Over the year, I observed Jennifer's learning to teach science remained along a narrative dimension. The internship experience showed her that preparation was essential to determine which demonstrations were safe and reliable, and which ones weren't.

Chapter Five: The Case of Carol

I argue that Carol construed science along both narrative and paradigmatic dimensions. She aimed to engage students in the making of explanations of phenomena in terms of the conceptual tools of science. Carol coordinated between narrative construals of experience (that served as examples to be explained and interpreted from a paradigmatic perspective) and scientific conceptual tools. Over my year spent with Carol, her learning developed along both narrative and paradigmatic dimensions. Experience helped shape her use of paradigmatic models. It also helped her develop scaffolding that could support her students' thinking in the context of narratives that were engaging for her students.

Chapter Six: Comparison Across Cases for the Opportunities to Learn.

I argue in this comparison chapter that the opportunities to learn science by the students of these interns were shaped by the ways they make sense of scientific knowledge. Using instructional representations as the bases for comparison, I showed that the norms and practices of the interns provided their students with dramatically different opportunities to learn science.

Having reviewed each of the arguments made in the previous chapters, I now look across them to offer three conclusions and note some of their implications for teacher education. The three conclusions have to do with teaching science, learning to teach science and the role of subject matter in teacher education

First, I conclude that the interpretive framework of narrative and paradigmatic ways of knowing provides a new perspective on the sense-making of interns' teaching practices. Second, I conclude that learning to teach science involves learning to coordinate between the two-dimensions of science subject matter: narrative and paradigmatic ways of knowing. And finally, I conclude that science teacher education needs to pay careful attention to the ways in which pre-service science teachers make sense of subject matter. I will now discuss each conclusion in turn.

Conclusions

The Narrative and Paradigmatic Ways of Knowing Interpretive Framework

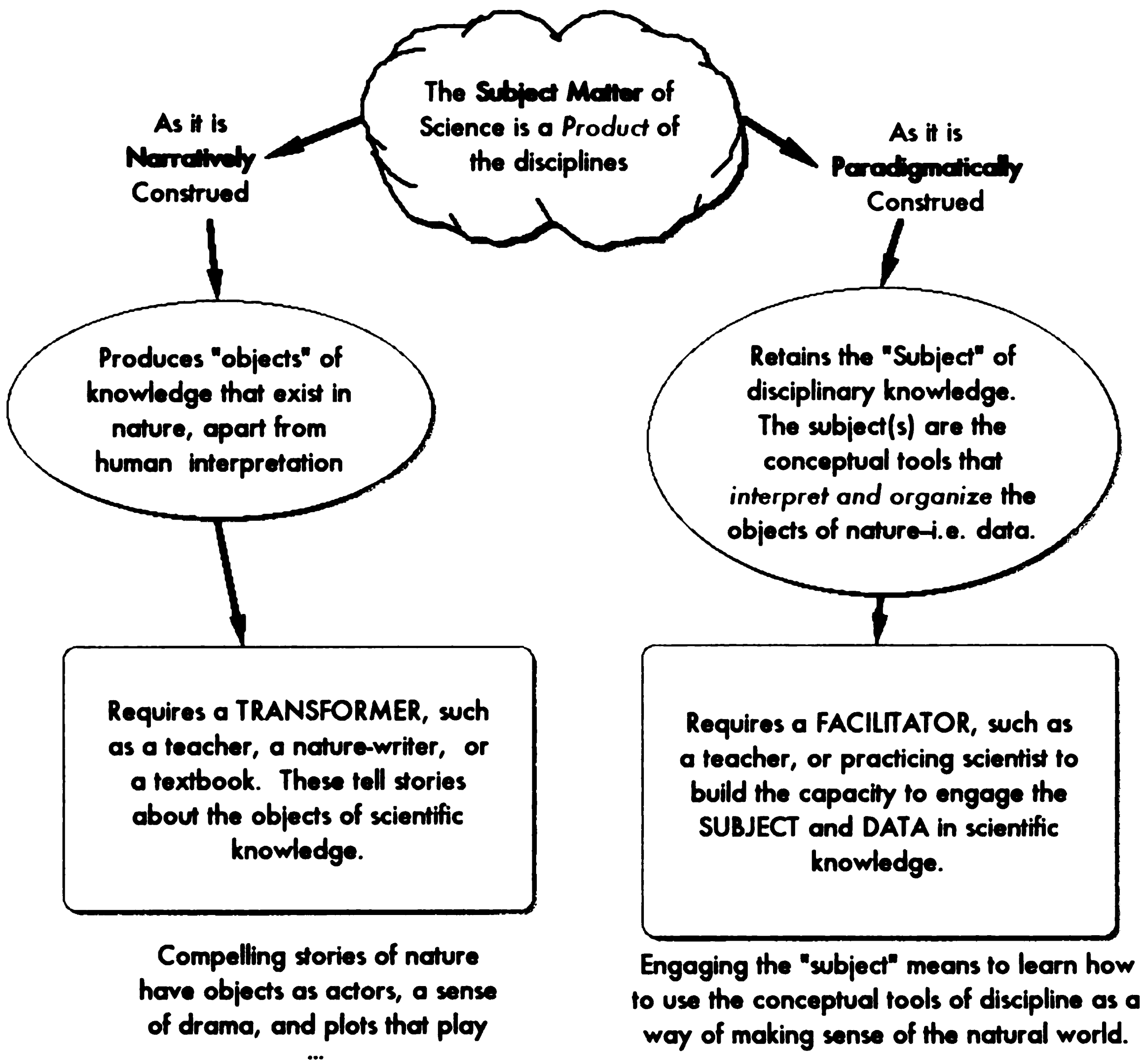

Figure 7.1. Narrative and paradigmatic ways of knowing science interpretive framework.[6]

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[6] Graphical and conceptual elements for this representation have been adapted from Palmer (1998).

This representation of the framework illustrates the relationships between the products of disciplinary science and their narrative or paradigmatic construal. It emphasizes that there are two fundamental ways of making sense of science as subject matter. It is primarily a map that shows the relationship between the products of the discipline and their representations as either narrative or paradigmatic. Note however, that this map is not an illustration of pedagogical practice -- though certainly there are pedagogical implications for these relationships. I will review and expand on this framework to explain these relationships, and then explore several of their pedagogical implications.

Narrative and paradigmatic construals. Narrative construals of science transform or change the products of the discipline into "objects" in nature. These objects largely stand apart from human interpretation and are portrayed such that one seemingly observes the objects directly. For instance, in the cases presented, Jennifer portrayed magnetic fields as an object in nature to be observed. For Sam the mole was simply a number used in calculations, which, if you stated it clearly enough, was easy to understand. In both cases, instead of conceptual tools used to explain phenomena, these products of the discipline were considered objects to be learned about in and of themselves.

Paradigmatic construals of science retain a focus on the products of the discipline as conceptual devices used to organize and interpret phenomena and data. A magnetic field is therefore not a "thing" but a conceptual tool used to explain the orientation of iron filings, for example, when near certain materials (such as magnets, but also current-carrying wires). The mole is a convention used by chemists to facilitate the comparison and analysis of chemical reactions, among other things. It essentially defines a common equivalence between the number of atoms or molecules and their mass. In both instances, as products of the disciplines, they can be used as conceptual tools to help interpret and engage data.

Representations. In addition to describing the ways in which science can be construed, this framework also informs how construals are made into representations. Construals imply a "construer" and it is the construer's role to form a representation of disciplinary knowledge. It is important to note that in each construal, there is information that is changed and/or lost. After all, if a representation didn't differ from its source material, it wouldn't be a representation. What is important to keep in mind is that the way knowledge is construed affects its representation. Different construals of knowledge result in different representations of that knowledge, and therefore create different access to that knowledge.

Narrative construals require a *transformer*[7] to create a representation. The transformer converts products of the discipline into representations of science that take the form of stories about nature. Transformers include teachers, nature-writers, nature guides at parks and textbook authors. Compelling stories of nature have animals, plants, or phenomena as the main actors, there is a sense of drama or conflict, there is a point

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[7] The reader might wonder why "transformer" instead of "translator?" I find that translation as a metaphor implies little information loss besides perhaps shades of "nuance." In the process of representing a narrative construal, the actual meaning is changed, and so the term "transformer" emphasizes this change in meaning.

where the conflict is resolved in some way, and a conclusion. In Figure 7.1, the transformation of disciplinary science to narratives of nature is represented relationally by emphasizing that the objects of nature must pass *through* the transformer, to be re-presented as stories to students or other people.

Paradigmatic construals need a *facilitator* or person who organizes evidence in support of an argument and results in a representation. This facilitator is often a scientist who is writing or presenting an argument, or it can be a teacher who engages students in efforts to organize and interpret experience. The interactions between phenomena and the person is mediated by the conceptual tools of the discipline (or some version of the conceptual tools, as is often the case in classrooms). This contrasts with narrative construals where the objects of knowledge are mediated by the transformer. The designation of a *facilitator* is meant to emphasize that this person works to create a representation that allows more direct engagement between other people and the knowledge of natural phenomena. In the framework representation, Figure 7.1, this is emphasized by showing the placement (by the facilitator) of the subject and data at the center of network of people. Good representations allow students or other people to engage the subject and data more directly using the conceptual tools of the discipline.

Implications for teaching science. As previously noted, good narrative representations of science are compelling stories about nature. They are potentially interesting and motivating as contexts in which students can see that science is worth doing. To be clear, I value the role of narrative representations in good science teaching. Teaching itself can be considered a narrative endeavor (Egan, 1988; McEwan, 1995). And when done well, it has a similar structure to a well-told story.

In his book, *The culture of education*, Bruner (1996) makes an elegant argument for greater inclusion of "narratives of science" in the curriculum of science. Bruner does not use this phrase in the same way that Myers (1990) and I have. Instead he focuses on the potential for stories about science to combat the tediousness of what constitutes much of present science instruction in schools. By championing the role that stories of scientific discoveries might play in the classroom, he raises important issues about what is motivating and interesting about science for students. Bruner argues that a better understanding of what makes a good narrative can likely be translated into instructional practices that would make the subject matter of science come alive.

In a complimentary vein, Kiernan Egan (1997) argues that developmental stages in youth learning resonate with various narrative approaches. Such narratives should be used to tap into the powerful resources of students' interests and motivation leading to the better design of curriculum.

The goals Bruner (1996) and Egan (1997) espouse are certainly not new. Consider the following, which is taken from the introduction to a 1925 textbook.

> The authors of *Elementary Principles of Physics* have long felt that students lose interest in Physics because of the formal presentation of the subject. There have been too many new terms, abstract concepts, and laborious calculations. The attempt has been made in this book to bring the subject to the student in language that he can readily understand and in steps which progress with his own mental development. This has been done without sacrifice of accuracy or completeness.

> The student's *natural* interest in scientific phenomena is expressed by the questions: "What is it?" or "How did it happen?" Once he has answered these questions, he must next discover "Why does it happen?" Seldom does natural curiosity lead him to ask concerning measurements and mathematical relations the question: "How much?" (Fuller, 1925, p. iv)

This quotation underscores the long-standing challenges in actually embedding opportunities to learn in paradigmatic ways within compelling narratives. Rather than a process of simplification -- as this text implies -- this study shows that science can be construed in narrative and paradigmatic ways, but the challenge of teaching does not diminish. This framework does however, provide a way to be clearer about what it is that is being taught and learned in science classrooms.

If we take narrative construals of science to be a central element in science teaching, the question becomes how to provide opportunities to engage students with paradigmatic construals of the subject matter? The case of Carol illustrates one way this might be done. Carol used stories and cartoons of experiences that held narrative interest for her students. These narratives were used as contexts in which to develop the students' abilities to make explanations of phenomena using the conceptual tools of natural selection. In using narratives in this way, Carol shifted the role of examples from being purely illustrative to being sites of application for paradigmatic understanding. The role of labs, activities and demonstrations thus can serve dual purposes. First they can be illustrative in a narrative sense. But they can also be seen as opportunities to engage in paradigmatic interpretation and explanation.

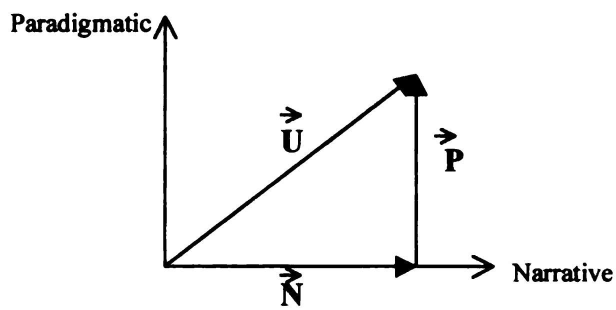
In my own work as a teacher educator I utilize the notion of the cognitive apprenticeship (Collins, Brown & Newman, 1989) to help pre-service teacher candidates structure learning activities along the lines of establishing the problem, modeling, coaching, fading and maintenance. This model works well in structuring the kinds of opportunities students need in order to develop both narrative and paradigmatic understandings of science. However, the model also works to structure a narrative construal of science. Under a narrative interpretation, establishing the problem is akin to telling students clearly what they will be working on. Modeling is demonstrating how to do the problems, and coaching is helping students work problems in class. Fading is equivalent to homework and maintenance is the strategy of occasionally putting problems from previous chapters on tests.

This is a problem in my work as a teacher educator because I have aimed to utilize the cognitive apprenticeship model in the service of helping teacher candidates learn how to teach science -- in what I now consider to be, paradigmatic as well as narrative ways. I can see now that the cognitive apprenticeship model, can itself be construed either narratively or paradigmatically, and serve as a representation that tended to reinforce rather than disrupt traditional notions of teaching and learning.

Learning to Teach: Coordinating Between Two Dimensions of Science

The interpretive framework illustrates the ways in which products of the discipline can be construed either narratively or paradigmatically. Using the framework, I have argued that narrative and paradigmatic ways of knowing are fundamentally different and independent from each other. I have shown that both Sam and Jennifer view science narratively, and Carol uses a blend of narrative and paradigmatic perspectives. This argument raises an important question: how can someone view science from both perspectives if the perspectives are independent?

To answer this, we can look at what narrative and paradigmatic understandings contribute toward some notion of a "total" understanding in science. This relationship -- the relationship between narrative and paradigmatic understanding and "total" understanding -- can be illustrated in a vector diagram that takes understanding to be a resultant vector that is composed of a narrative understanding component and a paradigmatic understanding component. Because narrative and paradigmatic are independent, they are represented as orthogonal vectors in "understanding space" as depicted in the following diagram.



U = P + N

Figure 7.2. Two-dimensional representation of understanding space.

If one considers understanding, **U**, to be a representation of the "net" understanding a person has about a science topic, we can decompose that understanding into narrative, **N**, and paradigmatic, **P**, parts. Therefore, a person's overall understanding is the vector sum of these two components.

It is helpful to compare the understanding vector, **U**, to an ordinary velocity vector, **V**. In introductory physics, students learn that the motion of a projectile can be analyzed by considering the projectile's overall velocity as the vector sum of two orthogonal velocity components -- the horizontal ($\mathbf{V_h}$) and vertical ($\mathbf{V_v}$) velocity vectors. The velocity of a projectile can then be decomposed into these two parts: $\mathbf{V} = \mathbf{V_h} + \mathbf{V_v}$. It is important to note that neither of these components is actually "seen" in the moving projectile. What is seen is the overall velocity, **V**. The components of this velocity vector are just analytic devices that describe important aspects of the projectile's overall motion.

Similarly with the understanding vector **U**. I am arguing it is analytically useful to view understanding as the vector sum of two orthogonal understanding components: narrative and paradigmatic understanding. So, for any particular science topic, there can be -- at least in principle -- a decomposition of that understanding into these two components. Like the horizontal and vertical velocity components, narrative and paradigmatic understandings do not, by themselves exist. What exists is understanding. Narrative and paradigmatic are simply useful analytic tools for describing that understanding.

The question about the interns' understandings can now be more clearly addressed. To say that Carol understands the science subject matter in both narrative and paradigmatic ways is to say that she has non-zero contributions from these two components to her overall understanding of science. To say that Sam and Jennifer understand science in narrative ways, is to say that they have non-zero contributions from the narrative component, and zero (or little)[8] contribution from a paradigmatic component.

By decomposing understanding into these two components a number of interesting points can be made. First of all, considering understanding to be a two-dimensional construct is richer than the more common single dimensional construct. The more common consideration of "total" understanding is to describe understanding as ranging from "shallow to deep." The two dimensional construct I suggest here, allows greater specificity for the overall understanding vector, while incorporating the shallow to deep designations as descriptors for each of the component axes. So, instead of considering understanding along a single dimension to range from shallow to deep, one can consider the vector understanding (**U**) to be made up of two components (**N** & **P**) that independently range from shallow to deep.

This is helpful because it enables a more descriptive and analytic characterization of the ways interns know science. There is much to learn in learning to teach science, and interns learn much about their subject matter in the course of teaching it. As the old adage goes, the best way to learn something is to teach it. But what it is that one learns in the course of teaching science is uncertain (McDiarmid, Ball & Anderson, 1989). In order to clarify the potential of the vector metaphor, we will now consider each of the three interns on a graph. The graph illustrates what the interns learned about science over the course of their internship.

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[8] It should certainly be acknowledged that to claim exact "values" (such as zero) for any understanding would require much more sensitive assessments of subject matter understandings than I made.

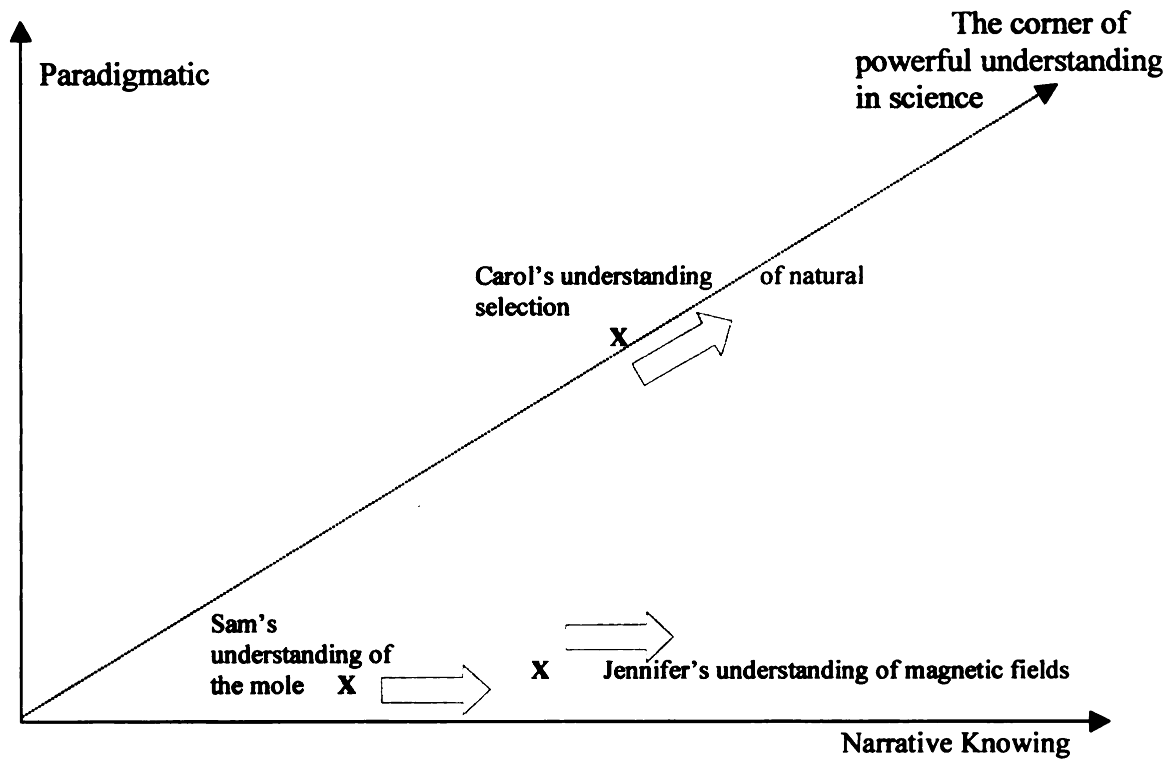

Figure 7.3. Interns' placement in understanding space.

This graphical representation allows me to characterize both the position of each of the interns (represented as an "x") as well as their trajectories of learning (represented as a block arrow) over the course of the internship year. First of all, the units on each of the axes are heuristic in nature and range from shallow to deep understanding. To be at the origin, would be to know nothing at all about science, and to be at the opposite corner -- designated as the "corner of powerful understanding" -- would be to know science in a way that is powerful. By powerful understanding, I mean that a person has an understanding that allows for the flexible coordination between narrative and paradigmatic construals of the products of the discipline.

Sam is positioned relative to the other interns closest to the origin and along the narrative dimension. Sam knew several facts and ways of working with the mole concept in chemistry but his understanding was not deep. If Sam's "total" subject matter understanding is regarded as the sum of narrative and paradigmatic components, one would find a positive contribution in the narrative dimension and no evident contribution from the paradigmatic. The block arrow represents this total understanding vector with respect to my observations over the course of the year. Sam learned things about science that deepened his understandings along a narrative dimension, but they did not contribute to his paradigmatic sense-making.

Jennifer is positioned further along the narrative dimension than Sam because she had a much deeper narrative understanding of subject matter. She constantly sought to find new and better illustrations for the ideas she wanted to teach. But like Sam, her construals were narrative in structure and over the course of my observations, Jennifer's learning, as represented by the block arrow, involved a deepening of understandings along the narrative dimension alone.

Carol is positioned in the center of the graph to depict her total understanding as the sum of non-zero contributions from both narrative and paradigmatic dimensions. Carol had a rich narrative understanding of natural selection, and she coordinated this with a relatively deep paradigmatic understanding of the subject matter. Together, her total understanding, over the course of my observations, deepened in both dimensions and is represented by the block arrow pointing toward the corner.

Carol's position on the graph and the arrow depicting the trajectory of her learning over the course of the year show that not only did she make sense of science differently than did Sam and Jennifer, but that how they learned science was directed toward different targets. Sam and Jennifer, over time, learned deeper narratives of science and did so over the course of the internship. Carol, over time, learned both deeper narratives of science, but also how paradigmatic understandings of these narratives allowed for the use of the conceptual devices of science to interpret and explain the natural world.

How an intern makes sense of subject matter knowledge is related not only to the kinds of learning opportunities provided to their students, but it is also related to the trajectory of their learning. These trajectories likely will have long lasting impact on the interns' learning over the course of their careers. And of course, how the interns know and make sense of science will serve to constrain the opportunities to learn science of their students.

For Sam and Jennifer, this meant that over the course of their internship, they typically sought to explain the science more clearly, to find activities that would better illustrate, or to find activities that students' could do better. Each of these was aligned with a narrative construal of science. Though I cannot know for sure, the evidence I gathered over the year did not suggest that the interns would seek to engage paradigmatic construals of science in the future.

For Carol, learning to teach science meant grappling with emerging paradigmatic understandings and their coordination with more narrative construals of the subject matter. Carol aimed to devise models that would be simple, yet relatively consistent, with the products of the discipline. She sought to build her students' abilities to use these in the service of explaining phenomena. Over the year, I consistently saw her aim to develop more robust understandings of science that engaged both narrative and paradigmatic dimensions.

My conclusions thus far have been that science as subject matter can be construed in both narrative and paradigmatic ways and that these ways of knowing science impact both what is known by the interns, as well as how interns' learning was constrained by these ways of knowing over time. These two points lead me to my final point.

Science as an Explicit Part of Science Teacher Education

Throughout this study, the pervasive role of subject matter understanding has been shown to shape the ways in which the interns designed lessons, presented information, interacted with students, and thought about their teaching and learning. I now return to the point at which I started, the problem of practice I called "talking past" Jacob.

Recall that my puzzle with Jacob centered on what I thought was an authentic conversation about teaching and learning a lesson about the physics of color. Though we shared a common experience of an afternoon spent exploring the ways in which light was absorbed and transmitted through various filters, the lesson Jacob taught was a flattened version of the ideas I thought we'd engaged the day previously. At the time the interation with Jacob happened, I wasn't able to articulate what was happening. Now, I think that it was likely that Jacob's understanding was more narratively construed while I was making sense of the subject matter from a more paradigmatic perspective. Further, what excited me most about the lesson was the way in which students would have the opportunity to engage in the interpretation and organization of data. It was (and still is) amazing to me that such dramatic color effects can be explained with a small set of ideas. For Jacob, I think that what I interpreted as excitement about the ideas, was likely excitement about the motivational aspects of teaching color in this way. If Jacob viewed this from a more narrative perspective, the teaching of light and color can be difficult to motivate as a lesson. By getting students to interact with the materials, it is reasonable to think that students would be more motivated to learn the material. But the learning opportunity that was provided -- beyond the chance to look through some color filters -- was to be told the rules (which are actually statements of patterns) for color addition and subtraction.

It is not possible for me to recreate my experience with Jacob. And I recognize that a fair amount of conjecture is contained in the previous paragraph. It is relevant to my conclusion however, because had I been able to articulate the distinctions made in this study, I would likely be able to discuss the nature of our respective subject matter understandings. A common tension felt by teacher educators is to determine how directive one should be when working with a pre-service teacher. A colleague of mine characterized this as "walking the line between rude and worthless." While he perhaps overstated the case, the danger exists that teacher educators who visit classrooms every other week can appear to the pre-service teacher to be someone who pops in to tell them what they're doing wrong.

This framework, however, might be helpful in providing a more open space for conversations about subject matter. It can do so because it does not dismiss the narrative understandings that many pre-service teachers have -- and thereby incur the discomfort mentioned above. Instead, it values narrative understandings as but one dimension of understanding. Being able to discuss, teach and learn with more explicit attention to narrative and paradigmatic construals is likely to improve communication about what types of subject matter understandings are being engaged.

I am ultimately hoping this interpretive framework will facilitate improved communication. In working with pre-service teachers, I do believe that the learning opportunities are richer in reform-minded science classrooms. I view it as my job as a teacher educator to make the case for this kind of teaching and to prepare future teachers to teach in reform-minded ways with one important caveat: that these teachers also find benefits in teaching this way. The best that I can hope for is that I can help teachers learn how to teach in reform-minded ways, and to do so in ways that allow us both to feel authentically heard. If a pre-service teacher chooses not to teach in ways that are different, though I might feel disappointed, I at least can respect that decision. What I am uncomfortable with is watching cohorts with whom I've worked closely, leave a program unaware that there was something more to teaching than what they learned. If this study can help me make some progress in addressing this problem of practice, then I will be pleased. It is, however, but a start. And the only way to tell if the ideas here have merit is to observe how they play out in my future work with pre-service teachers.

Limitations of the Study

The limitation of the previous explanations is that they don't solve any problems. There remains a tremendous amount of heavy lifting to do on all counts. Learning science in ways that promote both narrative and paradigmatic understandings are difficult and time-intensive. The pace at which teachers must prepare lessons for students is much faster than the pace at which subject matter understandings can be explored and developed. Also, all along the way, the rhetorical devices of both narrative and paradigmatic construals tend to obscure the role of human interpretation in knowledge production. So, how is a pre-service teacher supposed to cope with the enormity of this task? And how is a teacher educator supposed to manage subject matter understandings as well as the many other aspects of learning to teach that this dissertation conveniently ignored? I think it likely that there is no simple way to do this for someone at the beginning of a teaching career.

The agenda that I have begun to lay out hints at what it might mean for a teacher to be a life-long learner of science. It also sheds light on the kinds of materials that are important for teachers to have in order to develop the subject matter understandings needed to teach science in reform-minded ways. To expect a teacher to do what Carol did -- that is, devise simplified models of disciplinary knowledge for the topics of light, photosynthesis and natural selection -- is neither realistic for pre-service teachers in general, nor is it a wise use of human resources. Curriculum can be developed that provides models of disciplinary knowledge that are grade-level appropriate. Assessments likewise can be designed that allow a teacher to assess both students' and his or her own understanding of the subject matter. The overwhelming majority of interns with whom I've had the pleasure of working with, have been very serious about trying to learn more about how to teach science. Providing them some specific guidance, beyond vague admonitions to "always learn more," could help them more deeply develop either narrative or paradigmatic ways of knowing their subject matter.

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