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LEARNING TO TEACH INQUIRY SCIENCE: EXPLORING THE

IMPACT OF SUBJECT MATTER SPECIFIC INDUCTION

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LEARNING TO TEACH INQUIRY SCIENCE: EXPLORING THE IMPACT OF SUBJECT MATTER SPECIFIC INDUCTION

By

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ABSTRACT

LEARNING TO TEACH INQUIRY SCIENCE: EXPLORING THE IMPACT OF SUBJECT MATTER SPECIFIC INDUCTION

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Scholars and policymakers agree that teachers are central to the reform of teaching and that teachers' on-going professional development is critical to the improvement of schooling. Of particular recent interest is the character and content of early career support for teachers, often known as "induction programs." This study takes one such program—one devoted to the development of new teachers' content and pedagogical content knowledge—and asks: "What (if anything) do new teachers learn when presented with opportunities to expand their knowledge of subject matter and the teaching of subject matter?"

To answer this question I studied the Exploratorium Teacher Induction Program (TIP) and followed six first-year TIP science teacher participants over 14 months, tracing the development of their thinking about subject matter for teaching. The TIP offered novice teachers ample opportunities to learn science and ways to teach it. I documented participants' teaching, probed their knowledge of subject matter in interviews and observations, and tracked their professional development. I also carefully documented the opportunities to learn subject matter in the TIP, and I analyzed this evidence to discern if, and in what ways, their experiences learning science in the TIP translated to new, productive ways of thinking about teaching science.

I examined three aspects of subject matter knowledge for teaching: the role of students' subject matter ideas in instruction; scientific inquiry in instruction; instruction as a means to stimulate students' continued study of science. These constructs are the subjects of three chapters, across which a pattern develops, with some teachers showing substantial gains while others show lesser or no gains. I explore three factors that influence changes in teachers' performance and discuss implications for induction. In conclusion I discuss a tension that permeates the analyses: induction is necessarily pragmatic, supportive and useful to novice teachers. At the same time, to advance teachers' knowledge and instructional capacity, it must strategically advance longer-term developmental goals.

For Theo

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My student peers at the college of education were exceptional. Four in particular contributed to this study. Jodie Galosy was my "partner in crime" on the Exploratorium study, which served as the basis for her dissertation and my own. Jodie was a sounding board and collaborator at every step. Jodie, Courtney Bell, Mark Olson, and I also formed a dissertation writing group. For two years we met regularly to read, discuss, and edit our emerging work. Mark was instrumental in developing the subject matter tasks used in the study and helped with data collection. You are wonderful colleagues who have become dear friends. Thank you.

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While many have contributed invaluably to this study, the mistakes are my own.

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Chapter One

Subject Matter Specific Induction: Prospecting for Teacherly Knowledge

As he prepared to teach reproductive health to his eighth grade physical science class, Geoff Chiu was worried. It wasn't the content. Describing the paths of human sperm and eggs up to a point "just short of fertilization" (November 2003) was a breeze. As a trained biochemist with 15 years experience in medical labs, he had run hundreds of fertility tests and he knew human reproductive anatomy. He also knew that many of his students were already sexually active and many others soon would be, so this lesson could have immediate value and interest in a way that, say, atomic weight or heredity might not. In his first year of teaching, however, Geoff had come to see eighth graders as a tough audience and he worried that they might run wild with dirty jokes and gross humor given the opportunity to "talk sex."

After the bell and once his students settled into third period, Geoff's lesson was underway, but the students did not act out. Instead they seemed to hardly notice his presence or acknowledge the day's topic. Geoff took his position next to the overhead projector at the front of the classroom and launched into his lecture. He talked for 20 minutes, during which he put up two overheads (the cross-section of the male testes and then the frontal outline of female reproductive anatomy), pointing to aspects of the diagram as he went. Among other things, he characterized the size of sperm, noted the location of the fallopian tubes, and defined ectopic pregnancy. Meanwhile, a dozen students were deeply engaged in other activities: six pooled their desks around a card game at the rear of the classroom, two boys near the front kicked paper footballs across the classroom and mocked "field goal" signs to one another. A girl in the corner was working on math problems, and several other students stared blankly ahead. Just a few faced Geoff, visibly straining to attend to what he said over the classroom clamor, and take notes.

After a while, Geoff seemed to get uncomfortable with me observing this lesson as it was obvious to both of us that nothing much of value was happening. He glanced at me and rolled his eyes at an outburst from the card game. On several occasions, he stopped and asked for the students' attention: "Excuse me. Excuse me, people. You'll need to know this." The card games, math problems, football, and sly side conversations slowed momentarily only to pick back up within a minute. Near the end of his lecture—by which time several note takers had joined the blank starers—Geoff looked at me with a helpless shrug and tilt of the head, as if to say, "Hey, what can I do? I'm teaching. They just aren't learning."

Despite his knowledge of the content and his appreciation of the need for students to understand it, Geoff's lesson completely failed to engage his students' thinking. I can't imagine anyone learned much. Geoff's story is not unusual. It reminded me of my own struggles as a new teacher to engage students in meaningful ways and of dozens of classrooms I've visited over the last few years. Why is it so hard for well-intentioned—sometimes even well prepared—teachers to engage students in learning? What would help Geoff do a better job engaging students in thinking about science next time around?

Let us consider some candidate answers. We might suggest strategies for managing student behavior—a system of enforceable rules about appropriate classroom behavior might calm and focus his students. We could offer Geoff a pedagogical approach—maybe group work or Socratic questioning that might motivate students and give them a more physically active role in learning. And these could help, but *what* would these strategies help? Manage students to focus them on *what*? Motivate them to do *what*? A third suggestion—which I consider in this study—is that Geoff needs help in learning to think pedagogically about science. Content knowledge is simply not enough. Maybe with some help thinking about the content itself in new ways—to consider what is interesting about science, why students might care to learn it, the types of problems they face in understanding it—Geoff could take his substantial understanding of content and turn the curriculum into something compelling for students.

This, of course, is not a new idea. It resonates with Dewey's (1902) claims that teachers need to understand the psychological—as well as logical—aspects of the subject matters they teach. It also lands squarely in the territory envisioned by Shulman and his colleagues when Shulman (1986) hypothesized that teachers need pedagogical content knowledge. In this study, I join those researchers in exploring the professional knowledge required if teachers are to teach in intellectually engaging ways. In particular, I ask the question: What kinds of supports in a teacher's early career can contribute to the development of such knowledge?

Overview of the Study

Scholars and policymakers agree that teachers are central to the reform of teaching. They readily agree that teachers' on-going professional development is critical to the improvement of schooling. Of particular interest to many scholars and policymakers of late is the character and content of early career support for teachers, often known as "induction programs." This study takes one such program—one devoted to the development of new teachers' content and pedagogical content knowledge—and asks: "What (if anything) do new teachers learn when presented with opportunities to expand their knowledge of subject matter and the teaching of subject matter?"

To answer this question I studied the Exploratorium Teacher Induction Program (TIP) and followed six first-year science teacher participants in that program over 14 months, tracing the development of their thinking about subject matter. The TIP offered novice teachers ample opportunities to learn science and think about ways to teach it to their students. I documented their teaching, probed their knowledge of subject matter in interviews and observations, and tracked their professional development. In particular, I carefully documented the opportunities to learn subject matter in the TIP and I analyzed this evidence to discern if, and in what ways, their experiences learning science in the TIP translated to new, productive ways of thinking about teaching science.

The TIP's home is the Exploratorium, a "museum of science, art, and perception." New science teachers spend two years in the program during which they attend a four-week intensive Teacher Institute, work with mentors, attend Saturday workshops, and tap a range of other program resources. This study explores teachers' opportunities to learn within the TIP, evidence of the influence of the program on teachers' subject matter knowledge, and the extent to which one sees traces of the TIP's influence in the new teachers' science teaching.

Subject Matter Knowledge for Teaching

Every study or subject thus has two aspects: one for the scientist as a scientist;

the other for the teacher as a teacher… It is the failure to keep in mind this double aspect of subject matter which causes the curriculum and child to be set over against each other. (Dewey, 1902, p. 200-1)

Pedagogical content knowledge goes beyond knowledge of subject matter per se to the dimension of subject matter *for teaching*. I speak not of content knowledge here, but of the particular form of content knowledge that embodies the aspects of content most germane to its teachability. (Shulman, 1986, p. 9)

At the heart of this study is the idea that teachers need to understand the content they teach, and that understanding has both disciplinary and pedagogical dimensions. Some teachers enter their positions with stores of knowledge about the subjects they are to teach and, over time, some will transform their knowledge and develop clear and compelling ways to portray their subjects to students (e.g., Borko & Livingston, 1989; Gess-Newsome, 1999; Wilson, Shulman & Richert, 1987). Other teachers, less "highly qualified," enter teaching with more fragile or fragmented content knowledge. They face an even more daunting challenge, for they must learn more content and learn how to transform that content into meaningful experiences for their students. It is the transformed knowledge—and the opportunities one can offer teachers so that they might learn to transform it—that I am interested in.

More than disciplinary knowledge of subject matter, subject matter knowledge for teaching—Dewey's psychological aspects of content or Shulman's pedagogical content knowledge—reflects the subject matter as it is used in instructional practice. A teacher's subject matter knowledge is unique because he uses it in ways that others—scientists, the public, technical workers—do not.[1] Dewey (1902) called for teachers to "psychologize" the subject, or reinterpret its fundamental concepts and methods in powerful, accessible, and stimulating ways for students. Thus, it is not enough for a teacher to know, for example, that "matter takes up space and has mass." She must understand how to make that claim meaningful to students. Dewey's argument was that a teacher who understood the human experiences associated with that abstraction would be in a better position to help students connect with the idea. Thus, in preparing to teach the idea of "matter," the teacher might ask herself, "How do I know that air is matter? How could I prove it?" Since she wants to help students make sense of this abstract knowledge, she might think about what experiences they bring to the study of matter (perhaps they've played with balloons, bounced balls, put their hands out of the window of a fast-moving car and felt the wind), as well as the experiences that scientists have had in developing that understanding.

From her knowledge of both students' and scientists' experiences, she might identify ways to connect scientific ideas to her students: what they might care to know about matter; how it relates to their lives; and how it might be helpful to them to know about it. For example, some children may have emptied ice from an ice tray to find that the cubes of ice had "grown"—when they poured it, the water was at the top of each little cube compartment in the tray. But two days later, the cubes seemed to be bursting out of the compartments. Such student experiences can be readily linked to scientific concepts. Ice doesn't really grow. But when water freezes, the molecules in it take a crystalline

[1] Throughout this study I alternate between the male and female pronoun when referring to a teacher or teachers generally. Defaulting to the male pronoun is inaccurate and buries the fact that most teachers are women. I find referring to both (e.g. "s/he") awkward, and clumsy, hence my decision to alternate between the two. Readers who prefer "s/he" will forgive me for our aesthetic differences.

rigid form that causes it to look bigger from the outside.[2] For the teacher, "ice growing" can be a way to help students make connections between the world as they experience it—and perhaps wonder about—and ways of understanding it scientifically.

Building on Dewey's argument, Shulman (1986, 1987) claimed that teachers needed a particular kind of content knowledge—pedagogical in nature—that involved both an understanding of students' ideas about specific ideas, and the most powerful instructional representations that teachers could use to build bridges between their students and the subject matter. I return to these ideas in more depth later in the study. For now, I note that this research lies squarely in that tradition, exploring how new teachers might develop such knowledge, especially in programs designed to support such learning.

Subject Matter Specific Induction

"Induction," or early career support, has become an increasingly popular policy (Fideler & Hasselkorn, 1999) employed to serve many ends. Some induction programs aim to retain teachers. They want to slow what Ingersoll (2003) has called the "revolving door"—teachers entering and exiting the workforce and moving from school to school—and propose that providing mentoring and continued training can help stabilize this problem and create conditions conducive to teacher retention (e.g., Colbert & Wolff, 1992). Other programs conceptualize induction as one point along a career-long learning continuum that spans preparation, induction, and continuing professional development

[2] Liquid water has a partially ordered structure in which hydrogen bonds are constantly being formed and breaking up. In ice, each molecule is hydrogen bonded to 4 other molecules, thus the rigid structure of ice creates more open space within an ice cube. Consequently the cube's "size," a macroscopic feature, increases as microscopic properties change in other ways. Read more about this at http://www.edinformatics.com/math_science/info_water.htm.

(e.g., Feiman-Nemser, Schwille, Carver, & Yusko, 1999; Feiman-Nemser, 2001). In the latter case, proponents propose that even well prepared new teachers are but "well-launched beginners" who need support to learn a range of things. They see induction as a multi-faceted form of professional development. For instance, Feiman-Nemser (2001) suggests that teachers need opportunities to learn about the context of schooling, designing responsive instruction, creating classroom community, and developing a professional identity.

Current debates about teacher quality place teachers' knowledge of subject matter at the center of the discussion. Everyone agrees that teachers need to know their content. But there are substantial disagreements about what that actually means. Do teachers need undergraduate majors in traditional disciplines? Do they need a breadth of content knowledge that reflects the spectrum of content that one finds in K-12 schools? Is there a ceiling to the kind of content knowledge effective teachers need? Is subject matter knowledge a sufficient condition for teaching? Given these debates, the growing interest in content-rich induction programs is particularly relevant, for those programs offer us opportunities to see how, when, and under what conditions, new teachers need to adapt their subject matter knowledge in order to teach their content.

Subject matter-specific induction is one variation on induction, which places the subject matter at the center of program activity. Subject specific induction efforts might match novices with experienced mentors who teach the same subject (Feiman-Nemser, 1990), offer novices on-going professional development workshops in the subject (Luft, Rhoerig & Patterson, 2003), and link new teachers with on-line resources and virtual mentors.[3] In these programs, novices may learn content, how to transform content into pedagogically useful forms, to identify and create curriculum materials, to organize and manage students and instruction in their subject in particular, and to build a network to nurture teachers' on-going professional education.

Although these "content-rich" induction programs are not as prevalent as they might be, they bear careful scrutiny, especially given current arguments about the role that subject matter knowledge plays in policy talk and efforts toward educational improvement.

In short, new teachers need to learn to think about subject matter pedagogically. And induction might be a place they can do so. The TIP provides a unique opportunity to explore that possibility.

Preview of Chapters

In chapter two, I introduce readers to the details of the study, describing both the study design and my methods. This is a case study of the TIP in which I characterize the opportunities to learn in the program, and closely analyze changes in teachers' knowledge over time, considering knowledge and (perhaps) learning in light of the opportunities to learn subject matter. I describe a range of methods I used to document teachers' knowledge and practice, as well as their opportunities to learn subject matter in the Exploratorium TIP; discuss data analysis; and introduce the six teacher participants who are central to this study.

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[3] The National Science Teachers Association, the New Teacher Center at the University of California Santa Cruz and the Math/Science Resource Center at Montana State University are currently developing an online mentoring program for beginning science teachers. This is described at http://www.newteachercenter.org/eMSS/index.php.

In chapter three, I describe the TIP and situate it within its institutional home, the Exploratorium. I characterize the unique mission of both—to make science broadly accessible to the populace. I provide an overview of the program and its myriad components, which serve up multiple opportunities to learn science. I then focus on three core program components: a four-week summer Teacher Institute at the Exploratorium, Saturday Workshops that take place throughout the academic year, and classroom-based mentoring.

Chapters four through six are the analyses of change in teachers' use of subject matter in teaching over time. Each looks at one aspect of subject matter learning that stems from the TIP opportunities to learn, and examines how teachers' use of subject matter changes over time. Chapter four concerns pedagogical content knowledge, focusing in particular on teachers' use of students' ideas about subject matter. Chapter five addresses teachers' portrayals of scientific inquiry. Chapter six characterizes teachers' use of instruction to tap students' drive to learn or what Schwab (1978) called their "Eros."

Throughout chapters four through six a pattern develops, with some teachers showing substantial gains while others show lesser or no gains. In each chapter, I develop a hypothesis about factors that influence changes in teachers' performance. In chapter seven, I look back across the evidence to explore these hypotheses and the implications for better induction programs and better research.

Chapter Two

Research Method and Case Study Participants

The research reported here is based on a field study of six contrasting cases within one teacher induction program, the Teacher Induction Program at the Exploratorium. The study's logic is based on that of a case study, "an exploration of a 'bounded' system...over time through detailed, in-depth data collection involving multiples sources of information rich in context" (Creswell, 1998, p. 60). I studied the TIP through direct observation of program activities, document analysis, interviews with participants and staff, and extensive analysis of six first year lower-secondary science teacher participants (Fall 2002 to Spring 2004). The question that drove design, data collection, and data analysis was: "What (if anything) do new teachers learn when presented with opportunities to expand their knowledge of subject matter and the teaching of subject matter?"

The chapter is divided into four sections. In the first, I provide an overview of the study design and description of the study context. Next, I describe specific data collection activities used to examine both teacher learning and the program. Third, I discuss data analysis. Finally, after describing the methods, I introduce the teachers who take center stage through the remainder of the study.

Overview

The design of the study entails a single case study within which there are six contrasting cases of new teachers. Thus, there were two levels of data collection—

a program and teacher level, as Figure 2.1 indicates.

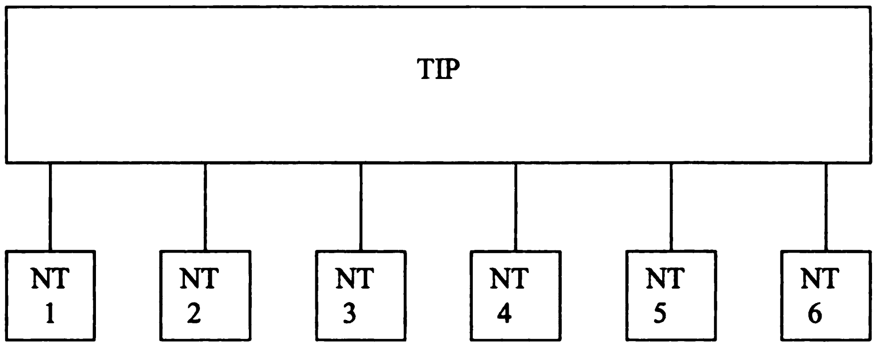

Figure 2.1

Diagram of Two-Level Study Design

Program Level

To look at how induction influenced teachers' subject matter knowledge for teaching required describing the opportunities to learn subject matter in the TIP, and describing the development of teacher participants. Data collection at both levels was embedded in a larger five-year evaluation study (Spring 2000 through Summer 2005) during which my colleagues and I documented the range of program components through interviews with staff and participants, and field observations.[4] Data collection for teacher participants in the current study spanned 14 months from September 2002 through November 2003; data were collected to inform the evaluation efforts, but tailored to the particular questions that drove my research interests.

[4] The evaluation of The Exploratorium TIP was a collaborative project with Suzanne Wilson and Jodie Galosy. Descriptions of the program and conceptualization of research design are best understood as collaborative products. Two dissertations were written based on that study, including this one and Galosy (2005).

I chose the TIP for two reasons. First, the TIP is an instance of subject matter specific induction; a recent innovation in teacher education that is emerging as a policy solution to the problems of less-than highly qualified teachers. Second, I had access to this site through the on-going evaluation study and so I had already established important relationships with key informants and familiarity with the program itself.

Within this study, I chose to focus on physical science. This focus stems from two interests and one methodological concern. First, the TIP's particular strength is in physics—the Exploratorium was founded and is staffed by physicists and the TIP grew out of a physics teachers' group, so focusing on physical (not biological) science seemed the most likely way to see evidence of change. Second, I also wanted to examine parts of the program that could potentially have broad impact. Almost all students take physical science courses or integrated science courses which emphasize physical science in middle and/or early high school. Finally, methodologically, I wanted to be able to compare the six teacher cases. By selecting one content domain, I took advantage of a natural experiment at the TIP. All of the six teachers were expected to teach the same topics, and all of them had access to the same TIP experiences. I wanted to track the patterns of their learning given these similarities.

Teacher Level

To capture change in teachers' use of subject matter for teaching, I collected data on teachers' use of subject matter in practice between Fall 2002 and Fall 2003. I split data collection into two time periods: time one (t_1) spans Fall 2002 through Spring 2003, and time two (t_2) spans late-Summer 2003 through Fall 2004. These are the periods preceding and following the TIP's summer Institute, which is considered the "heart" of the program and perhaps the most significant experience with regards to new teacher learning. In fact, the placement of the summer Institute is one of the most unique aspects of the Exploratorium's theory of new teacher learning. Instead of inundating the new teachers with materials and ideas at the beginning of their first year of teaching, the TIP waits until the novices have a year of teaching "under their belts." The theory is that the new teachers will then be more poised to pick up and take advantage of the ideas and materials they encounter in the summer Institute. If they participated in such an Institute prior to teaching, they might be blinded by their concerns for stepping into classrooms for the first time. Since the summer Institute is a substantial part of the program, and given its unique location in the chronology of the novices' learning, I was curious to see whether, how, and to what extent teachers used subject matter in new ways after their participation in the Institute, and if changes could be linked to their experience in the TIP.

Sample. Of the TIP science teacher participants, I chose those who taught at least one lower secondary (eighth-tenth grade) physical science course in 2002.[5] I sought six teachers, reasoning that this was the greatest number of teachers for whom I could manage to collect data.

I made initial contact with the case study teachers at the September 2002 TIP orientation where I presented a brief overview of the study and solicited volunteers. I described the data collection activities entailed in the study (see below). I also explained that participants would receive $500 in stipends, tapes of their teaching, and that previous participants in the evaluation research reported that study afforded them a valuable outlet

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[5] Actual course titles vary and include "Physical Science," "Physical Science II," "Integrated Science," and "Conceptual Physics." Each of these courses is an integrated curriculum that includes biological and physical sciences.

for talking about their teaching. I solicited volunteers who were currently teaching physical science and anticipated continuing to do so, and who were also interested in the physical science track of the TIP summer Institute. Volunteers filled out a short form with contact information and a description of their assignment (school, course load). Sixteen teachers volunteered to learn more about participating in the study.

To pare this group down, we analyzed teachers' program applications, and we met with TIP staff to gather their first impressions of the teachers. Applications allowed us to verify teacher assignment and subject matter background, while TIP staff helped us steer clear of those new teachers who seemed to be overwhelmed with their new duties, or who staff thought were likely to drop out of the program.[6] We developed a short list of eight teachers to contact and learn more about.

In October 2002, we contacted eight volunteer teachers and conducted a short phone interview, to review the components of the study, the terms of participation, and answer any questions they had. Afterward, two teachers opted out, citing concerns about the time commitment, and a third we chose not to invite based on concerns expressed by TIP staff that the teacher was already "in over his head." Later in October, we conducted initial interviews with five teachers.

After the phone interviews, we chose not to invite one teacher who was a 20-year veteran in her first year of teaching science, opting to focus on "true" beginners, or people with less than a year of experience teaching science, or any other subject. Another teacher, a first year alternatively certified teacher, decided after the first interview that

[6] While it is important to collect data on these kinds of participants as well, for moral reasons we chose not to overburden any new teachers who were already struggling, and for methodological reasons, we aimed to find teachers who would be in the program long enough to track the effects of the summer Institue on their learning.

she was not interested, citing concerns about the time commitment. We invited three teachers to participate—Michelle McCoy, Geoff Chiu, and Avner Vangarten—all of whom opted to participate and are introduced at the end of the chapter. In November 2003, we contacted three additional candidates from the original list of volunteers via telephone, and conducted brief interviews. All "true" novices: Joaquin Melendez, Andrea Roland, and Susan Wei joined the study in November and are also introduced later in the chapter.

New teachers' professional and personal lives were at times quite unstable (job reassignment and dismissal, household moves, long-distance romantic relationships, and warnings of layoffs) and this impacted data collection efforts. Here I comment briefly on two major changes that directly impacted teachers' participation in the study. First, in Spring 2003, during region-wide layoffs, each of the six teachers in this study received warning from their district, that his or her job was not secure for the coming fall. Ultimately, no one was laid off. However, Andrea, the sole "under-credentialed" teacher in the study, feared that due to her low credential status, she would not be hired back. Fearing the lost job, she chose not to attend the summer Teacher Institute and instead taught in a summer school science program at a local charter school. Consequently, she did not participate in the second subject matter interview, though she participated in all other aspects of data collection.

Second, Joaquin was fired from his job with a few weeks left in the school year. He completed the year and, in fact, attended the Teacher Institute as he had originally planned. But he dropped out of the study prior to the start of the 2003 school year. Last I heard from Joaquin, he planned to substitute at a private school in Fall 2003, and then to travel in Europe for several months. Consequently, Joaquin participated in none of the t_2 data collection.[7] As a result of this unevenness in participation I have uneven amounts of data on teachers, which shaped the process of data analysis, a subject I return to shortly.

Data Collection

The TIP

The TIP consists of a range of components and resources, but my data collection efforts were focused primarily on three core program activities: the summer Teacher Institute, Saturday workshops, and mentoring. Though others (e.g., on-line resources, the Exploratorium library) are also available to teachers, I decided not to focus on those given limitations on how much data I could collect and consider. Here again I focused primarily on the physical science sections.

Teacher Institute and Saturday workshops. The four-week intensive Teacher Institute is the core TIP component, which all teachers attend between their first and second year in the program. We focused our data collection efforts on the Teacher Institute in three years of the evaluation study (2000, 2001, 2003). Each summer, the program offers four distinct tracks of study (e.g., High School Physics or Physical Science) and every teacher attends one of these tracks for the entire Institute. We collected data across these tracks, and at mentor-novice work sessions, and we also interviewed program staff. Data collection is summarized in Table 2.1. In this table, each cell contains the number of observations we have for each program component. An observation is an instance in which we spent 25 minutes to several hours on a given day

[7] Given the statistics on teacher retention, this turnover is predictable. I might have chosen to over sample in anticipation of losing several participants. But the data collection was too labor-intensive for the resources available. Future research on new teachers ought to be designed with these retention issues in mind.

in the field taking field notes, or conducting interviews of similar duration with staff and participants in the summer Institute.

Table 2.1

Data Collection for Summer Teacher Institutes

Year/Activity Observed	HS Physics	MS Physics	Biology	Math, Math/Science	Mentor Group	Other[8]	Interviews of staff
2000	3	1	2	0	1	2	5
2001	0	0	1	2	3	1	3
2003	4	1	0	2	4	2	2
Total	7	2	3	4	8	5	10

Observations of the summer Institute included a wide range of activities:

- Structured observations of workshops across the content areas and components of the typical workshop structure (beginning, middle, end and "down time" of classroom-based sessions, exhibit walks and discussions)
- Observations of mentor-novice groups and pairs, including lesson planning, developing curriculum boxes, and informal discussion
- Interviews with program staff, guest presenters, and affiliated staff
- Interviews with teacher participants

[8] This category includes a range of activities that do not recur regularly throughout the summer Institute, but are unique activities of the Exploratorium TIP, such as observing teachers in the workshop building mini-exhibits, orientation day observations, observing "Iron Science Teacher," etc.

To document the Teacher Institute, we conduced 50 hours of observation and another six hours of interviews with staff.[9] We primarily relied on participant-observation methods. We sat in workshop classrooms, watched the goings on, asked questions of participants, shadowed the group as it walked the floor, all the while taking copious notes. However, the Exploratorium staff expects active participation by all visitors, and so our efforts to take notes were often in tension with the expectation that we participate in the exhibits. For example, during my first visit to the summer TI, Lana exhorted me to "Get in there and work with the materials—we don't allow hitchhikers here!" (June 2002). Though I sometimes found ways to avoid active participation in order to focus on what I saw as my primary duties as recorder (of materials, activities, participants), many times my colleagues and I were actively involved in workshops. This kind of participation provided a unique vantage point. As researchers interested in what teachers might take away from the program, we had some opportunities to see what *we* could take away (although we do not presume that our experience is similar to what others might have seen, learned, or felt). It also provided close observation of staff and teacher learners, which we later wove into interviews with both groups. We used similar strategies to document Saturday workshops, two of which were observed.

Mentoring. Mentoring in the TIP is planned, organized, and enacted by the novice and mentor pair. This made it difficult to arrange observations of mentoring, especially since we were collecting data from afar; asking people to schedule mentoring sessions

[9] Jodie Galosy, Mark Olson, Suzanne Wilson, Barnett Berry, and Ann Spindel all contributed to the data collection efforts. As noted previously, all data were collected for program evaluation purposes. This study, while part of that evaluation, nevertheless has a narrower focus. Accordingly, the data on the TIP that is most relevant for this study is that in the high school physics and middle school physics observations (the first two columns, above).

when we were on site ran counter to the program's personalized, flexible character. Furthermore, coaches and teachers sometimes felt that that work was too personal to be put under the microscope of data collection. Due to the loosely structured format of mentoring in the TIP, we decided to interview mentors and to spend less time trying to orchestrate the complexities of scheduling observations of mentoring.

Another complication was the fact that novices worked with multiple program staff. From the standpoint of the TIP, each novice was assigned a "mentor" and a "coach."[10] The program envisioned coaches working in the classroom in a "coaching cycle" and mentors would work outside of the classroom consulting with teachers, planning instruction, for example. But this distinction between mentors and coaches was lost on novices who saw before them human resources to be tapped as appropriate.

In order to locate the best informants—those who actively worked with novices—I asked the novice participants to nominate program staff members who had worked with them during their first year in settings other than program workshops. I located five TIP mentors and in late March 2003 I interviewed them, some nine months after novices and mentors first met. In the interviews, I probed four topics: the mentor's professional background and history with the Exploratorium; their past, current and (anticipated) future duties and interactions with TIP novices; and their assessment of case study teachers' development.

[10] I ought to also note that the program is committed to self-study and its own continual re-invention. And so the roles of mentor and coach—and the meaning to those terms—shifted over the course of the evaluation and this dissertation.

Teacher Participants

As Figure 2.2 summarizes, data were collected between Fall 2002 and Fall 2003 and were split into time one (t_1) and time two (t_2), which were (roughly) the period preceding the summer Institute and the fall following it, respectively.

	Time One (t_1)				Time Two (t_2)
	Fall 2002	Winter 2003	Spring 2003	Summer 2003	Fall 2003
Touching base (TB)			TB	TB	TB
Observation (Obs)	Obs*		Obs**		Obs
SMK Interviews			SMK I		SMK II
Stimulated Recall (SR)					SR
PD Logs	PD	PD	PD		PD

* Videotaped ** Unit Series Videotaped SR Stimulated Recall Interview

Figure 2.2

Data Collection for Teacher Participants

Data Collection with Teacher Participants

Data collection included interviewing, observing teachers, and teacher-maintained logs of professional development activities. I begin by describing four kinds of interviews and professional development logs, and then move to observations.

I conducted interviews with teachers for two major purposes: (1) to trace their use and thinking about subject matter; and (2) to track activities in their professional lives, including class load, mentoring, and the full range of opportunities to learn (including the TIP). I conducted 26 semi-structured interviews across teachers (I also interviewed them about specific lessons; I discuss those with observations). Unless otherwise noted, all interviews were in person with the exception of the check-in interviews, which took place by telephone. I audio-recorded all interviews but the check-in interviews. I summarize the four types of interviews in Table 2.2. The stimulated recall and subject matter interview series were unique to this study so I expand on those briefly below. (All interview and observation protocols are included in Appendixes A and B.)

Table 2.2

Description of New Teacher Interviews

Interview	Purpose	General Description	Approximate Length
Getting started	Introduce teacher and support	Teachers describe their teaching preparation, teaching situation, support; and confidence/concerns	50–60 minutes
Check-in	Update information	Teachers discuss their progress in teaching, support, and confidence/concerns	15–20 minutes
Subject matter Interviews	Examine teachers' pedagogical thinking about subject matter	Teachers discuss content, curriculum planning, analyze students' responses on an open-ended tasks	40–45 minutes
Stimulated recall	Examine teachers' pedagogical thinking about subject matter	Teachers analyze excerpts of their t_1 teaching videos	40-60 minutes

Getting started. Conducted in Fall 2002, the getting started interview was the first substantial opportunity to learn about participants and so covered the gamut of relevant background information as well as descriptions of teachers' school and class assignments. We prompted teachers to talk about their pathways into teaching, including university studies, teacher preparation, and previous work experience (where applicable). We asked them to describe how they came to know about and enter the TIP and to describe other current professional relationships and learning opportunities. They also talked about their experiences as students of science and in teacher preparation, including student teaching experiences. We prompted them to talk about their current assignment, including class load, interactions with peers, supervisors, and mentors. Here we had teachers expand upon their comfort and familiarity with the subjects they were assigned to teach as well as with the students in their classes.

Touching base. The touching base or "check-in" interviews dealt with content similar to the getting started interview, but helped track changes to participants' teaching situations, and professional development activities (including formal and informal mechanisms of support through school, district, and other PD programs). We prompted participants to describe specific support through induction programs, including the TIP and district- and state-level programs, as well as other science-specific and general professional development activities, and to elaborate on previously mentioned professional development activities.

Professional development logs. We asked teachers to log their professional development and induction activities on a quarterly basis. A short form prompted teachers to describe professional development experiences, including their source (e.g., district, school, museum), evaluation of its usefulness and applicability to the classroom, and to make general comments about the experiences. This provided us with useful information about the frequency of particular types of support, as well as specific topics to probe in the touching base interviews.

Subject matter interviews. There were subject matter interviews administered before and after the summer Institute. These interviews were organized around subject matter tasks designed to engage teachers in thinking out loud about a particular piece of subject matter content. Each teacher responded to three of five subject matter tasks in each interview. The tasks describe an everyday circumstance and framed phenomenon of light or sound (See Table 2.3).

Table 2.3

Everyday Subjects Depicted in Subject Matter Interview Tasks

Task	Title	Description/Prompt
Task 1	Man Seeing	A man standing facing a tree with the sun at his back. Prompt: How does the light from the sun help the man to see the tree?
Task 2	Man's Shadow	A man faces a bright light source. Prompt: Draw the man's shadow. How would it change if he walked closer to the light?
Task 3	Broken Pencil	A pencil is half submerged in a cup of water. Prompt: Why does the pencil appear to be bent or broken?
Task 4	Eraser Clap	A student claps two chalkboard erasers together in front of the class. Prompt: How do her classmates hear the sound?
Task 5	Xylophone	Xylophones have short keys and long keys. Prompt: Why do you think that short keys make higher pitched sounds while long keys make lower ones?

The tasks were structured with three purposes in mind. First, I wanted to see change, so I chose content that I thought all teachers could talk about. The summer Institute sessions consistently addressed visual and auditory perception as the first portion of the four-week Institute (Exploratorium, n.d.).[11] Second, I wanted to be sure that the teachers could comfortably talk about the content. I reasoned that most of the teachers would be able talk about lower level content, so I chose concepts that are found in the elementary and middle school science portions of *Benchmarks for Science Education* (AAAS, 1993). Third, I wanted to have similar data across all of the teachers. Because the content I observed in their classroom teaching varied according to grade level, time of year, and curricula, I designed these interviews to focus all of the research participants on similar content.

The tasks followed a common form. They depict teaching situations in which teachers are asked to analyze student responses to about real world applications of physical science concepts of sound and light.[12] For example, in one task, high school students are asked to explain how light helps a man see a tree. The teacher participants were then asked to analyze a student response and describe what the student appeared to know or not know about how light helps the man see. Following this, I asked teachers what they would do instructionally in response to the student. In the second subject matter interview, the teachers analyzed the transcript from the first subject matter interview, critiqued their performance, and added new interpretations and ideas about how to teach the content. I expand on the construction and use of the subject matter interviews in Appendix A.4, an annotated description of one of the interview tasks.

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[11] Initially, I hoped to include a fourth criterion: that the content would map well onto the curriculum that participants teach. This was not possible given the breadth of assignments, though four of the six teachers did teach units that covered either sound or light in their first year.

[12] Mark Olson helped develop and field test these tasks; his expertise in both physical science and in what beginning teachers know and do not know helped considerably. He also participated in analyzing the teachers' performances.

Stimulated recall interview. I constructed customized stimulated recall interviews for each teacher based on the videotaped observations from t_1. For each observation, I selected three to five clips that zeroed in on teachers' treatment of subject matter, including instances of teachers explaining concepts, introducing a new topic, and student-teacher or student-student interactions. During these interviews, I asked the teachers to describe their reasoning about the particular instructional approach they took, what they hoped students would learn about the day's topic, whether they thought they had accomplished their instructional goals, and finally, to critique their teaching, and generate ideas about how they might change the lesson if they were to teach it in the future.

Observations of teaching. I summarize the number of teaching observations in Table 2.4. I observed and recorded ethnographic field notes during two to six class sessions per teacher in total. Whenever possible, I conducted 15–20 minute pre-observation and post-observation interviews with the teacher; either on tape or documented in writing. I also collected teacher materials from the observed lessons when they were available.

Two to four class sessions per teacher were also videotaped by a local videographer. The videotaped sessions followed a process adapted from the TIMSS video study,[13] which included collecting other data as well—teacher materials, student work, and a teacher questionnaire. We also requested that teachers provide lesson plans, copies of curriculum materials, and any other class handouts. For student work, we asked teachers to select six students—two high, middle, and low achieving—and provide copies of their work for each lesson. We also requested that teachers complete a questionnaire

[13] The Third International Mathematics and Science Study (1999) http://nces.ed.gov/timss/. Jodie Galosy, my collaborator on the larger evaluation study, took the lead in developing these materials.

for each lesson that situated the lesson, indicated the goals and resources used, and evaluated whether the lesson accomplished what the teacher intended. Although well intentioned and often apologetic, most teachers did not submit these accompanying materials more than once or twice, and no teachers submitted materials for all sessions.

Table 2.4

Observations of Classroom Teaching

Teacher	Participant Observation (# of class sessions)
Andrea	4
Avner	6
Geoff	3
Joaquin	2
Michelle	5
Susan	3

Other data were collected as well, including survey responses from all TIP participants (see Wilson, Galosy & Shouse, in preparation). Because those data were not directly used in my analyses, I do not describe them here.

Data Analysis

The process of data analysis was non-linear, iterative, and recursive (Miles & Huberman, 1994). For instance, when what I saw in the field did not confirm initial impressions from earlier interview data, I went back to that data and reconsidered my initial impressions in light of fieldwork. Alternatively, conversations with other researchers on the project, or with Exploratorium staff, would often give me pause, as people would challenge my interpretations. These occasions often led me to other data sources, revision of my impressions, and/or confirmation of my findings.

My analyses included diverse efforts: transcribing hundreds of pages of interviews and observations, entering 51 documents in an Atlas/ti database from which I developed 53 codes. I also drew pictures, talked with peers, colleagues, and professors about what I thought might be happening in the data, as a way to test out ideas. I wrote extensive analytic memos about individual teachers and their learning, as well as about themes that arose in the analysis. One form of data reduction and representation led to another. They were not all equally productive, but each led to more focused and disciplined analyses when I felt confident that I had mastered the data and clearly saw three substantive themes worth pursuing (which I describe in chapters three through six).

There were three overarching goals in data analysis. I mapped opportunities to learn subject matter in the TIP; (simultaneously with the first) examined qualities of teachers' pedagogical uses of subject matter at t_1; and considered the t_2 data relative to t_1. In chapters three through six, I describe the specific analytic techniques I used to construct the arguments in the chapters. Here, I present an overview and some specific examples of the analyses, along with a glimpse into my intellectual journey through the work. I relied heavily on data reduction, display, and interpretive methods as described in Miles and Huberman (1994).

Mapping Opportunities to Learn Subject Matter

Initial efforts to track what teachers' had an opportunity to learn in the TIP preceded the design of this study. In the evaluation study, we wrote up extensive field notes on the TIP's major program components. We reduced these into memos, which we later compiled into reports to the sponsor (Wilson, Galosy, Shouse, Spindel, Snyder & Berry, 2001; Shouse, Galosy & Wilson, 2003). Over time, close analyses of teachers' talk about the TIP, and how they thought it influenced their thinking and practice (as well as trends we noticed in initial summaries of our survey data), also gave rise to ideas about opportunities to learn in the TIP. Interviews in the field during t_2 data collection—particularly those concurrent with the 2003 Teacher Institute—gave rise to new insights. I transcribed these interviews immediately while in the field, and annotated my own observations as to how teachers' observations corroborated or negated my emerging ideas about the TIP.

To develop a composite image of the opportunities to learn in the TIP, I compiled all of these data sources: fieldnotes, excerpts from interviews with teachers (including 82 mentions of the Exploratorium and the TIP in the Atlas/ti database), my memos and those of colleagues on the evaluation study. I read these numerous times, annotated them, and diagramed the recurring activities in which teachers interacted with or about subject matter.

Analyzing Evidence in Time One Data (t_1)

To discern trends concerning teachers' entering capacities in the t_1 data, I started by compiling all relevant codes in the Atlas/ti database for each teacher and printing summaries of the data (organized by teacher). This included teachers' dispositions about science, their experiences as students of science, and their expressed views about teaching across science disciplines. I read these multiple times and annotated the documents.

This was an unwieldy amount of data, so I reduced it by locating "thick instances" of teachers' instructional use of subject matter.[14] I wrote many of these up in short memos. Early on, I compiled thick instances for particular teachers from which I generalized to the individual teacher a notion of their entering thinking about subject matter. Clustering thick instances turned out to be the essential data reduction step, allowing me to conduct analyses across time.

Another strategy was to map backward from t_2 data—starting with "where teachers ended up" and looking back at where they started—to determine what, if anything, had changed. This analytic strategy came late in the study after all of the data had been processed—written up, transcribed, and/or entered into the Atlas/ti database. I used the thick instances of instruction as I would for much of the analyses to come.

Analysis of Change

I thought about analysis of change in two distinct ways. I looked at change within cases and I looked at change across cases. Within cases, for example, I looked at teachers' performance across time. One particularly helpful memo concerned a thread across several interviews with Michelle in which she described her teaching and learning of light. This memo is included in Appendix C as an example of the kinds of analytic memos—longer and shorter—that were generated on the way to the analyses presented here. I also clustered together all t_1 and t_2 instances across teachers. This allowed me to consider how the group may have been changing and whether any changes evident were shared across teachers or unique to a particular teacher or group of teachers.

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[14] "Thick instances" are those in which I have documentation of a teacher's instructional goal and how she acted to fulfill it in a classroom context or interview setting. This includes instances in which teachers spoke about lessons they actually taught and those they intended to teach.

As already noted, after churning out maps of opportunities to learn and analytical memos about those opportunities to learn and individual teachers, I began to notice three themes across the data concerning what (and if) the new teachers were learning. First there was the theme of the role of student ideas; a second theme concerned the novice teachers' efforts to learn to teach the inquiry aspects of science; the third theme concerned the new teachers' efforts to teach science in ways that are intrinsically interesting to students. As I moved toward these themes, I virtually abandoned other attempts to analyze the data and created a particular analytical frame for each theme. I introduce each of these frameworks at the beginnings of chapter four, five, and six.

The Teachers: Personal Histories and Landscapes of Induction

Teacher participants were drawn from non-selective public middle and high schools in the San Francisco Bay Area. Each teacher worked with a socially, ethnically, and linguistically diverse student population typical of the region. Across their schools, no fewer than 20% of students were from low-income families,[15] while no more than 23% of students were Caucasian, and 9–44% of students were nonnative English speakers. With one exception, all teachers were certified to teach their subject at the grade they were assigned.[16]

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[15] Here and throughout this study "low-income" or "low SES" is based on percentage of students who qualify for federally subsidized free and reduced-price lunch.

[16] Andrea was completing her student teaching in her own classroom. As of November 2002, she needed only to complete this and pass the state single subject (biology) licensing exam which would clear her to teach all science up to eighth grade.

Table 2.5

Teacher Participants' Preparation and Teaching Assignment

TEACHER	Grade/ Science Courses	Teacher Preparati on	Subject matter Major	Credentia l, as of 10/2002
Andrea	8 Physical Science 7 Life Science	Post-BA	Health	Emergency (biology)
Avner	12 Physics 9 Integrated Science	Post-BA	Electrical Engineering	Physics
Geoff	8 Physical Science 7 Life Science	Post-BA	Biochemistry	Biology
Joaquin	9 Integrated Science	Post-BA, MAT	Biology MA, Ecology	Biology + CLAD
Michelle	12 Physics 10 Integrated Science	Undergrad	Physics Education	Physics + CLAD
Susan	9 Conceptual Physics	Post-BA, MAT	Biology	Biology

Here I provide a brief introduction to all of the case study teachers, but focus especially on three: Avner, Michelle, and Geoff. These teachers participated across the entire 14-month period of data collection and were particularly talkative, which provided me with a good deal of insight into the experiences of new science teachers in the TIP. After describing these three teachers, I make briefer introductions of Joaquin, Susan, and Andrea, the other three participants.

Avner Vangarten. Avner is white, and was 26 in October 2002. He grew up and attended a public school system in an upper-income suburb north of Chicago. He graduated from a top tier public university with a degree in electrical engineering. Upon graduation, he was certain he was not interested in corporate work, but was not sure what he wanted to do. He opted for a stint in the Peace Corps and was assigned to Burkina Faso.

Avner had his first teaching experience while in the Peace Corps, serving as a high school mathematics teacher for one semester after a three-month preparation program. Avner worked with a direct approach to instruction under a highly competitive secondary system. As he explained:

> A big part was teaching in the math and science part of the training; they highlight a very didactic teaching style. Plus there are no books for students to have. As you are going along you say, "theorem 3.5… write down the theorem." They are very into an older, more traditional style of teaching: know the definitions, be able to apply it all the way down the road. They basically copied the French. They take the old French textbook and old French curriculum and everything. So it's very rigorous comparatively. (October 2002)

Avner's experience in the Peace Corps turned him on to teaching. He began to consider teaching as a potential career through which he could work to equalize opportunities for students in the U.S., as he explained, "After I finished I figured I'd continue to teach and wanted to work in an urban area. Even right here in the U.S. there are such huge disparities" (October 2002).

Avner returned to the U.S. and sought a post-BA teacher preparation program with a distinct social justice angle. He considered several programs before opting for one in Oakland, California. The program was intended specifically to prepare teachers for work in urban schools. He won a Governor's award, which offset the bulk of his tuition expenses in return for his commitment to teach California's neediest students for at least two years after program completion.

The one-year program was heavily field-based. Avner worked in two placement schools (one each semester) in the same urban, working-middle class district where he was eventually hired. As a student teacher, he taught physics and algebra. In the morning he taught, in the afternoons he reconvened with classmates at the university to debrief and discuss educational theory. Avner felt the structured opportunities to talk with his peers on a regular basis about real classroom events was particularly valuable for his development as a teacher.

Following the post-BA program, Avner was offered three jobs, two in secondary and one in middle school. He explained that he felt compelled by the middle school position because it might allow him to intervene in students' lives before they were turned off to science. However, he accepted the job at Rockville High School, one of his student teaching placement schools, citing the comfort that came with familiarity with the school's staff and an interest in helping more ninth graders make a crucial transition in their science education.

> I felt really comfortable with the staff and students. I felt like just having worked with the students here I don't know what it was, but they just really appeal to me. I also felt like ninth grade is a big transition. And if they get in, get on the boat, then they will probably be fine. If they miss that, they can make it up, but it is really difficult psychologically when you've not gotten there the first time. To try again and again is just difficult. (October 2002)

Fall semester of his first year, Avner taught three 90-minute block courses: two sections of ninth grade physical science, and one physics section (the sole physics section offered at Rockville). He was one of two integrated science teachers in the school and the only physics teacher. He reported little school-based collaboration or mentoring, though he did continue to work with his supervising teacher (from student teaching) from the neighboring high school. They met every couple of months early on in the school year and, later, Avner joined him as a consultant on a project to develop a curriculum and statistical software package for high school physics. Avner was also active in the Physics Teachers Resource Group, which convenes physics teachers in the region to swap materials and instructional ideas.

In October of his first year teaching, Avner was confident in his knowledge of the science he would teach. He had excelled in science as long as he could remember. In his electrical engineering major, he took a range of applied and theoretical physics courses. Though there were several topics he was to teach that he had not studied since high school (e.g., geology, biology), he was certain he would remember these and have no trouble teaching them to ninth graders.

Avner felt particularly well prepared to teach physics which, across the units within the courses he taught, accounted for over half of his load. In fact, by the fourth week in his first term at Rockville, he was already thinking about ways to change the curriculum to reflect his social justice interests. He hoped to build an interest in physics by removing the mathematics wherever possible, as he explained,

> I'm hoping [to] get rid of some of the barriers to physics. The kids who are like "Oh physics, it's like the hardest class. We can't go there." Well, I don't know. I guess that a lot of [teachers] are into keeping math [in physics] which is keeping the kids out of [physics]. But at the same time, those [students] who aren't in the class aren't getting the ideas. (October 2002)

Michelle McCoy. Michelle is white, from a middle class New Jersey suburb, and she entered teaching fresh out of college. She was one of a handful of physics education majors (and one of two women), in her cohort at Eastern State University, a large research-oriented university in the northeast. Her university preparation had been split between the Physics Department and the College of Education. In physics, her classmates were mainly upper division physics majors and graduate students. Highly computational, and well beyond what Michelle believed she would need to know in her teaching career, physics courses reflected the department's emphasis on training future scientists. In contrast, teacher preparation courses dealt with understanding student diversity, reflecting on field-based experiences, and preparing lesson plans. These courses, unlike the physics courses, sometimes seemed like "common sense," as Michelle explained:

> So a lot of my physics classes were more graduate levels, so I did have a tough time with some of my physics classes there. My [education and physics] classes were two separate entities, so I felt that I was learning physics beyond what I needed to use as a teacher. And then my education classes were helpful, but at other points, I felt that they were almost common sense. (October 2002)

Michelle's student teaching brought the worlds of science and education together in more concrete ways. She was placed with a cooperating teacher who had been teaching physics for over 30 years at a suburban high school. Over the course of his career, he had designed and built dozens of lab set-ups and often presented labs three times a week. Michelle worked closely with him, gradually assuming instructional duties over the course of the academic year. By the end of the year, she was teaching four physics classes by herself, leaving just AP physics to her cooperating teacher.

In planning lessons during student teaching, Michelle drew heavily on the labs and demonstrations her mentor had developed and honed. This facilitated her planning and re-introduced Michelle to the physics she had learned as an undergraduate. The demonstration-heavy approach she observed, and used in student teaching contrasted with university physics:

> I learned a lot from [my mentor teacher]. I got a lot of good lab ideas, and a lot of good demonstration ideas, and he really helped me to realize that a lot of the concepts in physics can actually be demonstrated. Going through my physics classes in college, rarely did I see any demonstrations. Mainly we did calculus problems, so I didn't even know how to demonstrate all of the theory that I had learned. I mean, maybe I knew there was a way, but was not learning how. I went into his classroom and it was almost the other extreme. So it was going from no demonstrations ever to "What should we do with all this stuff?" (October 2002)

The questions of what to do with "stuff" and how to organize interactive science teaching were important to Michelle and popped up periodically studying our conversations. These entering questions also put her in a very good position to take advantage of the learning opportunities of the TIP which—as I'll describe and explain in chapter three—are very much driven by doing "stuff" and using "stuff" to explore science.

Michelle's physics background worked to her favor in the job market. In the summer of 2002, San Francisco Bay area schools were, in her words, "desperate for physics teachers" and she was offered interviews at six. During a mid-summer trip from her home in New Jersey to San Francisco, Michelle interviewed at four schools and received offers from each one.

In August 2002, after interviewing with the science department and principal at Rockville High, Michelle was hired to teach two sections of senior physics and three sections of physical science, a course that integrated physics, biology, and chemistry for tenth graders in the "non-science" track. She felt comfortable with the physics students, who she saw as college bound and achievement oriented, and reported excellent rates of attendance, participation, and assignment completion. However, physical science students posed a novel challenge. This required course served students unlike those she had worked with previously: 80% were freshman, the balance were sophomores and juniors who had failed physical science the first time around. One section of Michelle's physical science was comprised predominately of first and second-generation immigrants from Central America and the Pacific islands. One section served "sheltered" English Language Learner (ELL) students.

Michelle reported that she enjoyed working with the physical science students, although she felt that most of them failed to exert adequate effort, and some "aren't very bright." By mid-year several of her physical science students opted out of high school to pursue a GED, or transferred to the technical school. Her experience was a mixture of enjoyment and frustration, as she put it, the physical science students "make me laugh the most, but they also make me crazy" (October 2002).

Although Michelle felt she had a reasonably strong grounding in physics, she was worried about teaching the scope of integrated science, which included units in chemistry and biology. Her physics education program had included just one chemistry course and no biological sciences. The prospect of teaching these subjects was daunting. Our first interview was littered with Michelle's doubts and concerns: "Teaching integrated science… is where the challenge comes in… Chemistry, I just don't feel like I have the knowledge to make it fun for them… Biology, I'll probably be learning that with them!" (October 2002)

> If I want to go beyond [worksheets] and want to get students to interact more with each other or with the lesson, I need to come up with my own ideas, which is tough when I don't have the content background especially with the chemistry. (October 2002)

While subject matter concerns and a new, more diverse student population were challenges, Michelle didn't face these alone. Michelle had an embarrassment of riches when it came to induction support. Across levels of the school system—the district, the school, and the department—she had regular contact with support for classroom management, school and district policies, and teaching science. Her principal and assistant principal ran a series of six half-day meetings for new teachers to help them with management concerns, and to encouraged them to seek help from both the administration and their department chairs. Through the district she had a BTSA mentor who, she explained, also advised her on classroom management and district-level policies.

> Rob taught history and he helped me a lot with classroom management issues…. He also lets me know administrative wise what's going on too. For example I'm asked to sub for gym teachers who are out for sports during my prep. My

principal asked that I do it. He told me I'd be paid for it and that the pay increased each time. (October 2002)

Where subject matter was the problem, Michelle leaned on her department chair, who met with her weekly to share instructional materials for teaching the integrated science course. To Michelle's chagrin, her chair "had learned better" (October 2002) than to do activity-based lessons, preferring to do bookwork and lecture. Yet, despite the difference between what her chair had to offer and what she really wanted to do in teaching, Michelle used what she could from her chair and was happy to have it.

With this abundance of support, I wondered if all this help ate up too much of Michelle's time. But Michelle saw it all as genuine support and found that she could sort challenges she faced to different support providers. The one thing she had not yet experienced much of—but would soon through the TIP—was support geared specifically toward teaching physics.

AWS: So you have all kinds of support people in your life. Do you see them all more or less as support, or…?

SM: Yes, definitely. And all support [me] in different ways. If I have a problem, I know which one to go to for which kind of support. The one thing I wish I had more of is physics support… or more interactions with physics teachers. Then again I can also email [the TIP staff] and I've gotten emails from people I've met at the Exploratorium [orientation] too. So that's good. (October 2003)

Overall, Michelle expressed a sense of confidence that she had what it would take to do the job well, but that it would take time to build her knowledge and skill. She was most concerned about teaching subjects she did not understand, but expressed some concerns even about teaching physics—her strong suit—in ways that it engaging for her students.

Geoff Chiu. Geoff, unlike Avner and Michelle, was a non-traditional first year teacher who came to teaching after 23 years of working, mostly in medical technology. A middle-aged Chinese American father of three, Geoff decided to quit his job and train to become a teacher. Medical technology had become boring and as his own children entered middle school, Geoff wanted to find ways to reconnect with them and understand schooling as they experienced it. In his mid-fifties, he entered a credentialing program fulltime.

Since childhood, Geoff had planned to study science in college and, if possible, go to medical school, even though he had never been an outstanding student in science. As an undergraduate, he studied at Flagship, a prestigious state research university. Geoff was surprised to be admitted, given his middling academic record, speculating that a clerical error might have worked in his favor:

> I got into Flagship—I don't know how, because my GPA was only 3.05 or something like that. I thought you needed a 3.5 to get into Flagship, but somehow I got in. I don't know why. To this day, I haven't asked anybody. (October 2002)

Undergraduate education was extremely challenging for Geoff, who majored in biochemistry. He was disappointed after graduation, when his low test scores prohibited him from going to medical school or dental school. "I tried to get into medical school. My MCATs were the pits. Well, then, I decided maybe I could go into dental school and I took the DAT and my scores weren't all that great" (October 2003). Geoff found his way eventually to medical technology, doing a good deal of lab work along the way. This got boring, though, and he eventually quit his job at the local hospital, and enrolled in a post-BA credentialing program.

At a regional state university near his home, Geoff took a 12-month credentialing program and worked toward dual certificates in science and mathematics. He found the program somewhat uneven, especially in the area of classroom management. Furthermore, he found the literacy course—which emphasized "Ebonics and whole language" (April 2003)—to be a bore. However, he felt his science education course had been both rigorous and helpful:

> This course was taught by a renowned science educator.... It was very hard, and she had us do a lot of work. She had us script lessons. For that class, you had to be ready for whatever she threw at you. She gave us many useful ideas about teaching science and taught us a philosophy: you should have students have hands on things before you teach them the lesson – then they'll really be able to connect and understand the idea. You can't start with the abstract idea. (April 2003)

Geoff student taught at Galileo, a high achieving middle school in a wealthy neighborhood, generally seen as the top middle school in the Big City System. His experience at Galileo was further rarified in that he taught an honors seventh grade math course and a seventh grade science course serving a group of students that overlapped substantially with his honors math course. In retrospect, Geoff felt that, by virtue of his student teaching course assignment, he had been somewhat sheltered from the diversity of middle school students he would encounter in his first year.

> [Student teaching] was one semester. I taught at Galileo. It's one of the top middle schools in Big City. I had to teach two classes. I taught the seventh grade

> science class, a seventh grade math honors class... Two-thirds of those students in my math class were in my science class so I don't think I got a full experience in my student teaching because I had that overlap of students. I probably should have chosen a different math class or a different science class to teach rather than the ones where the students were similar. (October 2002)

Geoff took the first job offer he received, teaching mathematics and science at Listo Middle School, also in Big City District. Located on the "other side" of Seaside Avenue (which divided the owner-occupied homes of the neighborhood surrounding Galileo from the mixed-income housing around Listo), Geoff's assignment at Listo included three courses: two 100-minute seventh grade mathematics/life science blocks (one honors section), and one section of eighth grade physical science. Geoff felt his background in mathematics and biochemistry suited him well for the seventh grade course. However, he explained that physical science was not his "strong suit," noting that he had taken but one physics course in high school and one in college nearly 25 years ago. With the exception of the chemistry units, the content of the physical science course—force and motion, energy, astronomy—would be a challenge.

Geoff's concerns about subject matter paled in comparison to his pressing, insistent, and intense worries about dealing the student population, and low rates of achievement. At Listo, over 40% of students qualified for free and reduced lunch, test scores were in the bottom decile of comparable schools in the state. Geoff perceived little student interest in science, and among their parents, discouragingly little academic press. The social circumstances of Listo students' lives were extreme:

> The other side of Seaside Avenue over the top of the hill is a high drug area. They have kids hanging around the street corners dealing drugs. It's a rough neighborhood. And all those students, the district says they have to go to Listo. So, lots of students don't have parents that are home, or don't have parents, or have grandparents taking care of them, or older brothers and sisters. (October 2002)

From the start, Geoff was frustrated with the students' response to his teaching. He was particularly troubled by his eighth grade physical science students. Reflecting on an ambitious and frustrating first week of teaching, he was exasperated:

> I gave them four lessons on matter: what is matter, describing matter, density, and states of matter. And then I gave them a multiple choice test, 15 questions, pretty much straight from the material that I gave them. Before I finished handing out the test, I got some tests back! They just wrote down letters. They didn't even (voice rises)—*they didn't care!* They really didn't seem to care what they learned! They were just in the class. Learning content is inconsequential to them. (October 2002)

Geoff's reflection is as thick with frustration as it is with evidence that Geoff is a novice. It seems unlikely an experienced teacher would think that in one week any group of eighth grade students would possibly learn all that he tried to teach. One colleague read this excerpt and quipped, "And on the seventh day, He rested."

Geoff did little to seek support from peers in his early weeks and months of frustration. Early interactions with colleagues who seemed nice, and expressed encouragement, dwindled as he wore into his second month of teaching. Frequently, he walked the halls, slowing down to peer into classrooms of his more experienced colleagues. He observed students behaving in ways that accorded better with his expectations: they raised their hands, wrote things down in their notebooks, and "showed respect" to the teacher.

When he saw students behaving well in other classrooms, Geoff was unsure whether this was due to his peers' skillful teaching, or because they had students who were easier to teach. After all, he had started the year without a complete set of textbooks, and received very little guidance from fellow teachers and the administration, so maybe getting tough students was part of being new: "I kind of want to say that I got the bottom of the barrel as my initiation. Compared to what I've seen in other eighth grade teachers' classes. But it may not be true because I haven't seen all of them" (October 2002).

Andrea Roland. In 2002, Andrea was a first year teacher at Hine Middle School. In Spring 2001 she had earned her bachelor's degree in health at a state research university. In her last year there she started a fulltime job as an office manager at a construction company. Not long after graduation she decided to quit the job and go back to school to pursue a teaching credential.

She studied in a newly-created regional teacher credentialing college toward a post-BA credential. In her senior year of college she realized that she wanted to teach science, but was not interested in going back for another dose of university science, but instead she opted enter teaching with her health degree and planned to take a qualifying exam for a biology teaching credential. As she explained:

Probably my last year (of college) I decided I wanted to teach science.... [But after] I had been out [of school] for a long time, there was just no way I was going to do more science to get my degree in biology—it would have required like another year of school! (November 2002)

Andrea saw her credential program as neither rigorous nor helpful, but a necessary evil, standing between her and the job she wanted. This particular program had come to our attention in the evaluation study and Andrea was the third of three students to characterize it so. One teacher called it "a credential mill," and Andrea's assessment was similarly harsh. Andrea had a hard time seeing the program's teaching of "theory" as valuable, as theory was presented without clear and regular applications to see how it might "work" or not in a classroom. Her reflection on the general teaching methods course is representative of her opinion:

The teacher was a complete idiot...like the theory (he taught) is fine, but you haven't been in the classroom! [Even if] the things you do are potentially really good, you don't actually use them. When you don't go and test that specific thing out like the next day, I don't think it's as functional. So we did some model lessons and read a lot of articles. I didn't find it very helpful. (June 2003)

Andrea went on the job market having yet to fulfill her student teaching obligation and three credits shy of graduation. She attended a Big City District hiring fair in June 2002, where she was hired and eventually assigned to Hine, days before the Fall semester began. She would teach three sections of seventh grade life science (one was "sheltered" serving English Language Learners (ELL)) and one section of eighth grade physical science. She arranged to complete "student teaching" on the job, in her own classroom, under the supervision of the Big City New Teacher Office.

Although she had taken almost no courses that mapped onto the eighth grade physical science course she would teach (one course in high school physics and entry-level undergraduate chemistry), Andrea was not worried about her knowledge of the subject. She reasoned she could always read the book in advance and be well prepared to teach, and answer student questions, "I understand it. I have a textbook at home I just read it over the weekend, so I know" (November 2002).

Hine serves a largely poor and immigrant student population, in which 73% of students in 2002 qualified for free and reduced price lunch, and 44% of students were ELL. Andrea quickly formed a close bond with her students and expressed commitment to "sticking it out" for a few years. However, by her third month on the job she also grew impatient with the administration's lack of focus on serving students and supporting teachers in tough circumstances. She saw Hine as the district's "dumping ground" for tough students (November 2002), and felt her principal failed to serve students and support teachers:

> There's no discipline program, no detention, and we don't even have phone numbers on emergency cards for some of our problematic kids. We have no way to contact parents even if the kid is bringing a knife to school or punching someone. And our principal will come to the meeting talking about, "Oh I went to a principal's meeting and you'll have to fill out this form about what sort of money you spent last year in the department." Ok, that's administrative stuff that

needs to be done. But, honey, why don't you just step back into your office, make it up and send it back? (November 2002)

George, the other "half" of the science department, was the antithesis of the administration. He was practical, helpful, and collaborative from the start, telling Andrea about the TIP, and he was committed to Hine's students. He taught four sections of physical science and passed his units to Andrea. They met every week to talk about the curriculum and to organize "bins" for each unit in the science materials closet.

Susan Wei. Susan Wei is a U.S.-born Chinese American who was 22 years old in November 2002, her first semester as a "real" teacher. She grew up in the San Francisco Bay area and attended Big City's premiere magnet high school. There, she explained, she had studied harder and longer than she did later, at the southern California research university where she majored in biology.

Although she was never particularly fond of science as a student, Susan had planned to go to medical school at the insistence of her mother. However, by the end of college, she explained, she was finally able to make decisions about her life autonomously, and decided to nix medical school plans, and go into teaching.

She entered an MAT program at an elite private university immediately after receiving her degree. She talked excitedly about the program, which ran June to June, and was "very intense, very difficult" (November 2002). Each day was split half and half between the field (summer school or high school placements) and the university classroom. Among other things, Susan recalled fondly doing a lengthy "child study," of an African American middle school boy; developing an interactive multi-media instructional CD on ecology; learning about "constructivist teaching" and performance assessment; and compiling and sharing materials with friends from the MAT science cohort, with whom she maintained regular contact via email throughout the study.

In June 2002, she was hired at Whitman High School, nestled in a suburb south of San Francisco. Susan liked her school—the principal was "really, really cool" and her department chair was very supportive, and knew science "like a guru"—but felt Whitman was *too* comfortable. As early as November of her first year, she was thinking about moving to an urban school in 2003. She wanted to "give back," as she believed she—a privileged Christian—should, but she was not convinced that teaching middle class kids was a good way to do that.

Yet, hers was by no means a easy placement—with 23% of students ELL and 14% poor—and Susan's 100% required course load presented plenty of teaching challenges. This well-groomed campus with Spanish-tiled roofs, and manicured shrubbery, served many students who were uninterested in science—especially in the non-college preparatory track—and some were "wise guys" who joked around and never completed assignments. This annoyed Susan, and sometimes tested her will. On one occasion, when her sixth period class was "out of control," she sent more than half of them to the office with referrals.

Further, the assignment to teach conceptual physics—exclusively—was both unexpected and unwelcome. Conceptual physics, or "basic physics without mathematics," as she put it (December 2002) was not what she was hired to teach. Susan, and the other two conceptual physics teachers at Whitman, thought they would be teaching integrated science up until the week before school started:

None of us has ever taught conceptual physics and we weren't planning on teaching conceptual physics. I was hired as an integrated science teacher, and the week before school started, they were like, "Well, we're going to switch." (November 2002)

Susan had never liked physics and had taken only required physics courses (one in college, one in high school), but she rolled with the change and hoped that her commitment to making science enjoyable to students would supplement what she lacked in physics background.

Joaquin Melendez. Joaquin, a 40 year-old Salvadoran immigrant, earned a master's degree in ecology in his home country, in the mid-1980s. Just out of school, in his first semester teaching undergraduate biology there, he and other university educators were rounded up and detained under a policy of political containment of the Salvadoran military dictatorship. Upon release he fled his war-torn country for San Francisco.

After 18 years of odd jobs and driving an airport shuttle in San Francisco, Joaquin decided to get back into teaching, this time at the secondary level. He earned a master's degree in the same credentialing program that Geoff attended. Like Geoff, he was lukewarm about the quality of the experience and criticized the program for not doing enough on classroom management. But for his thesis project—a 100-page literature review on immigrant student high school drop out, which he cited regularly in our conversations—he saw the program as a mediocre educational experience.

In August 2002, Joaquin was hired at Ballou High, a notoriously rough school, crawling with security guards, and enclosed by a 12-foot iron fence. Ballou serves a diverse student population (43% impoverished, 27% ELL), including a substantial number of immigrants from Latin America and the Pacific islands. In November 2002, Joaquin was excited to finally be teaching, especially the many immigrant students at Ballou. He saw his main challenge as a teacher there to “get my kids interested in science” and to “help them feel safe” (November 2002).

From his interview, Joaquin understood that he would teach biology, but when he reported for duty, he was reassigned to teach four sections of ninth grade integrated science. The units in Newton’s laws, electricity and magnetism, astronomy, and matter were not his specialty but like Andrea, he felt he could read up and would be okay to teach them. However, he was outraged that any first year teacher would be assigned courses he was little prepared to teach, calling this a “crime” of the administration.

Misassignment was one of many problems Joaquin saw, and attributed to Ballou administration, and the Big City district. He scoffed at the offer of a mentor—another inexperienced teacher who had on occasion come to *him* seeking help:

> So Robert was a kind of mentor. But I was surprised when the guy came to me looking for advice, saying, “Joaquin, what can I do with the kids?” (Laughter) How is this possible? I have no person to go to, to ask [for help]—nobody who really knows! (February 2003)

The system—in his eyes—did little for students or teachers:

> Nobody said a word to me. Nobody said, "Hey there's a pit there. Be careful." They put me in a classroom and left me alone. Now I'm failing, and they blame me—the same thing that they do with the students. The kids fail, and they blame the students. They blame the victim. That’s the policy. (February 2003)

Three factors that shape the teachers' working lives

The six teachers I've introduced shared important characteristics, which led me to select them to participate in this study. They were all novices with less than a year of teaching experience; taught lower-secondary science; and entered teaching with science degrees and teaching credentials.[17] They taught in non-selective, diverse public schools in the same metropolitan area, and importantly, they all participated in the TIP. But they were not equally prepared to teach, nor to take advantage of the learning opportunities afforded by induction support. I pause to discuss three important factors that influenced teachers' working lives and, which may have implications for how they use and make sense of opportunities to learn about subject matter in induction.

Science background/teaching load correspondence. Although all participants held at least a bachelor's in science, their areas of expertise corresponded variably with the content in their teaching loads. Concerns and commentary about the breadth of science topics in the curriculum cropped up repeatedly in the analysis. Five of six teachers taught across multiple school sciences (biology, physics, chemistry, earth science), while one (Susan, a biology major), taught only conceptual physics. Thus, they all taught science that they had not studied beyond high school or a single undergraduate course.

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[17] As mentioned earlier, Andrea was a slight exception to this statement in that she was completing certification requirements Fall semester 2002.

Table 2.6

Correspondence of Subject Matter Major and Teaching Load

	Subject Matter Major/ Load
Andrea	High
Avner	High
Geoff	High
Joaquin	Low
Michelle	Low
Susan	Low

Note. Determined by percentage of units in load that correspond with academic major. Low-below 50%; High- 50% or above

Teaching across the sciences was a considerable concern for five teachers (Avner was the exception). Geoff's own struggles as a student crept in as he talked about teaching the physical science class, and he worried, in particular, that he did not know physics at all. Michelle felt she knew too little biology and chemistry to make class interesting for students. Joaquin and Andrea (both biology majors) were concerned about, but not overwhelmed by, the prospect of teaching physics and chemistry. Both knew this entailed extra preparation, but reasoned they would figure out the content well enough to teach it at a low level. Susan, whose load was entirely in physics—a subject she loathed, indeed, avoided as a student—was at a loss, and relied heavily on others to help her prepare for class. In contrast, Avner was certain he knew the all of the sciences well enough, and would not have to learn much content on the job.

Comfort with diverse student populations. The fact that all of the teachers taught diverse student populations had important implications for what they thought they could and should do instructionally. Commentary on students was everywhere in the data. For some, teaching poor, minority, or immigrant students was the very reason for entering teaching (though serving diverse students presented real challenges). For others student diversity was just a part of the job, for better or for worse. But all of teachers talked about what the students could or could not do, needed or did not need, and the implications for their efforts to teach them, or their own satisfaction with their job. Table 2.8 summarizes teachers' comfort level with the student populations they served in 2002-3.[18]

Table 2.7

Comfort with Student Population

Teacher	Comfort Level
Andrea	High
Avner	High
Geoff	Low
Joaquin	High
Michelle	Moderate
Susan	Moderate
High Desirable population	Moderate neutral
Low Undesirable population	

Avner and Joaquin were both excited about teaching "underserved" students, to give them the leg up they needed. Both took special preparatory measures for teaching poor and minority students: Avner sought and completed a credentialing program with an urban, social justice bent; and Joaquin wrote a thesis about immigrant student drop out. Andrea, too was animated about working with "forgotten" poor, and immigrant students. She quickly built strong, personal bonds with them and accommodated their learning needs (e.g., summarizing textbook chapters in an effort to match content to student reading ability), though she had not sought out this population originally.

In contrast, both Michelle (to a small degree) and Geoff (to a substantial degree) worried about working with a diverse student population. At Rockville, Michelle worked

[18] One hundred twenty-six teacher comments about students appeared in the Atlas/ti database. I compiled and printed out comments about students, by teacher, and summarized their overall attitude about the students they serve. With the exception of Susan and Michelle the cases were very clear-cut. Susan and Michelle both struggled with whether they would rather teacher different student populations, but neither ever railed against one group of students or another, as Geoff did repeatedly. Thus, I classified Susan and Michelle as "moderately" comfortable.

with non-college-bound students, who posed significant challenges she hadn't foreseen in her senior physics student teaching placement. Though her concerns about motivating and managing diverse students were evident throughout the study, she enjoyed the challenges they posed and continuously sought ways to serve them better. Geoff was less accommodating. His students were "regular" track students in a low-performing school, quite unlike the honors students at competitive Galileo, where he student taught. Geoff was shocked at his students' apparent lack of interest and motivation. His discomfort did not wane substantially.

Susan's position was unique. She longed to work with a population that was *less* academically oriented than her "blue collar suburban" students at Whitman. She invoked her Christian commitment to serving the needy, and linked this to her motive for teaching. She wanted to teach "ghetto kids," as she put it, and considered going back on the job market the following year to seek a less privileged group of students to serve.

Induction support.[19] Evidence of support—for managing students, designing instruction, or "learning the ropes"—was, in fact, abundant in the data, though unevenly distributed across teachers and topics. Most reported support—across teachers—derived from the department and district. Much support was devoted to classroom management, with less specifically to science, a bit to school and district policy, and almost none devoted to "inquiry science."[20]

[19] The notion of support here is one that relies on the teachers' sense of what is and is not supportive. Those components of "support" that are not seen as such, are not included.
[20] Inquiry science is science that entails asking questions that are not immediately evident and using evidence to answer scientific questions. See chapter five.

	Department	School	District	External/ Non-TIP
Andrea	$\mathbf{X}_{sm, q}$		$\mathbf{X}_{sm*}$	x^{*}
Avner	x_{sm}			X_{sm}
Geoff		x	x_{sm}	
Joaquin			x	
Michelle	X_{sm}	X	X	
Susan	$\mathbf{X}_{sm}$		X	

$\mathbf{X}$ Once every two weeks or more   X Once every six weeks
x once or twice in a semester   __ No support reported
$_{sm}$ Denotes subject matter specific support $_{q}$ Denotes inquiry science
* Denotes component of initial credentialing program

Figure 2.3

Sources and Frequency of Induction Support

On the high end, Michelle had extensive support from the department, school, and district that covered the gamut of topics, including science curriculum and instruction (though she longed for more opportunities to talk shop with physics teachers). She worked with her department chair to plan curriculum, met with her BTSA advisor and assistant principal to consult on management problems. These were regular, on-going sources of support that she used throughout the study. Andrea also reported several sources of support substantial support. Weekly meetings with George, her colleague, were all about preparing curriculum in the short- and long-term.[21] The other major support activity Andrea reported was the series of field observations and follow up interviews for her "student teaching."

[21] George, who introduced Andrea to the TIP, would later serve as her TIP mentor as well.

Susan and Avner had less, but still substantial support, some of which also included subject matter support. Susan and her peers' unexpected foray into conceptual physics was at least well supported. Her chair convened weekly meetings of the three conceptual physics instructors to help them pool curriculum resources, and to document a curriculum outline for the years ahead. Susan also worked with a BTSA mentor every month or so throughout the year, mostly on management concerns, and some teachers' union developments in the wake of proposed layoffs. Avner had little interest in working with his colleagues—most of whom did not teach courses that he taught. However, his former supervising teacher worked with him on physics curriculum planning. By October 2002 and throughout the study, the two were deeply involved in an external curriculum development effort. Avner also hooked in to a local physics teacher network.

Geoff and Joaquin worked with limited support. Geoff noted occasional classroom management meetings with his principal and fellow novices. He reported frequent meetings about getting posters with the state standards listed in each classroom, and new requirements to write standards on the board each day. Joaquin reported turning in regular lesson plans. He also reported occasional meeting with a representative from the Big City New Teacher office and his "mentor teacher." Generally, he saw all of this as useless or worse, as cynical attempts to control him or compromise his work.

With this background in place, I now turn to analyses of the TIP and teachers' learning of subject matter in induction. Over the coming four chapters, the (potential) factors for learning that I have just described, lie more or less dormant, as my charge is to look closely at the TIP and at teachers' uses of subject matter. In the closing chapter, however, I will return these important aspects—the organizational landscapes and personal histories of teachers—to the foreground as I try to sort out factors that influence teacher subject matter learning in induction.

Chapter Three

The Exploratorium Teacher Induction Program: Science-Specific Induction in Formal and Informal Settings

As a rule, induction programs are sponsored by school systems or universities and they tend to focus on generic issues of pedagogy and classroom management for all new teachers—to the exclusion of subject matter specific concerns (Thompson & Paek, 2004). Such induction is often premised on the idea that new teachers face enough challenges in organizing students and curriculum, "learning the ropes," and figuring out what it feels like to be a teacher. They can wait a few years to get those things under their belts before facing the hard work of learning more content or how to teach content. This folk wisdom is supported by a long line of research that suggests, in fact, novice teachers are not "ready" to focus on the subject matter until they have gotten comfortable with these aspects of the job (e.g., Carter & Richardson, 1989; Fuller & Bown, 1975; Huling-Austin, 1986; Odell, 1986; Veenman, 1984). However, more recent scholarship questions the quality and the claims of that line of work (e.g., Grossman, 1992), and new induction programs do not all presume this stage theory (e.g., Luft, Roehrig & Patterson, 2002).

The Exploratorium Teacher Induction Program (the TIP) is one such program. Eschewing the folklore that new teachers are not able to deal with subject matter, this program focused primarily on the fact that all teachers deal with subject matter—constantly—and that all teachers, including brand new ones, need support in that aspect of their work.

In this chapter, I describe the opportunities to learn science available in the TIP. This description sets the stage for the analyses that follow in which I examine what teachers learn from these opportunities. I begin by briefly discussing issues of science-specific induction. This is followed by an overview of the program, and finally a more detailed description of the TIP's core opportunities to learn.

Why Science-Specific Induction?

There are several good reasons to frame induction as subject- or science-specific. Here I'll nominate three.

First, novice science teachers need science-specific support to develop curriculum. Science curriculum materials are of a low quality (Kesidou & Roseman, 2001) and frequently entirely absent. Thus newcomers to science departments—more often than their peers in other subjects—walk into classes for which established curriculum are not evident (Sanford, 1988). Accordingly, new science teachers are often forced to "improvise" a curriculum (Sanford, 1988). Creating a curriculum on the fly may be particularly tricky in science instruction which can be material-intensive—beyond texts, notebooks, and chalkboards, science instruction can include lab-based work, fieldwork, simulations, computer modeling, so finding ways to support novice curriculum development can be crucial in science.

Second, novices are usually assigned the least desirable teaching load. Secondary departments generally assign courses by seniority and novices end up with introductory courses, or those in which the students are the less motivated and/or prepared (McLaughlin & Talbert, 2002). In science, introductory classes include multiple disciplines (such courses often involve the integration of the physical sciences or the biological sciences), which ironically (given their lower level status) actually increases the demands on teachers' content knowledge (requiring a breadth of knowledge that not all university science majors experience). So even a highly qualified novice science teacher with a bachelor's degree in one of the core K-12 disciplines—biology, chemistry, physics, earth science—will find herself teaching across all of those subject domains. In a statewide survey of novice science teachers in Arizona, Luft and Cox (2001) found that 40% of those in their first three years taught at least one course in which they did not have a major. These results resonate with other national studies of teacher misassignment (Ingersoll, 2004). Real science-specific support may lighten the burden of preparing and teaching multiple science disciplines by providing novices opportunities to learn science that they teach.

Third, although scholars currently dismiss the general notion of teacher shortage (arguing instead that we face a teacher distribution problem (Ingersoll, 2004)), science is an exception, for there exist real teacher shortages in science. Providing support for new teachers might help alleviate this problem. For example, Smith and Ingersoll (2003) found that first year teachers who were provided a mentor in the same content area and participated in joint induction activities such as co-planning were less likely to leave their school or leave the occupation. These results suggest that attending to subject -specific concerns in induction can have measurable impact on retention.

Though there are now several subject-matter specific induction efforts across the country, there is little research on what such induction looks like and what novices learn from it. Even locating truly "content-rich" induction efforts can be difficult, as researchers with the Mathematics Science Teacher Induction Study (MSTI) found.[22] They sought to study six content-rich math and science induction efforts. In developing

[22] The MSTI is a collaboration between Edward Britton, Tania Mafdes, and Frances Montell at WestEd and Lynn Paine, Brian Delaney, Steve Ryan, and Suzanne Wilson at Michigan State University, and Mark Olson at the University of Connecticut.

their sample, the researchers surveyed over 40 programs ostensibly focused on subject matter, but found that most were "content-rich" only in name.

In peer-reviewed journals, I located only two studies of science-specific induction; both focus on the same program, Project Assist in Arizona (Luft & Cox 2001; Luft, Rhoerig & Patterson, 2002). Sponsored by the University of Arizona, this program serves several local school districts with mentor training, occasional workshops, and coordinated trips to science teaching conferences. Luft and Cox (2001) looked at the effects of induction on teachers' beliefs about, and implementation of, inquiry science teaching. They surveyed teachers under three induction treatments: no induction program, generic induction, and science induction. They found that the science induction group was more favorably disposed to inquiry teaching and reported teaching more inquiry-based lessons. This finding is promising and suggests that science-specific induction merits further attention.

In this study, I document the Exploratorium Teacher Induction Program (The TIP) and trace its influence on novice participants' instructional portrayals of science over time. The remainder of this chapter is devoted to a description of the program.

The Exploratorium Teacher Induction Program (The TIP)

Science for the Masses

The TIP is housed within the Exploratorium, an internationally recognized science museum that was conceived in the mid-1960's by physicist Frank Oppenheimer whose vision was to "create a collection of experiments that would make natural phenomena accessible and understandable to everyone" (Exploratorium, n.d.). Oppenheimer—Robert's brother—was an innovative physics professor at the University of Colorado where he designed a course around exhibit-based learning experiences in which students monitored their own progress and proceeded at their own pace. This pedagogical idea became the conceptual basis for the Exploratorium's collection.

The Exploratorium is committed to bringing science to the masses and expanding Oppenheimer's vision though inviting, open-ended science experiences. Interactive museum-based and traveling exhibits, science activity publications, student and teacher workshops, on-line resources, manuals for how to build "snack"-sized versions of museum exhibits carry the Exploratorium's vision of science for the public far and wide. Exploratorium staff travels—nationally and internationally—to schools, conferences, and they appear on network television and radio programs, serving up science wherever they go.[23]

The Exploratorium also has a long history of commitment to teachers, offering summer Teacher Institutes around particular scientific topics since 1984. After all, those teachers could take the Exploratorium science into schools, thus acting as ambassadors of Oppenheimer's commitment to an educated, enthusiastic, science-literate public. That professional development falls clearly within the tradition of other subject-specific professional development, like the National Writing Project (NWP) (Lieberman & Wood, 2003), in which teachers have an opportunity to engage in the subject matter—that is, they "do" science in ways similar to the NWP's commitment to having writing teachers write –as well as think about creating subject-specific curriculum for K-12 students. The Teacher Induction Program (The TIP) is a natural extension of the Exploratorium's

[23] The Co-director of the TIP has appeared on the *David Letterman Show* and often comments on scientific developments for National Pubic Radio's *Science Friday*.

tradition of working with K-12 experienced teachers and is now one of several current Exploratorium teacher development programs.

The Teacher Induction Program

Long interested in working with experienced teachers, in the mid-90s, Exploratorium staff members noticed that the teacher work force consisted of more and more novice teachers. Accordingly, they established the Teacher Induction Program (The TIP) in 1998 to serve new teachers in greater San Francisco (Exploratorium, n.d.).

The TIP is designed to enhance novice teachers' knowledge of science and teaching, bolster their professional networks, and sharpen their classroom skills over the course of two years, and beyond. In fact, the TIP understands its work to involve acting as a "professional home" for teachers throughout their careers. Each spring, new science teachers apply to the TIP for admission in the coming fall. Staff members review applications and admit participants who are (a) assigned to teach science or mathematics at the middle or high school level; (b) are in the first through third year of teaching science;[24] and (c) show some commitment to teaching science for several years to come.

The two-year program offers a range of options, some of which are required and some elective. Required components include a one-day program orientation, the four-week summer Institute, and at least one short-term workshop per semester. Participants may choose to attend an additional workshop each semester, and they can participate in individual or small-group mentoring. They may also take advantage of a range of program resources such as the Exploratorium library, on-line forums on science teaching, and unlimited visits to the museum.

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[24] This includes experienced teachers who are new to teaching science. The program also shows preference for teachers who work in public school systems, but does not exclude private school teachers.

Participants earn stipends ($10/hour for orientation and participation in workshops, and $1100 for completing the four-week Teacher Institute), emblematic of a stance the TIP takes: teachers are professionals, and need to be treated as such. They are also often in need of resources, which the program makes available in abundance (e.g., curriculum materials, "raw" hardware for building classroom exhibits and demonstration materials, exclusive the TIP on-line forums). Peter Berg, the TIP Co-Director, described the program's distinct teacher-service orientation to an incoming the TIP cohort this way, "We feed you, we pay you, and we give you free stuff" (September 2003).

The program staff itself is a rich resource, readily available to teacher-participants. The staff includes full time Exploratorium employees, part-time retired teachers, and program alumni. All staff members are current or former science teachers, elementary through university science faculty. It is an exceptionally tight-knit, high-energy, high-élan group whose members are tied together by their passion for science. Many of them also have science-related hobbies. For example, Ernesto Diaz, a long-time Exploratorium staffer who coordinates the TIP's mentoring component, designs and builds high fidelity audio systems in his spare time; one sees traces of his hobbyist enthusiasm in electricity and magnetism curriculum and workshops in which participants build speakers. Greta VanPelt, who mentors novices and keeps tabs on their requests for program support, is passionate about surfing. She brings this interest into the TIP program in a workshop on waves and beaches. Peter's passion for adventure travel takes him to the ends of the earth (literally), including the North Pole and Tierra del Fuego (the southern the TIP of Argentina). Peter brings his travels into workshop sessions through anecdotes and real time webcasts. One such webcast involved Peter talking to the TIP participants (while he was at the North Pole and they were in San Francisco) about global warming and looking at evidence of shrinking icebergs.

Staff members' personal and work lives flow together in other ways as well. They frequently get together outside of work to share a beer, see movies, hike. Their spouses all know each other. Many are dog lovers whose lumbering retrievers join novice teachers at the Institute. "We all have dogs. I hope no one here is allergic. We sometimes forget to ask. If you are let us know. Otherwise, expect to see our dogs and meet them in sessions" (June 2000).

Though less tight-knit, the part time staff is similar to the full time staff in many respects. As former and current science teachers in the Bay area, their commitment to science teaching is clear, and they too share a range of personal interests that meld nicely with their science education practice. In our conversations, I heard about robotics, electrical and radio engineering, carpentry, antique homes, and refurbishing antique technologies.

Duties are fairly well split between the two groups. Full time Exploratorium staff members run the program's core operations. They are the lead instructors in the four-week summer Institute sessions. They assign mentors to novices, and provide a one-week training session for mentors prior to the Teacher Institute. They also plan and organize regular Saturday workshops, serving as instructors in some of these, and recruiting Exploratorium alumni teachers or part-time staff members to lead or co-lead sessions. Both part time and fulltime staff serve as mentors. They travel from school to school to visit new teachers, organizing one-on-one and (occasionally) group meetings of novices, and use a number of mechanisms to share materials with novices. Occasionally, when program novices work in a school where an active Exploratorium alumnae works, the experienced teacher will serve as a mentor.[25]

The TIP presents participants with a range of opportunities to learn science, and how to "do" science in their own classrooms. These include workshops and Institutes in which teachers assume the role of "student" as well as classroom and school-based support of mentor teachers. These opportunities to learn science across settings reflect the unique qualities of the TIP science.

Subject-Specific Opportunities to Learn

While participants have many opportunities to learn within the program, two components—mentoring and workshops—account for the majority of learning opportunities, especially those that are subject-specific, and it is to those that I now turn. Workshops include the four-week Institute and Saturday workshops throughout the academic year. This required component is organized by fulltime staff who periodically send out workshop sign up forms to participants. Mentoring, in contrast, is organized by mentors or mentor-novice dyads. Participation in mentoring is voluntary and may happen on the fly or with advance planning.

Summer Institute

A day in the Teacher Institute. The "crown jewel" of the TIP, the Teacher Institute is a four-week, 5-1/2 hour/day intensive experience devoted to science teaching and learning. Novice and experienced science teachers, mostly from the Bay area, but some from across the country attend to one of four subject matter tracks for the full term of the

[25] This description melds the program's two distinct roles for the "mentor" and "coach." I clarify this distinction below where the practices of these program staff are examined in greater detail.

Teacher Institute. In a given year, workshops may include High School Physics, Middle School Physical Science, General Science, Life Science, Math/Science Connections.

Teachers arrive early for the session scheduled 8:30 a.m. to 2:00 p.m. They head to their respective classrooms for one of two concurrent morning sessions, High School Physics or Math/Science Connections. Some 15 to 20 teachers trickle into each classroom between 8:00 and 8:30. They nibble on pastries, drink coffee and talk informally with peers and staff. Discussions of favorite units of study and interesting museum exhibits are interspersed with news about job openings in local schools, weekend plans.

Several teachers are clustered around Peter and Ron, the physics workshop co-instructors. Peter is describing his recent trek in the Himalayas, while Ron fields questions from workshop participants who want to know where they can buy cheap polarizing transparencies to recreate a classroom activity he told them about. Ron, a retired physics teacher, is the resident classroom expert and Peter, a former physics professor, is the scientific authority. Ron described their roles: "I take the concept and see how can we bring it to the classroom. Peter takes it and says, 'How can we bring it to the world?'" (June 2003).

While Ron is in the background busily sorting lenses, colored transparencies, prisms, and other materials that teachers will use later in the workshop session, Peter heads to the front of the classroom to get the workshop started with a warm up exercise. Some days the warm up time might be devoted to Peter's tales of personal adventures in high altitude climbing, bobsledding, or spelunking. These invariably have a scientific twist (though they may not be related to the focal topic of the day's workshop session). On this day, Peter opens a photography book to a page of close-up images of opal.

Passing around the book (open to a two-page high-resolution image of an opal), he explains that layers of silicate make the opal beautiful:

> It's the three layers of silicate that make it beautiful. The value depends on the background color of the opal. The black ones are most valuable because they provide a background that permits you to see the layers. That's where the beauty and value of dark opals come from. (June 2000)

As the image is passed around, one teacher notes that the photos remind him of a high-resolution scientific image he once saw and offered, "This reminds me of my favorite photo in zap book! Using a fiber optic camera, this guy took a photo from the back of someone's retina of a woman talking on the phone—" Peter doesn't miss a beat. Familiar with the book and the inverted image, he excitedly finishes the teacher's thought for him: "Yeah. It's upside down! This is like what we'll see in the exhibit today... Let's get out there!" (June 2000)

The museum floor is almost uninhabited at this early hour before the museum opens to the public. As Peter and the teachers walk out toward the exhibits, he explains for the first of several times that visual perception -- the day's topic -- is the basis of observation and the foundation of most scientific work. The teachers visit three exhibits (*Pupil*, *Lens—Adjustable Eye*, and *Goggles*). At *Lens—Adjustable Eye*, teachers encounter a bowling ball-sized model of a human "eye" mounted about four feet in front of a grated screen. Beyond the screen, about 10 feet past it, there is an image of a human face. By manipulating the sphincter muscle of the model's eye lens— increasing or decreasing its diameter—the user can look through the back of the "eye" and focus either on the near screen or the distant face image.

The lens, Peter explains, is held in place by elastic muscles. When at ease, the elastic muscle tightens to open the lens fully, allowing plenty of light to enter and focusing the visual field at a distance. Under this condition, the eye model is looking at the distant face. "Squinting is the opposite. We squint to narrow the lens and limit the amount of light." This way we block interfering light rays, and focus our eyes to work on closer fields. Peter went on to explain that our physiological default is to see objects in the distance, "We all by default look into the infinite. Scientists see this as a survival mechanism… We can see danger far off, but un-like Tarzan we'll miss the vine!" (June 2000).

While still at this exhibit, Peter also introduces a number of relevant real-world matters related to visual perception. He explains that most people become near-sited by 40 as their lenses stiffen. He describes how cataracts surgery works (the lens in capsule which surgeons liquefy it and "suck it out"). He fields the teachers' questions—"Why does the image appear upside down in the back of our eye?"—and describes three different types of eye surgery. Similar events are played out at each exhibit: Peter explains what the exhibit demonstrates, expands on the science, and shares anecdotes about relevant technological applications. Teachers ask questions and share their own stories and observations. After 40 minutes, they return to the classroom.

Back in the Teacher Institute classroom, teachers participate in activities that emulate or extend the ideas they encountered during the floor walk. On this day, among other things, the teachers used plastic magnifying glasses to examine the motion of their own pupil. They use pinholes to read small font text. For these and other activities, Ron offers guidance about how to use these activities with their own students. If you lack film canisters, he suggests that they can make a "monocle" by looking through the small opening left when their forefinger and thumb when tightly curled up (as when making the "OK" sign with a tight, little "O"). Peter tells participants of a student who reported back to him that she suggested her far-sighted father use the trick when he struggled to read the fine print on a menu without his reading glasses.

At 12:30, the classroom-based session ends and teachers enter an overlapping intersession between the morning and afternoon workshops. All of the TIP novices from both a.m. and p.m. sessions are on site, and they congregate to eat lunch and spend an additional 60-90 minutes on one of several activities. Seven Institute intercessions are set aside for the novice teachers to work on their curriculum box project, a unit of study developed during the summer Institute. The curriculum box is the product of novice and mentor joint work in which one to three novices with one mentor organize activities, materials, and assessments into a box that holds all of the needed materials for one unit they will teach in the coming academic year.

Some days, participants may choose how to spend their intercession time. Some participants opt to walk the museum floor, perhaps extending their analysis of exhibits visited in workshop sessions. Others work in the TIP library, perusing thousands of published titles, shelves full of teacher-developed units from Institutes past, developing multimedia projects, or surfing the internet for instructional materials. Others may choose to test out an activity with peers and staff or simply to "talk shop." Participants may also build "snacks," mini-versions of popular Exploratorium exhibits for classroom use.

As this portrait suggests, the TIP is rich with opportunities to learn subject matter. Subject matter is central in classroom sessions where teachers work through science activities, test their own ideas, and ask their instructors questions. From the moment they arrive at the museum, teachers talk about science and science teaching with peers and staff. Analysis of exhibits, joint work with mentors assembling curriculum boxes, side conversations with staff, visits to the library, efforts to build model "snack" exhibits—the opportunities to learn science are bountiful.

But I have merely skimmed the top of a typical day. To say there are many opportunities to learn science leaves much unsaid. What aspects of science do teachers have opportunities to learn? To answer this question, I return to the Teacher Institute classroom and examine finer grained instances of science teaching.

Recall the light and visual perception sequence introduced in the overview. Light is a core area of study in the summer Teacher Institute. Each of three years that we conducted fieldwork, light and visual perception was presented across Institute sections for no fewer than four days. Let us begin by considering some additional sessions devoted to these topics.

Middle school physical science. Lana opened the third day of the summer 2000 middle school science workshop session with the familiar refrain that observation is foundational to science, and that in this and in coming sessions, participants would explore light and visual perception. Sixteen middle school science teachers sat at rectangular tables arranged in a "U," two to three teachers to a table. Lana, the TIP Co-Director, and instructor for the middle school science workshop, explained that the day's activities would prepare the group for a cow's eye dissection to take place tomorrow. With little ado, she moved teachers into an activity exploring visual effects of light using Maglites™ (strong mini-flashlights). She asked that teachers remove the lens cover, allowing them to look closely at the light that is produced without the distortions caused by the lens. She then instructed them to place the light on their desks like candlesticks. Lana then turned out the light and asked teachers to discuss with their tablemate, "What is unusual about this light?" After a few minutes of teachers' observations, Lana flipped the light back on and the group debriefed:

Lana: What types of things did you observe?

T1: I see rainbow colors: ROY G. BIV.

T2: Mine is pulsing with my glasses I get a Star Trek vision…long lines.

T3: …with glasses on you have dandelion fuzz and spheres.

Lana: That's a good way to describe it. Like a dandelion. And with glasses on, you see the lines and there are more of them.

T4: The lamp is sort of… it looks like pollen… each strand coming out… Maybe I'm seeing things (incorrectly) with my poor eyesight.

Teachers generated descriptions of this type for about seven minutes, eagerly sharing their observations. Some continued to peek at their materials on the sly as they heard things that their peers reported. Shortly afterward, Lana pushed the group towards thinking about questions they might explore. "We could go on and observe this for a long time. But, now I'm going to pose a question…or, maybe I should have you come up with questions… you could turn your observations into questions." And they did: "What's causing the lines?" "What's causing the dandelions?" "When you squint your eyes what happens to the lines?" Some teachers had trouble with the task. In these cases, Lana reminded them of their charge, as in the following example.

T6:	The lines go away…if you get watery eyes…
Lana:	Okay, that sounds good…Can you make that a question we could answer?
T6:	(no response, five seconds)
Lana:	(To the class) How could that be turned into a question?
T4:	What happens to the lines when your eyes get watery?

Following a brief discussion of how to frame questions that are answerable through observation ("you have to be able to do something or watch something that will allow you to answer questions confidently"), Lana posed her own question to the group, asking them to consider whether the lines of light were real or imagined. She directed them to use materials at their tables to pursue their answers:

> When I squint, I'm noticing a sharp line; it is vertical going up and down. Is this—or the "dandelion" of light—coming from that bulb? Is it something your eye and brain is doing or is it real? I'll give you a hint. On your table you can run a lot of different experiments…(on the table there are bug boxes, index cards, rulers, tape, popsicle sticks). You and your partner talk it over… answer, "Are these rays really coming from the bulb?" (June 2000)

For the next half-hour, groups explored light. They used the transparent bug box as a lens over the light; they covered parts of the "dandelion" with the index card, looked through scotch tape at the light. Finally, they reported out and eventually reached the consensus view that the "light fuzz," "dandelion," and "shooting lines" observed around the bulb are not "real," but are of the participants' own psychological creation. The session stopped short of exploring (or explaining) why this might be the case. However, Lana pushed the group to figure out what part of their observations was not due to their imaginations. "You're right," she explained, "seeing is in part psychological." When making scientific observations, she reasoned, we have to be careful that we are well aware of biases and things we might want to see or not see, as these may cloud our vision and influence our observations. However, she went on to explain another component of vision is physical. Since light is necessary for vision, all visual stimuli we perceive are really light that is reflected off of objects and that enters the eye. However, because vision hinges on the physiological process of receiving light information through the eye, we are susceptible to visual trickery and misinterpretation as eyes are governed by minds.

High school physics. In this workshop session during the first week of the Teacher Institute in 2000, teachers started with the Maglite™ activity described above, but this group—physics teachers with stronger science backgrounds than their middle school peers—moved through it quickly. The physics workshop moved to a diffraction activity getting into the content in greater depth. After Peter conducted the Maglite™ activity as Lana had (participants observe, describe, and ask questions about the phenomenon, instructor explains in terms of the behavior of light) he expanded on the wave/particle duality of light.

Diffraction is the bending of light as it passes around an object's edge or through a slit. It can be observed in the fuzzy edges of shadows where light waves bend into the shadow region "behind" a solid object. The edge is not clearly demarcated, but diffuse. Diffraction's effect is most evident when light is forced to pass through very narrow slits where the wavelength of light exceeds the width of the slit. In the diagram below, the shadow cast on the left hand side indicates very little diffraction. In contrast, the shadow cast on the right—where the slit in the blocking object is very thin—results in a "fuzzy" image, indicating diffraction.

Peter used a low-tech set up to introduce diffraction. He asked teachers to tape two Popsicle sticks in parallel with about 1cm distance between them. He had participants hold the sticks close to their eyes and look through the slit between the two sticks at the Maglite™. Then he asked them to manipulate the distance between the sticks until they started to see some changes in the light. Without telling the teachers what effects they might observe, he asked them to conduct the exploration and describe what they saw (much as he and Lana had in the Maglite™ activity).

After exploring this phenomenon for a while, the group debriefed. Some teachers described "blobs of light." Peter pushed for more descriptive details. Others added that strips of blackness separated these "blobs" or "spots." Participants then talked about what happened when they changed the distance between the sticks: the blobs changed in size, and moved closer or further apart; when the sticks were rotated, the lines along which blobs fell also rotated.

Here again, Peter had participants conduct observations for some time and encouraged them, once they had seen some visual effect, to vary the exploration. He suggested they rotate the sticks and describe any changes the ensued in their observations of the light and dark spaces. He conducted the same exploration, but instead of looking through the sticks, he looked at a single long strand of his own hair. He pulled a strand, doubled it up and created a makeshift diffraction grating. Peter explained that this is fun variation in classrooms and noted that depending on the diameter of your hair, the visual effects will vary. Teachers followed suit.

For 30 minutes of loosely guided exploration—during which teachers talked among themselves—Peter walked around the room, listening to their observations. He then stopped the explorations, turned on the light and began to recount what he had heard, noting which group had said what. People had seen "blobs" or "spots" of light separated by black spaces or "bands"; they had seen blobs rotating and moving as they rotated their parallel sticks. He then offered an explanation: what they were seeing was evidence that light is a wave. Larger waves squeeze through the thin slit and as they hit its edges, they spread out, overlap, and add together. He likened this to the collision of two water waves emanating from two distinct sources. Where the crest of one wave overlaps with the crest of another wave, the two waves combine to make a bigger wave. This kind of harmonious combination, he explained, is what is happening when you see a bright blob of light. In other cases, the trough of one wave overlaps with the crest of another wave. In these instances, the waves cancel one another out, and you see a dark band or blob.

This quick explanation played well to an enrapt audience. For some teachers, this was a "Eureka" moment. For others this satisfied their need for accessible, low-tech ways to help students explore the behavior of light. Some experienced teachers saw this as a way to extend their already well-developed instructional repertoire for diffraction. Though participants may have taken from this experience a range of lessons, they expressed a common excitement and pleasure in the experience.

Yet, despite the "ahas" around the room, Peter did not belabor the point. Instead, he played on the teachers' interest and took the opportunity to introduce yet another idea: that the wave model of light, which they had just "discovered" (and which he described), works well for some accounts of light, but not for others. Indeed, other behavior is best explained with a particle theory. This wave/particle duality, he explained, illustrated the use and limits of models in science. This observation too seemed to play well to the teacher audience who intently watched, as he talked:

> We develop models that help us explain what we see. In some cases, we see things that suggest light is a wave. In other cases, we watch what light does and it acts like a particle. This is why being clear and honest about what you see is important. (June 2000)

Saturday Workshops

Throughout the school year, the TIP also offers Saturday workshops of two types: science teaching workshops (ways to organize, work with parents, assess students, etc.) and science content workshops (inquiry into scientific concepts). The science teaching workshops are only offered to new teachers; the science content workshops are offered to Teacher Institute alumni as well. However, new teachers are given the first opportunity to register for science content workshops and generally get their first choice.

During the 2002-2003 school year, novices chose from lists of science content workshops that included: *Are You a Birdbrain?* (an exploration of birds' anatomy, physiology, flight and evolution); Get Into the Swing of Logarithms; Traits of Life (which included a tour of a new Life Sciences collection at the Exploratorium and opportunities for teachers to begin creating classroom versions of the exhibits); Cars, Carts, and Newton's Law; Temperature and Thermodynamics; Astronomy Day; A trip to RAFT (Resource Area for Teachers), a warehouse full of inexpensive and unusual materials for teachers; Science and Math at the Zoo (a picnic and "sleeping bag" overnight at the San Francisco Zoo); and Energy, Work, and Heat.

Options for new teachers ("science teaching") workshops during 2002-2003 included: Planning Ahead (or Swimming vs. Treading Water); Lab Safety and Organization; Did I Teach Them ANYTHING? (a workshop of evaluating student learning); What Is This and What Can I Do With It? (a workshop on exploring the materials available in the science supply closet in most schools); Shopping for Science; Using PVC and Other Tubing; Making and Using Power Supplies; Testing (how to create your own tests and use standardized ones); and Positive Communications. (See Appendix X for full listing of 2002-2003 content and teaching workshops.)

A glimpse of two workshops we observed (one from each category)—Cars, Carts, and Newton's Laws (science content) and What Is This and What Can I Do With It (science teaching)—will help describe the kinds of experiences new teachers have in their Saturday workshops. In both workshops, teachers had opportunities to participate in science activities, discuss science content, and talk about how to make the activities "work" (both from a management and learning perspective) in their own classroom. In addition, we saw teachers take advantage of the time and space workshops provided for new teachers to talk with other science teachers (new and experienced), compare teaching situations, share activities/equipment, and voice concerns.

Cars, Carts, and Newton's Laws. About 25 teachers (novices and Teacher Institute alumni) attended the workshop Cars, Carts, and Newton's Law, a four-hour science content workshop, held in a classroom at the Exploratorium. During one part of the workshop, two experienced middle school teachers (TI alumni) took the group through activities utilizing "mousetrap cars" to explore velocity. A mousetrap car is powered by the spring of a mousetrap. Teachers spread out on the cement museum floor with their cars, meter sticks, and stopwatches. In small groups, they tried a series of experiments that investigated the influence of different size wheels and different size mousetrap "lever arms" on the velocity of a car. Teachers laughed as they tried to get the hang of winding up the cars and using the stopwatch to time the car's movement over set distances ("Ready? One, two, three!"). As they worked with the cars and recorded their findings in a chart, the teachers chatted with each other about how much space would be needed for the activity in their school ("Maybe we could use the gym") and their teaching situations ("How many kids do you have in your classes?"). Some discussed how to ensure accurate data collection – for instance, debating whether (and how) they should account for differences in their individual reaction times when timing the cars ("We should keep the same timers").

When they returned to the classroom, teachers calculated average velocity from their data and posted it on the walls. As the teacher leaders commented on the posted data, they also shared what they learned over the years from watching their middle school students work with mousetrap cars ("They expect large wheels to go faster'). The teacher leaders also provided some suggestions for displaying the data and discussing it with student and ways to use the activities to "go deeper" with high school students.

After the teacher leaders finished the activity, one of the Teacher Institute staff (Peter) continued the discussion of how teachers could use the activities in their own classroom. Peter asked each group to describe some of the strengths and challenges of the activity and what improvements they might suggest. Several teachers mentioned concerns about doing the activity with large classes. While acknowledging that class sizes of 36 teenagers might necessitate groups of six students, Peter emphasized the importance of making sure that each student in a group has something meaningful to do as a group member (e.g., timing or recording the data).

What Is This and What Can I Do With It? This four-hour Saturday workshop, took place in Michelle's classroom in early Spring 2003. The long black lab tables, , the countertops along the walls of her room, were covered with equipment pulled from the glass-fronted cabinets lining the room, and the supply storeroom behind the classroom. Ten new teachers attended this "new teacher only" workshop. As they entered the room, the teachers had time to wander around the room, inspecting and puzzling over the equipment. Some equipment (e.g., tuning forks) was easily recognizable. But some of the displayed equipment—oddly shaped glass containers, large coils of wire, cardboard tubes, a long metal tube with holes—were less familiar to most of the teachers.

As teachers explored the equipment, they also discussed concerns about the "letters of termination" many of them expected to receive (or had just received) from their districts. Several teachers felt certain they would be hired back in fall; the letters were "standard procedure" for districts due to budget cuts and uncertain enrollments, as well as teacher retirements. Others were less confident. They were frustrated that they would not know for certain if they had a teaching position in their district until, perhaps, late August, when it would be too late to look elsewhere.

While teachers explored the room and chatted with one another, two mentor teachers, John (Michelle's mentor) and Harold, prepared to demonstrate some of the equipment they had pre-selected. The teachers sat in desks or gathered around while the mentors explained the purpose of a particular piece of apparatus and suggested ways to use it in the classroom. They selected equipment for teaching a variety of topics in physical science, including electricity, electromagnetism, motion, light, and sound. The equipment included a convection chamber, a vacuum pump, a Bernoulli pressure tube, an electromagnet, spectroscopes, polarizing filters, Pascal vases, and heat conductors. John and Harold seemed delighted with the vast array of equipment in Michelle's classroom, commenting to the group (as only sciences teachers could do) that Michelle was "blessed to have so many discharge tubes." As John and Harold enthusiastically demonstrated the use of the equipment, they also gave advice on safety precautions to take with students and suggested less expensive substitutes for one piece of equipment or another. For instance, after working with a projectile motion device, Bill showed the group how to illustrate the same phenomenon with two coins.

The teachers seemed fascinated by the demonstrations. Their questions came rapid fire, both about the concepts being illustrated and the technical issues of equipment use. Teachers seemed more interested in learning about new topics and materials than preserving any illusions of their own expertise. Several teachers requested explanations of how a polarizing filter works. John and Harold used the overhead projector to draw a picture illustrating the way a polarizing filter reduces the light that gets through. After a "fiber optics" demonstration using a plastic spiral and a laser, a teacher asked, "What else can you do with a laser pointer?" Bill and Harold quickly improvised demonstrations of a few applications for optics, reflection, and refraction with a laser pointer. By the close of the workshop, most teachers had several pages of notes as well as contact information from other teachers with whom they could share equipment and ideas for lessons.

At this point I pause to reflect briefly on the characteristics of the opportunities to learn science in workshops at the TIP.

Science is portrayed as intellectually alive and vigorous. This is evident in the emphasis on perception, the first topic across Teacher Institute workshops, which is conceptualized as psychologically complex and sometimes deceiving. Further, teachers are taught to be skeptical—based on their understanding that human observation itself can be faulty; this sets the stage for open-minded inquiry into phenomenon. Teachers are pushed to ask questions (e.g., How does light behave?), to make descriptive observations, and draw inferences from these as they did in both Peter's and Lana's Maglite™ activity.

The TIP science is framed in everyday experiences. Pondering the "real" or "imagined" state of reported observations, dissecting a cow's eye to figure out how vision works, controlling the flow light into one's own eye in order to read the fine print on a menu, building musical instruments to examine explore sound energy and pitch: these and hundreds of other examples are the stuff of the TIP science.

This emphasis on everyday science, while pedagogically useful, also reflects what Schwab (1978) referred to as the "primitive principles" of the disciplines. As he put it, echoing Dewey, "One of the origins of scientific knowledge is the effort to codify and extend commonsense knowledge" (p. 202). Commonsense knowledge, or knowledge about our everyday experiences, is both the point at which science originates and one that it returns to "immature science and sciences in moments of frustration and regression often refresh their enquiries by renewed contact with the earth of common sense" (p. 203).

As participants "do" science—they ask questions, explore phenomena, pose explanations about the natural world—The TIP science invites diverse ways of looking at phenomena. Participants in Lana's workshops posed their own ideas and questions about what was going on. However, Lana did not stop at asking questions and finding ways to explore light. After participants conducted their explorations, she explained light behavior and the differences between physical and psychological perceptions of light. And they extended their inquiry into light by looking at the many exhibits on light and perception at the Exploratorium. Through a range of various experiences, participants were exposed to many perspectives from which perception can be considered.

Further, the TIP arms teachers with a storehouse of ideas, materials, and support to do the same for their students. After every floor walk, participants return to the Exploratorium classroom to do activities intended for use in their K-12 classrooms. These include building mini-exhibits, conducting investigations, and doing whole class demonstrations.

In short, crafting familiar experience into puzzles, the TIP intends to make science inviting and wondrous. Participants—like museum visitors—are invited into puzzling phenomena and the scientific explanations that help us make sense of them. Through experiences like those described here, participants have multiple opportunities to explore, learn about, and understand science. However, understanding science—and seeing how it can be represented in the world around us—is but one aspect of what teachers need to learn in order to help K-12 students have similar experiences in schools. And so the TIP includes other opportunities to learn that are closer to the classroom, opportunities that help new teachers put these ideas into practice and reflect on when and why they work, or don't. The primary component that supports such learning is mentoring, and it is to that program feature that I now turn.

Mentoring

Participants have additional opportunities to learn subject matter with their mentors. Mentoring is designed to be flexible so that teachers with a wide range of skills and capacities, working in diverse settings, can access specialized support for their particular needs. Mentoring takes place in one-on-one meetings, new teacher support groups, and classroom coaching sessions where the TIP science is delivered to new teachers in support of their classroom teaching.

Mentors themselves bring diverse professional backgrounds. Of the five mentors I interviewed, two were retired teachers, one was a fulltime the TIP museum educator, one was a semi-retired substitute teacher, and another a fulltime middle school teacher. All identified themselves as science teaching specialists; each had extensive experience teaching physics and physical science, as well as other school subjects including art, woodshop, engineering, reading, mathematics, and science education methods. They all have a long-standing relationship with the Exploratorium, having attended workshops and summer Institutes throughout their careers.[26]

[26] Harry, the least experienced and youngest member of this group reports the shortest affiliation with the Exploratorium at eight years. All of the mentors have attended the summer Institute multiple times as students and Ernesto has worked at the summer Institute for several years.

Table 3.1: Mentors' Professional Background and Role in the TIP

Mentor (Case Study Novice)	Teaching Experience	Professional Status	Responsibilities with NTs
John (Michelle)	HS physics, suburban	Retired teacher	Mentor to 7 Workshops
Ernesto (Susan, Joaquin)	MS physical science, urban	Exploratorium staff	Mentor[a] Training support Coordination
George (Andrea)	MS physical science, urban	In service teacher	Mentor to 3 Workshops
Harry (Avner)	HS physics, urban	Retired teacher	Mentor to 7 Workshops
Rhonda (Andrea, Geoff)	MS physical science, urban	Semi-retired, substitute teacher	Mentor to 5

[a] *Note.* As mentor coordinator Ernesto has some responsibility for all new teacher participants.

Three forms of mentoring occur in the TIP, including coaching/modified coaching, stand alone meetings, and new teacher meetings. I describe each.

Coaching. Coaching is the most intensive and long-term form of mentoring. Mentors learn about a coaching "cycle" in a four-day mentor workshop preceding the summer Institute. The coaching cycle includes three major phases—observation, modeling, and emulation—interspersed with novice-mentor debriefing sessions. In the observation phase, the mentor observes the new teacher and debriefs with her to determine what the teacher needs and would like help with. This is followed by modeling, during which the novice looks on as the mentor teaches a class or several classes that might have been co-planned or developed by the mentor. Modeling is followed by a period of debriefing in which the mentor articulates her motivations and thoughts about the lesson and helps prepare the novice to teach the same lesson to another group of students. Finally, in the emulation phase, the novice teaches while the mentor observes. Once again, the novice and mentor debrief, analyzing the lesson's successes and shortcomings.

Consider a coaching session between Ernesto and Elizabeth, a seven-year veteran sixth grade teacher in her first year teaching science. Elizabeth was scared to teach electricity, a topic she did not recall ever studying. In February, Ernesto met with Elizabeth and taught her some basic concepts about magnets and magnetic fields, and showed her how to build simple electromagnets with a screw, wire, and battery. After a few meetings, Elizabeth gathered together her courage and newfound knowledge and started an eight-week unit on electricity and magnetism in early March. She and Ernesto also planned for him to join Elizabeth in teaching a culminating activity in late April. On that day, Ernesto showed up at Elizabeth's classroom to build speakers. He brought spools of copper wire, dozens of magnets, and boxes full of plastic tubs.

Ernesto and Elizabeth sat down to talk through their plans. Ernesto would take the lead in first period while Elizabeth observed. Then they would debrief and switch during third period. Ernesto planned to start by giving students three clues about how speakers work: a coil of wire is alternately attracted and repelled to an alternating electrical charge; the cone pulses in and out with the alternating current; air pulses in a similar pattern and travels outward from the source as "sound." He explained that he would test speakers by plugging them into the jack in a boom box. Once the first group of students succeeded, he explained, students would modify speakers to make improvements.

This was scant guidance for the students, and Elizabeth worried that the lesson would frustrate and turn them off. But Ernesto reassured her. Though students would be frustrated for a while, eventually someone would figure out how to make the speaker work and this would be a moment of jubilation to be repeated for each student. And as the lessons unfolded, Ernesto's prediction turned out to be true. When the first group made the speaker work, Ernesto and the students celebrated. He threw his arms in the air, exclaiming, "They did it!" The class clustered around the speakers with visible excitement. Some students took the opportunity to diagnose their own non-functional speakers against the first successful model.

However, Ernesto did not allow students to dwell on success and within a few minutes challenged them to make the speaker more powerful. Subsequently, group after group followed the example and produced functioning speakers with increasing power as they tightened the copper coil, and experimented with different cone shapes.

The next period, Elizabeth taught the same lesson with Ernesto standing beside her. Though a bit tentative she offered the same scant guidance that Ernesto had, and showed students the materials. She virtually read the lesson from a script, and tightly controlled student activity calling on one table at a time to gather materials. She stepped in more quickly to calm students' frustrations than Ernesto had. Afterward, when Ernesto and Elizabeth debriefed, he encouraged her to be both more energetic and less present—to let kids get frustrated at not knowing what to do, to loosen the reins, and to have faith that the intellectual power of the activity would result in success.

Coaching, as this session illustrates, can inform teachers' knowledge and practice in important ways that induction activities based outside of the classroom cannot. Ernesto did not merely support Elizabeth's efforts to learn subject matter, but gave her extensive material and intellectual support to plan and instruct students about electricity and magnetism, a required unit in her curriculum, which she was not prepared to teach. This built on an earlier electricity and magnetism workshop that Elizabeth had participated at through the TIP; but the additional support helped Elizabeth translate her emerging understanding of the topic into classroom instruction for her students.

Ernesto's actual presence in the classroom during instruction also played a pivotal role. Where Elizabeth may have shut down the activity—concerned as she was with student frustrations—Ernesto explained that student frustration was important and productive. Elizabeth, like most novice science teachers, lacked an understanding about how cognitive dissonance and frustration can lead to learning. Her notions of motivating students were more simplistic than those of an experienced teacher. Having Ernesto by her side gave her a window onto how science could be exciting, dynamic, and engaging for her students in ways that she did not initially believe or understand.

Coaching also brings to light several challenges of taking the TIP science to school. Though a powerful intervention into novice science teaching, coaching was also time-intensive, difficult to coordinate, and often uncomfortable for mentors. Teachers' work is intense (Hargreaves, 1992) and densely packed with demands. During the academic year, participants frequently complained about not having enough time in the day. Michelle, frustrated that she couldn't feasibly master subjects she was required to teach, expressed a common frustration "I don't really have time, necessarily, to become an expert at this stuff!" (March 2003). Mastering the content was sufficiently challenging; learning to teach it in exciting—largely unfamiliar ways—seemed too daunting for words.

Coordinating mentoring activities—especially coaching, which required several sessions and took place in the classroom—can also be difficult. All of the mentors expressed frustration about scheduling visits to the novices' classrooms. Rhonda's frustration in scheduling with one of her novices was typical, "[My mentee is] doing all kinds [of things] -- she has several different preparations and she is also doing several different activities: after school, before school, lunch time activities. But she never has time to get together and talk" (March 2003).

Finally, while mentors understood the value of coaching activities—observing, modeling, and debriefing reflected mentors'—they were concerned such work would upset – rather than support the novice teachers, setting them up for feelings of failure rather than success. Harry, Avner's mentor and a retired physics teacher, told a cautionary tale. He had invited his former physics professor in to give a guest lecture to his students. The professor was a dynamic teacher who used several demonstrations that fascinated the students. After the professor left, Larry felt his own efforts paled in comparison, as did those of his students. They expected more than he could provide. As he saw it, he had set himself up for failure and did not want to put Avner and other the TIP novices in a similar position. Harry, like his peers, felt that mentoring should be supportive and maintain distance from classroom practice. Otherwise, new teachers might be left feeling inadequate.

Modified coaching. A second form of coaching was a truncated version of coaching. For example, mentors often observed novices and debriefed, but did not preplan the observation with the new teacher, nor model it. Alternately, they taught model lessons and debriefed afterward. Shorter term and less taxing on novices, modified coaching suits the TIP's orientation to supporting teachers. As noted in the coaching description above, teachers often seemed overscheduled and frenzied. Accordingly, they were more amenable to simple, single-day modified coaching sessions. Consider the following example.

In November of 2003, John—Michelle's mentor and a retired physics teacher—made an appointment to observe Michelle. They had met once at orientation and again at the TIP weekend workshop on electricity and magnetism where they planned to arrange a classroom visit. John called the following week to set it up. Michelle mentioned that she was going to do a lesson on lab safety in preparation for the unit in chemistry. She wanted her students to know how to operate safely in the lab, but worried that if they misbehaved during her lesson they would miss crucial information, thereby endangering themselves and others. She explained to John that this made her nervous.

On Tuesday of the following week, John arrived at the appointed time to observe Michelle's third period physical science class. During class, Michelle stood at the overhead projector and read through a list of safety concerns. She read rules about using gas, noted the location of fire extinguishers and how to use them, and pointed out the importance of safety goggles. She gave five-minute mini-lectures on each topic and sprinkled these with recall questions (e.g., What would you do if you had a fire at your lab station?). John recalled that her students joked about blowing up the school with gas, others talked quietly among themselves, while a few seemed engaged. Later, he reflected on his observations and the post-observation discussion with Michelle:

> The class would just start talking to one another and start shouting out. And this lesson was talking about safety! It was a lesson on safety, and she was basically telling. [Afterwards when we spoke] I kept shaking my head. I said, "No, make it

an activity. Make them go find the fire extinguishers. Make them a handout, but make it with things blank so they have to fill in what it is." (March 2003)

John was responsive to the Michelle's concerns and gave her feedback on the lesson she wanted help with. In so doing, he helped her meld her interest in doing more laboratory science with concerns about managing labs safely. As a busy new teacher, she invited in a little mentoring, tailored to her own needs, and John provided that, nothing more.

This brings to light a problem that is uniquely suited to science-specific mentoring. Some challenges of working in classrooms with real students are not easy to replicate outside of the classroom. Given the emphasis in science on using evidence, and developing knowledge through experiments, the nitty-gritty classroom management concerns are particularly worrisome and not easily transferable. I would not seem appropriate to have, say, a history teacher mentor Michelle on lab safety. Working with chemicals and other lab materials is practice-based, subject matter specific, and fits naturally in science-specific mentoring.

Standalone mentoring. Under the constraints of teachers' time, the difficulties of coordinating meetings, and the tentativeness with which mentors treated their novice colleagues' "turf," standalone mentoring meetings were well suited and popular among mentor-novice pairs. These meetings were often quick and dirty. Sometimes dyads met at appointed times, though often mentors would just show up in novices' classrooms to check in or drop off materials.

For example, Andrea explained that she and her mentor Rhonda could rarely meet as Andrea had but one planning period, hall duty between class periods, and usually had a classroom full of students doing homework in the afternoon. Instead, Rhonda would drop off materials on the fly. As Andrea recalled, Rhonda would show up and ask, "I have all this stuff, can you use it?" (November 2002). Similarly, Larry often made unannounced, but welcome visits to Avner. Larry would spend evenings sifting through boxes of curriculum materials, in search of "gems" for his novices. When he found a material he thought one would like, rather than coordinate a visit, he would jump in the car the next day. On one occasion Larry found 1980's era software drivers for motion probes. With vague awareness of Avner's interest in instructional technology, he delivered these to Avner on the off chance that Avner could to use them. Avner did.

Not all standalone mentoring was unsolicited. Novices also requested quick turn-around support from mentors. Twice in March 2003, for example, Ernesto responded to Susan's "emergency" calls for curriculum. He would drive from the city 25 miles south to Stephanie's school to deliver materials on a day's notice. Richard, Andrea's mentor and departmental colleague, passed lesson plans to her in the hall or after school on a weekly basis. Following a Saturday workshop in which John restored antiquated demonstration materials (What is This and What can I do with it?, described above), Michelle invited him to join her in scouring her school's science storage room. On several occasions, Joaquin asked Ernesto to meet him at a local café where they could plan his curriculum for the coming week.

The mentors took pride in being responsive. As Rhonda commented, "[I] let them get the picture that I am there to help in any kind of way: slave labor, going out and getting materials, whatever" (March 2003). Michelle's mentor, Dick, noted, "That's where I can do really good in the program: help[ing] teachers get their lab equipment going, set up labs" (March 2003). Harry, Avner's mentor, and a retired physics teacher explained, "What I really like doing is when they have a specific curriculum question or a material need, then I can jump on that sort of thing and really help out" (March 2003).

Getting instructional materials to novices was particularly prevalent in mentor's work. "Go-fering materials," (March 2003) as Larry put it, was a crucial mentoring practice. Mentors shared all kinds of materials with novices, including written materials (curriculum guides, favorite lessons, newspaper clippings on the eclipse), but more often they were the bulky objects of the TIP science. Ernesto gave Susan 2-liter bottles to serve as compression chambers for pneumatic rockets. John built a momentum demonstration using a modified turntable for Michelle. He also refurbished and gave her 1960's-era "carts," little cars used to teach speed and acceleration. Harry gave Avner a giant, convex mirror for light demonstrations. Rhonda lent Andrea her higher-powered vacuum and giant plastic bags. With these should "shrink wrap" a student to demonstration the fundamental concept that matter takes up space, even when we can't see it.

Novice teachers welcomed the materials and commonly asserted that materials were what they *needed*, and that mentoring was a good way to get them. Richard attained "permanent angel status" (January 2003) in Andrea's eyes helping her gather and organize instructional materials. Avner found Larry's support unique as he had been frustrated by his experiences in the Physics Teachers Resource Network. As he explained:

> All these physics teacher I know have been teaching [physics] for a while. They know everything and they have their routines. When I come and say, "I don't

> have the equipment, what can I do?" They are like, "Well, do you have an airtrack?" I'm like, "No, they are really expensive." (October 2002)

In contrast, Avner observed that Larry, his the TIP mentor, helped him assess what he had available in his classroom and to think about affordable materials he might consider, "My Exploratorium mentor came in, he talked about the physics class having a lack of materials in general, and trying to do things without spending much money" (December 2002).

In sum, the TIP mentoring is committed to helping teachers move on their interests in teaching the interactive, personal, and dynamic science that they have opportunities to learn in the TIP workshops. Some of the teachers actively sought support and all of the mentors actively offered it. Occasionally, mentoring was a well planned, well orchestrated, several day, smoothly coordinated set of activities that built on teachers' experiences in the TIP workshops or the summer Institute. More frequently, novices requested or were offered short-term, quick and responsive means of support that was linked to the intellectual and material requirements of taking the TIP science into their classrooms.

Conclusion

Participants have countless, diverse opportunities to learn subject matter and how to teach it in the TIP. These include formal presentations on science topics, intersession chatting with peers and staff, classroom-based mentoring; and a host of exhibits, library volumes, and virtual environments. The new teachers learn about science, science teaching, and curriculum in the summer and during the year, in the Exploratorium and in their own classrooms. They learn from experienced teachers, informal science educators, and scientists, as well as their peers. In addition, while I do not describe the full range of opportunities to learn here, they are given other opportunities to learn as well: workshops that focus on generic teaching issues like management, mentoring groups, special on-line forums just for Exploratorium teachers.

Throughout all of the opportunities to learn offered participants, a unique and compelling image of science prevails. That image is rooted in everyday experience, intended to draw in the natural curiosity of learners, and complicated by human perception and the fact that science is everywhere around us, an on-going, incomplete journey in which scientists and the public can both actively participate. Furthermore, throughout these activities, teachers—no matter how experienced they arte—are treated as professionals. It is up to them to design their professional development, to exercise their autonomy, and to draw from the rich array of resources and opportunities to learn.

The next three chapters build on this description of the TIP. The overarching question that ties these chapters together is: What do new teachers learn about science and about teaching science through this science-specific, content-rich induction program?

Chapter Four

Developing Pedagogical Content Knowledge: Learning to Elicit and Respond to Students' Ideas

Without good teaching, even "successful" students—those who receive high marks, and advance to post-secondary studies—often fail to understand the science they diligently study. They memorize the content only to forget it later (Clement, 1982; McDermott, 1984; Tsai, 1999; Elby, 1999). As they analyze conceptual problems, they attend to the surface-level, but miss deeper aspects (Chinn & Hogan, 2000). They may appear to learn things, but quickly revert to misconceptions in novel settings (diSessa, 1982).[27]

Some scholars see students' entering ideas as a barrier to deeper understanding; others see them as a resource for teachers to build upon. When student ideas are seen as barriers, teachers may enact conceptual change pedagogies to surface, challenge, and unseat those devilish misconceptions. And when student ideas are considered resources (Gallas, 1995; Hammer & Elby, 2003; Penner, 2001), they can be explored to inform instructional efforts to make science meaningful and relevant for students. Gallas (1995), for example, does extended "science talks" with her elementary students in which she acts as "listener and archivist" (p. 23) while students' ideas and questions fundamentally determine the curricular course.

Shulman (1986) introduced pedagogical content knowledge (PCK) into the research vernacular as a way to characterize the qualities of teachers' knowledge of content that reflect pedagogical concerns, like attending to students' ideas. Shulman

[27] There is considerable evidence to support the conceptual and perceptual difficulties of learning science. See Reinders-Duit's (2004) bibliography *Students' and Teachers' Conceptions and Science Education*, which lists over 6000 articles in the conceptual change literature. See http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html

hypothesized that PCK was one of five distinct forms of knowledge that teachers bring to bear on their practice; the others included subject matter knowledge, pedagogical knowledge, curriculum knowledge, and generic knowledge of students. Building on Dewey's notion of the tension between theory and practice, Shulman and his colleagues suggested that PCK was a unique kind of professional knowledge that exists at the cross-section of subject matter and pedagogy, "which goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986, p. 9). PCK is *not* the general pedagogical knowledge a teacher might employ (e.g., cooperative groupings, questioning strategies, classroom management systems). Nor is it the curricular correlates of disciplinary "content" and "process," which Shulman and his associates refer to as "content knowledge" or "subject matter knowledge." Rather, PCK is the melding of content and pedagogy.

PCK was picked up and operationalized in a range of studies which emphasized slightly different features of it. van Driel, Verloop & de Vos (1998) analyzed five prominent studies and noted two distinct features of PCK across studies: (1) the typical problems students might have with a particular subject and (2) stores of instructional representations. Teachers who can articulate the typical ideas and conceptual difficulties students face in learning their subject, and can generate appropriate, illustrative representations of key ideas "have" PCK, the authors argued.

Despite the important role student ideas play in their learning, many teachers do little to anticipate, respond to, or engage student ideas. Too often, teachers go about the business of teaching, with little attention to how students are making sense of the subjects at hand. Science teachers, in particular, may operate with little reference to student ideas about topics as they plan, teach in real time, and reflect on their teaching. For example, Gasper and Valcarcel (1999) analyzed the planning processes of 27 secondary science teachers as they prepared units during a lesson-planning workshop. Teachers reported adjusting their curriculum, but "they only considered general aspects such as level, age, and general knowledge of the subject in question" (p. 509). Rarely did finer-grained concerns about student beliefs about the subject matter come into play.

Teaching teachers to think about their learners and content is at the heart of the TIP, where learning science is about the experience of the learner. If the overarching question of this study is, "What (if anything) did the participants in the Exploratorium the TIP learn in their content-rich induction program?," then the purpose of this chapter is to focus on what the new teachers learned about using, and responding to student ideas in their teaching. I ask, "Do the new teachers who participate in the TIP learn to consider student ideas when they set about teaching science concepts in their own classrooms?" To wit, do the new teachers acquire pedagogical content knowledge for teaching science, in particular, pedagogical content knowledge that helps them unite an understanding of students with an understanding of science concepts? Here I want to know if, when, and under what conditions teachers' TIP experiences—articulating their own ideas about phenomena and interacting with a range of instructional materials designed to draw out student ideas— inform their teaching.

Learning to interpret student ideas about content is a considerable challenge for new teachers. In this analysis, I look at novice teachers' uses of student ideas as they teach scientific concepts, using a pedagogical content knowledge framework that attends to both concepts and student ideas about these concepts. This framework serves as the lens through which I examine teachers' practice both prior to and following their experience in the TIP Summer Institute.

Method

Three Levels of Pedagogical Content Knowledge

I developed a three-level framework for analyzing participants' pedagogical content knowledge (PCK). Each level is characterized by the presence or absence of two features: accurate science concepts and attention to student ideas about these concepts. I first describe the two features before characterizing the three levels of the PCK framework.

Few would object with the assertion that teachers need to understand the concepts they will teach. If they are to help diverse students acquire new concepts, at bare minimum they need to understand the concepts themselves.[28] For example, consider the concept "light travels in straight lines." A teacher might indicate conceptual understanding by using it to describe how light works in vision. He might point to it (or its absence) in a student's analysis of the same. Alternately, he might demonstrate understanding in indirect ways. For example, he might assert that "light from the sun takes over eight seconds to reach the earth's atmosphere," from which we can reasonably infer that the teacher understands that light travels. Any of these responses would indicate accurate use of the concept. Without this base level of knowledge, the difficult task of teaching students to understand light (or any concept for that matter) borders on impossible.

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[28] This is not to suggest that describing concepts is necessarily a pedagogical act, but that the *ability* to describe particular concepts is a necessary precondition to teaching those concepts.

But mere knowledge of the content is not sufficient and skillful teachers also consider student ideas about the specific concept—their understanding, experience, and difficulties in learning them—as the discussion of PCK above suggests. They use their knowledge of student ideas to plan and assess lessons, and to recalibrate instruction on the fly and for future lessons. This characteristic is related to Ball's (2000) argument that good teaching entails not just knowing subject matter, but "holding" it in a flexible way, Ma's (1999) observation that knowledgeable teachers see the subject matter from multiple perspectives—including that of the curriculum and the student—or the arguments made by science education researchers that teachers ought to understand the misconceptions or naïve conceptions that students bring to classrooms (e.g., Driver, Guesne & Tiberghien, 1985) are also relevant here. As students interact with a concept, these scholars argue, teachers need to gauge students' emerging ideas in relation to it. Only then will a teacher be prepared to strategically support student learning.

In the analysis that follows, I documented both (a) teachers' understanding of the concepts they taught; and (b) their sense of student ideas about those same concepts. In analyzing the data, I identified three levels of understanding in the new teachers: emergent PCK of a science concept (knowledge of both the concept and relevant student ideas about that concept), understanding of the science concept (without the accompanying knowledge of student ideas), and incorrect or incomplete understanding of scientific concepts.[29]

Learning to teach is learning to move from an understanding of content to a

[29] Although, as van Driel, Verloop and de Vos (1998) argue, PCK can be seen as having two components—one about students and one about instructional representations—for the purposes of this analysis, I focus exclusively on the student aspect of PCK. Future analyses will entail explicating the development of novice teachers' understandings of instructional representations.

pedagogical understanding of content. The new teachers' understandings reflected this: at times, their knowledge of scientific concepts was limited; at other times, their knowledge of the science was reasonable but they had yet to develop professional understandings of how students thought about those concepts; and finally, in a few instances, the new teachers were beginning to display an understanding of content that was distinctly pedagogical.

Data Analysis

I organized the data by first grouping all instances in which teachers talked at length about a particular concept they were teaching or, in observations when a particular concept was the focus of for more than 10 minutes during a lesson. In other words, I combed the data for the instructional representations, or emergent instructional representations in teachers' teaching and talk. I included only those instances in which I felt I had a fair chance of seeing both teachers' use of science concepts and their perception and response to student ideas.

Once identified, I sorted the instances into framework categories based on accuracy and evidence of student ideas. I determined scientific merits by consulting authoritative sources (e.g., Hewitt, 1989; Wenham, 1995). I classified instances as informed by student ideas when two criteria were satisfied:

1. Teachers stated, (during instruction) elicited, or responded to student ideas about particular concepts (e.g., matter takes up space, sound is a form of energy). This includes teachers' explicit acknowledgement that students "get it," that is, that students have partial, incomplete, or inaccurate ideas about the concept. Instances in which teachers

describe or appeal to general characteristics of students (e.g., curiosity, interests, capacity) did not qualify as evidence of teachers' use of student ideas.

2. Teachers used information about students' specific ideas to inform instruction. This can happen in planning, "on-the-fly" during lessons, and in reflection upon lessons in anticipation of future lessons on the concept.

Pedagogical Content Knowledge at Time One (t_1)

Across the t_1 data sources (including all interviews, and classroom observations), I generated 33 instances in which teachers worked with specific concepts in both real and interview-based instructional settings. I sorted these 33 instances into the respective levels of the framework. Here I report evidence from each category.

Emergent PCK

Ten instances at t_1 were sorted into the emergent PCK category. These instances were distributed across all participants. Avner accounted for four, Michelle for three, and Andrea, Geoff, and Joaquin for one each. I describe evidence from each teacher, elaborating on selected examples of their emergent PCK.

Each of Avner's instances derived from the subject matter interview. Recall that teachers responded to three tasks in this interview and for each task they selected a particular concept to discuss at length and to use (or not) in their proposed instructional response. Accordingly, teachers generated a maximum of three candidate concepts for this analysis, with the exception of Avner who generated four.

For example, consider Avner's analysis of Eraser Clap (task four), which prompts the student to explain how sound travels across a classroom when two chalkboard erasers are clapped together as described in chapter two. In that task, the student says, "The resistance that the two erasers put on each other created an energy that couldn't go anywhere – but it *had* to – so it went into the sound waves that the classmates heard. Some energy also went into heat." In reviewing the response, Avner noted that the student failed to account for how sound travels.

> I don't think the student has all that many ideas about how the students in the room—how basically the energy of the person clapping these things together is transmitted to the people sitting in the room. So, I think that that's the big thing. They need to learn more about sound waves and how the sound is transmitted through air. (March 2003)

Here Avner noted, accurately, that the student's answer lacks a clear conception of how sound travels. He suggested that sound travel is, in fact, an advanced concept built upon other ideas that he would want to discuss first. He proposed backtracking to help the student understand what waves are, before asking them to grasp the specific instance of sound waves. He reasoned that while sound waves are not easily observed, other examples, like water waves would be better place to initiate the study of waves and energy. Only after establishing wave motion in water did he propose pushing students to think about sound waves traveling across space. "After you go through water waves and things you can actually see, then [they will be able to] see that sound waves behave in a similar way" (March 2003). In this example, Avner works on the concepts of waves and how they travel. He is sensitive to evidence in the student response that the student is missing a key component and proposes a series of events to build student understanding. This illustrates what I mean by emergent PCK: Avner has a clear grasp of the concept at hand and works with it flexibly to hone it to the student's thinking.

However, emergent PCK in not just about citing student errors and responding, but it is also about corroborating students' accurate conceptions and proposing strategic ways to build on these. For example, in another instance, Avner corroborated a student's accurate response to Man Shadow (task two) and suggested a way to build on the student's understanding. The student response indicated that, as the man approached the light source, "his shadow would become wider and longer. This happens because he would be blocking more light the closer he is to it." Avner felt the student had "a pretty good grasp… of what would happen" and that there was "not that much missing" (March 2003). Given the student's sense of the behavior of light in shadows, Avner proposed developing mathematical relationships for the positioning of the man and the size of his shadow by graphing the position of the shadow on the ground as the man stood in different positions. Here Avner uses the student's accurate ideas about the behavior of light in shadows as the basis for an incrementally more advanced analysis of the same phenomena.

Not all of the instances of emergent PCK were tidy, full-blown instructional responses that elicited or reflected consideration of student ideas. In other instances, teachers worked with accurate conceptions, noted evidence in student thinking, but struggled to fit the two together sensibly in an instructional response. Participants may not always have come up with a definitive solution, but for a novice to put his finger on the problem, I suggest, is an important indication of emergent PCK.

For example, in Michelle's analysis of Man Seeing (task one) she noted that the student response depicted light "swooping" downward, passing from sun to observer to object, rather than depicting light reflecting off of the tree, back to the man. She contrasted diagrams from two student responses to characterize this error.

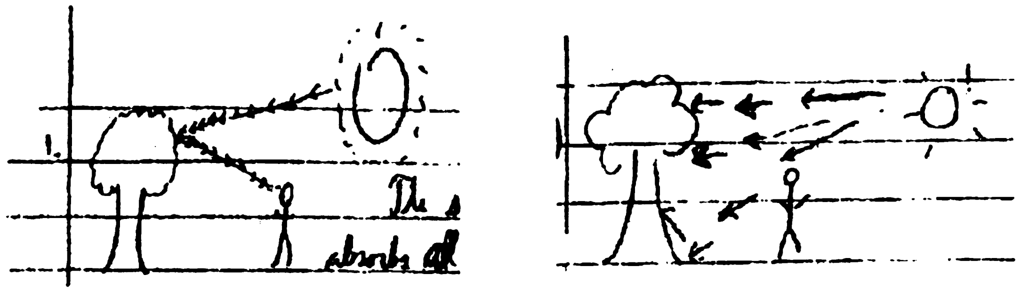


Figure 4.1

Diagrams for Task One Student Responses One and Three

In reference to these diagrams, Michelle noted:

> [In response 1] the sun's rays are just curved light waves. The light waves need to come sweeping in, but they don't have any reflection. The other student [in response 3] has the light bouncing off the tree or the leaves and then that's how the man is seeing. (March 2003)

While Michelle noted accurately that reflection was lacking in one student response and was evident in another, she was flummoxed about what to do instructionally. On the fly, she proposed having students "use a mirror" to examine reflection. How one uses a mirror to illustrate reflection of light in vision was not immediately clear to me, nor was it to her. As you can see, she quickly reneged:

> Maybe I'd bring in some kind of mirror or something. I could ask, "Why are you seeing your reflection?" to get them to see that there is actually light being reflected to the person's eyes—it might give them an idea that light is being reflected. I don't know. I would probably have a tough time with that. I'd focus on treating the sun as a light source—try to get rid of these little sweeping arrows—definitely target that, especially if that were a common response [among students in the class]. But again I don't know if I have a repertoire to do that. But once again, once I saw that problem, I'd go find the repertoire. (March 2003)

Though Michelle's instructional response is not decisive, she is pushing herself to develop instruction that responds to student ideas about visual perception (e.g., that it does not require light reflection). Even when she fails to generate an idea of what to do instructionally, she reaffirms her focus on teaching to build on student ideas, building her pedagogical repertoire over time.

Thus far all of the examples of emerging PCK that I have described arose in the context of interviews, which are stripped of the many real time classroom concerns and can be thought of as evidence that, on occasion, student ideas inform teachers' reflections and planning for instruction. However, teaching in a way that acknowledges and works with student ideas, can also require teachers to think on their feet in the heat of real time classroom activity. Students' views and ideas emerge in classrooms and cannot always be anticipated, and so teachers need to think on their feet and try to respond to unanticipated student ideas, confusions, or experiences they bring to bear on the topic at hand.

There were two "real" classroom-based observations (Geoff and Joaquin) in which I saw evidence of emergent PCK. I describe one of these here. I observed Geoff's lesson in which he asked students to document chemical and physical changes "around the house." Geoff introduced these notions to students using the familiar instructional rule that physical changes can be reversed while chemical changes cannot. He gave students a number of examples of state changes and classified these as either chemical or physical. Examples included baking a cake (liquid to solid), making Kool-Aid (dissolution of power to liquid), and toasting bread (soft to crunchy).

During class, Geoff offered examples and asked students to classify them. For example, Geoff introduced the example of baking a cake, which starts out as a liquid (batter) and ends up solid. One student suggested that when you bake a cake, this is a physical change. To the delight of his classmates, he explained that at a birthday party he saw kid eat too much cake and vomit the cake back up; that vomit was liquid and therefore, the student reasoned, this evidenced a reversible, physical change. Geoff acknowledged the student's idea, agreed that the example appeared to be one of a reversible physical change, but explained that it was not: when the student ingested the cake, to the cake was part of digestion, another chemical process. The liquid that came back up was not a reversal, but evidence of a new chemical change.

There was no clear evidence here that Geoff put great foresight into developing a lesson around student ideas. Geoff was notoriously lax in preparing lesson plans and this lesson was no exception. When I called him the day prior to the observation, he was still uncertain what he would do in class the following day. Yet, there was a glimmer of student ideas seeping in, and informing his instruction nonetheless. When the student put his reasoning about state changes out in the open, Geoff's reaction on the spot as to consider the student's thinking, evaluate its merits, and provide a reasoned response. This might be evidence of emerging PCK.

These are representative samples of the few instances of teachers' emergent PCK in which novices used subject matter flexibly; the new teachers anticipated, looked for, or read student ideas, and tried—with varying degrees of success—to pull together instructional responses. Largely, instances of PCK arose in interview scenarios and not in observations. So, while teachers may have emerging PCK, at this early stage of their professional development, that knowledge was still too undeveloped to translate into real actions in the classroom.

Understanding Science Concepts

At t_1 there were 17 instances in which teachers used concepts accurately but showed little evidence they anticipated, reacted to, or tried to elicit student ideas to inform their teaching. Each participant accounted for multiple instances of understanding that lacked attention to student ideas (and so was short of emergent PCK): Geoff (five), Susan (four), Andrea (three), Michelle (two), Joaquin (two), and Avner (one). Unlike the emergent PCK instances, which were weighted towards the subject matter interviews, the instances largely came from classrooms.

In typical instances, teachers pursued a concept in instruction for extended periods of time without making any clear effort to elicit, consider, or link the concept to student ideas about it. Instances of this type occurred both in lessons in which students engaged in doing activities and those in which teachers led the class in lectures and "discussions."

Consider Michelle's review session on matter from my second observation of her classroom. She had spent the previous several weeks doing science activities, which she felt had given students compelling examples, but had not provided "concrete" notions of the content. The review was intended to bridge students' informal experiences in activities with the definitive notions of science as portrayed in the students' textbooks.

Of the previous lessons that she wanted to build on in the review, there was one on energy levels in atoms. In that lesson, Michelle used books and a bookshelf as an analogy for electrons in the atom. Electrons revolve around the atom at a distance directly related to their energy level: the path of higher-energy electrons is further from the nucleus than that of low energy electrons. Accordingly, the top shelves represented higher energy levels and lower shelves represented lower energy levels. Michelle called on students to place books (representing electrons) on the bookshelf at high, medium, or low levels of energy. As she explained,

> We haven't actually done much bookwork. This is getting them concrete material on what we've covered in general. For instance, one [of the review items] asks how many electrons belong on the energy level closest to the nucleus. In class, I had a bookshelf with three levels and put the number two on the first, eight on the second, and so on. Then we took some books and then said, "Okay, you are carbon or whatever. Here are the number of electrons that you have, place them on the right energy level." (January 2003)

Though Michelle intended to have students revisit this example and connect it to a "concrete" review of the concepts, the review session never turned toward what students made of this experience, nor to the notion of electrons and energy levels. Instead, students answered problems on a review sheet that included questions about atoms ("What three parts make the atom? What are their charges?"), but there was no place where they linked the previous lesson, nor their ideas to the review. Michelle stood at the front of the room, helped students locate the answers to review questions in the book, and never reviewed the bookshelf energy levels lesson or any others.

Given Michelle's goal to bridge students' previous activities and the textbook notions, we might have expected to see her draw on students' analyses of the activities, or perhaps for her to talk with them about their emerging thoughts or difficulties they had understanding the activity. But this never arose. It is unclear whether or how particular student ideas may have motivated Michelle's interest. What students know, think, or believe about atoms and electrons was never taken up.

Another typical instance in which a participant clearly understood the concepts in play, but gave faint consideration to students' understanding, was Geoff's lesson in the mandatory sexual education curriculum (you might recall this lesson from chapter one). The lesson would track the path of sperm from the testes and of eggs through the fallopian tubes, stopping "just short of fertilization" (November 2003). Geoff felt the topic was extremely important, as he believed many of his eighth grade physical science students were sexually active. Geoff, a trained biochemist and medical lab jockey for 23 years, had no doubts about the content. However, he had some concerns about how the "immature" students might respond. He feared that students might make inappropriate jokes or offer crude, inappropriate language to describe genitals and sex.

Ultimately, Geoff's concerns were off base. As he stood at the front of the classroom, describing the path of sperm, this elicited no snickering and no vulgar language. He talked for 20 minutes, during which he put up two overheads (the cross-section of the male testes and then the frontal outline of female reproductive anatomy), pointing to aspects of the diagram as he went. Meanwhile a dozen students were deeply engaged in other activities: six pooled their desks around a card game at the rear of the classroom, two boys near the front kicked paper footballs across the classroom and mocked "field goal" signs to one another. A girl in the corner was working on math problems, and several other students stared blankly ahead. Just a few faced Geoff, visibly straining to attend to what he said and take notes.

In this instance, Geoff's knowledge of content was simply not enough. Nor was his awareness and concern that this was an important topic for his students' well being. There was no evidence of emergent PCK as student ideas—despite the relevance of the topic and Geoff's knowledge of the content—were nowhere to be seen.

Though Geoff's class was an extreme case, the scenario of parallel play between teachers "teaching" and students "not-learning" recurred across cases and pedagogical approaches. It was equally evident in more interactive or "hands on" activities. For example, Michelle taught a DNA lesson with the purpose of having students learn the four nitrogen bases for DNA and which base paired with which other base. Michelle had frequently commented on her the limits of her knowledge of biology and felt some trepidation about this topic going into the lesson. To add some luster to what she feared would be an uninteresting topic, Michelle planned to use an internet-based simulation that would allow students to visualize which nitrogen bases pair together.

"What are the four nitrogen bases for DNA?" was the warm up question, to which students wrote their responses on little shreds of notebook paper and passed them forward. Michelle then read the students' responses out loud. This was a brief exercise, as all of the students who answered the question had written the correct responses (adenine, guanine, thymine, and cytosine), having copied them from the textbook or asking a classmate.

After the warm up, Michelle introduced the internet-based simulation, which also showed how the pairings worked. A web page was projected onto a screen in front of the classroom. It depicted two columns of shapes that were labeled with the letters corresponding with the names of nitrogen bases (A, C, G, T). For a sequence of 12 individual nitrogen bases, Michelle serially clicked on one, asked students which it would be paired with, then dragged it onto the correct pairing. Michelle's students were uncomfortably quiet as she pleaded with them to participate. "Which nitrogen base pairs with adenine? If I drag adenine here what will happen? Anyone?" Students sat with their heads down, talked quietly with peers, or worked on assignments for other classes. Two students in the front of the class somewhat hesitantly answered Michelle's request, calling out "A" when she asked which nitrogen base would connect with T, and "C" when asked the same about the nitrogen base G.

Afterward, Michelle said that the DNA lesson was typical of her teaching in two respects: (1) that she tried to make it "engaging" and (2) that she came up short. She noted that, while students were not disruptive, they did not actively participate and this was disappointing. Especially with the world wide web-based DNA simulation, she had expected more buy-in:

> When I was just going through the internet thing myself, I thought it was a little more interactive and interesting than they thought. But in the past, they've been

> interested in those types of things. I could have improved it by putting a student in charge of the computer instead of me, to get them more involved. Because it was just me dragging those things over and they weren't really engaged with that. Like if I called on a student when you were observing, it was just *nothing*. (January 2003)

Michelle clearly cares to make the subject interesting to her students and she selected the world wide web-based lesson with that interest in mind. But Michelle did not consider and explore student ideas about the subject matter. Why would any student care about DNA? What does DNA help them do? Had they had any prior experiences with DNA? What was confusing about it? Across the pre/post interviews and observation, there was never a sense that Michelle had thought about these questions. This instance then falls short of emergent PCK, though it is informed by accurate understanding of the content.

Instances like those I've just described in Geoff and Michelle's classrooms were shy of emergent PCK and fell into the understanding science concepts level of the framework. One complication in interpreting these as evidence suggesting the teachers have little or no PCK is that teaching the observations are made in the complex classroom setting. It could be that teachers do care about and understand students' ideas—they may even have a personal "collection" of typical ideas—but that these are hard to draw on in practice where myriad concerns about management complicate knowledge use. However, evidence from the simpler context of scaffolded subject matter interviews corroborated these observations. In the subject matter interviews, I explicitly asked the novice teachers to consider students' explanations of phenomenon as they constructed instructional responses. But even in the absence of classroom pressures, where teachers were explicitly asked to plan instruction in response to student explanations, the new teachers were not prepared to do so.

Despite explicit direction to attend to students' ideas in the subject matter interview tasks, there were a handful of instances where teachers did not. In some instances, teachers described a concept accurately but offered no sense of students' ideas in their descriptions of the lesson. For instance, Susan suggested that the student response to Man Walking (task two) was missing the notion of light reflecting, but in her instructional response, she suggested a lesson that would splice light into its color components. There was no sense that this proposal was in any way informed by her analysis of the student response. Alternately, teachers observed student ideas, but made incorrect assertions about what the students were thinking. Consider one final example of the former type.

Geoff's performance on the Man's Shadow (task two) is particularly interesting as it indicated a sharp contrast between his own knowledge and what he saw in the student response. In this task, the prompt asked students to explain what would happen to a man's shadow as he walked toward light. The student response reads, "If the man moved closer to the light his shadow would become wider and longer. This happens because he would be blocking more light the closer he is to it." Geoff asserted that the student had a complete explanation, noting, "I don't think there is anything else. I think the student has gotten all of it" (June 2003).

In a sense, Geoff is right: the student response had some features that suggested understanding. But let us look at the two responses side by side (see Figure 4.2). The box on the left is text from the student response and on the right is text from Geoff's analysis. I have italicized segments of text to highlight where Geoff's language exceeds the evidence in the student response.

If the man moved closer to the light his shadow would become wider and longer. This happens because he would be blocking more light the closer he is to it.	First, he understands that you can block light by *a non-transparent object* and *shadows are caused by blocking of light by an object.* Then he also understands that as you move closer and closer to an object you block more and more of the light. Then he also knows that *as you move closer and closer to the light the area illuminated by light decreases because of the blocking of the object.*

Figure 4.2

Task Two, Response Two and Geoff's Analysis

Here Geoff fails to acknowledge a difference between the student's description of the effects of light and his "summary" which characterizes the behavior of light. This difference turns out to be fundamental to helping students grasp more sophisticated light phenomenon. As Driver et al. (1985) in their review of misconceptions research argue that students will often describe the implications of light (e.g., shadows) without grasping the *behavior* of light itself (Driver et al., 1985). They note that, "the fact that the path light takes is not itself directly visible presented special difficulties for children" (p. 128). Failing to distinguish the features of student's ideas from his own understanding limits what Geoff can do instructionally to help students. In this case, he sees no problems and his instructional response is to "do whatever is next in the book" (June 2003). In this sense, his own content knowledge might be obscuring understanding of the student's.

Inaccurate Science

There were 5 instances out of 33 in which teachers' used science concepts incorrectly in instruction.[30] Andrea and Susan each account for two instances, Michelle for one. Three were observed in subject matter interviews, one in Michelle's classroom, and one Susan reported about a lesson she taught prior to joining the study.

In two of the three interview tasks, Andrea's analysis of the content cast serious doubts on her own understanding of light and sound. For example, in her analysis of Man Seeing (task one) it was evident that Andrea did not understand that light, in visual perception, is reflected back to the observer. Below she compared two student diagrams (see Figure 4.3) as she reasoned about this task.

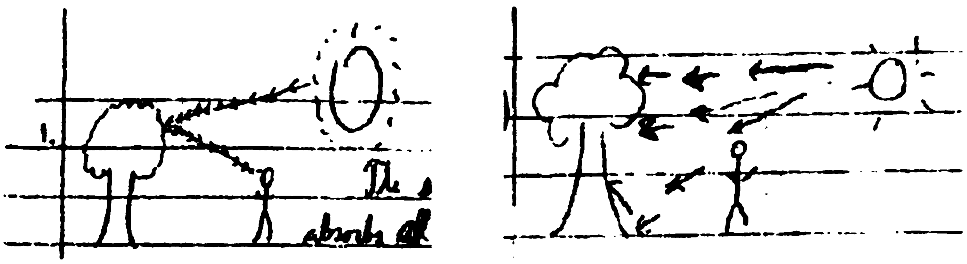


Figure 4.3

Diagrams from Task One, Student Responses One and Two

Andrea indicated that diagram two—which shows diverging, traveling light, but does *not* illustrate reflection—was more accurate than diagram one *because* it depicted the man seeing the tree independent of light. As she explained,

[30] This category is also likely underrepresented in the data. After all, participants had choices about what to teach and, within the interviews, which tasks they would respond to. It is unlikely that, when given the choice, individuals would opt to work on topics they are not familiar with. All of the teachers were teaching some subjects that they did not know well, and they all expressed some concerns about teaching these, so a level of basic conceptual error is expected.

I think this (indicating response two) is more accurate. It looks like it to me. Because the man is seeing [the tree] independently of the sun and in this one the sun [light] is bouncing off and coming back. (June 2003)

Andrea's thinking contradicts the scientific notion that what we see results from reflection of light off of opaque objects. This indicates that Andrea's knowledge is far from even emergent PCK, as she lacks the basic scientific knowledge that light reflects into our eyes when we see.

Andrea also struggled to characterize sound waves. In Xylophone (task five), Andrea critiqued the student's understanding of sound waves, noting, "I don't think it's very clear about their understanding of sound waves. I don't think they've explained it a lot in terms of how waves travel. They are saying that it is spread out, but they are not giving any specifics on the travel of the wave" (June 2003). Uncertain what she meant, I asked her to explain in another way what she would want a knowledgeable student to say. She was not able to describe what she would want a student to say because, as she noted, she lacks the understanding herself.

AWS: Can you think of what you'd rather hear a student say?

Andrea: No, because I don't really know much about sound waves. I'm sensing that they should specify more. (June 2003)

Clearly, Andrea had limited understanding of sound. Without much understanding herself, there was little she could do instructionally. She explained, "I would definitely bring a xylophone into class. I would hope that there is some kind of picture in the book" (June 2003). Andrea would have a lot of ground to cover simply to understand what sound waves are, let alone teach a group of students about sound waves in a way that draws or on reflects their understanding, experiences, and ideas about sound.

I observed a single lesson in which a teacher made a clear error in defining the lesson's focal science concept. This was Michelle's lesson in which she wanted students to observe the role of enzymes in digestion and understand that enzymes are special molecules that exist in our saliva that convert carbohydrates into sugars that our bodies can use.

The work of enzymes is not visible to the eye, but can be observed in other ways and Michelle's lesson was designed to help students note evidence of this chemical process using their sense of taste. She had students place crackers in their mouths for one minute. By leaving a cracker in one's mouth, the digestive action of enzymes can be observed, as the salty taste of crackers turns sweet. This happens as a result of enzymes doing their conversion work, turning starches into sugars that the body can use. After conducting the observations, Michelle asked students to list their observations and then engaged the students in a discussion on the role of enzymes in digestion. The students listed observations mixed with interpretations: "it got mushy," "it was slimy," "it tasted nasty," "it tasted good." While none of the students zeroed in on the expected outcome—the change in taste from salty to sweet—Michelle accepted their responses nonetheless. She wrote them on the board, did not challenge them, nor did she follow up with further discussion of the topic.

In this instance, Michelle lacked basic knowledge of the topic. In general, she was aware of her weakness in biology and she consistently expressed concerns about teaching biology which, as a physics education major, she had not studied in a single class since her own ninth grade biology class many years back. In the heat of classroom instruction, she stood little chance of helping students understand what enzymes do given her own level of understanding.

In a final example, Susan taught a lesson on pitch in which students were to characterize the pitch/length relationship of their own handmade PVC musical instruments. She told me about this lesson while discussing they Xylophone prompt (task five):

> For my class, we built saxophones. And some of them built longer ones and some of them built shorter ones. And I imagine this [task five] . . . my students would be able to answer too. That was all we were really looking for. If things had a longer length, how would the pitch be? (March 2003)

How would the pitch be? This was the question I wanted her to answer. When she did—though she had taught the lesson just a few weeks prior—she struggled:

> The shorter, the shorter keys would have a higher pitch… I think. But I can't remember really . . .. [pause] . . . I'm thinking. I kind of forgot. Is it amplitude? Are you able to help me with this or . . . ? (March 2003)

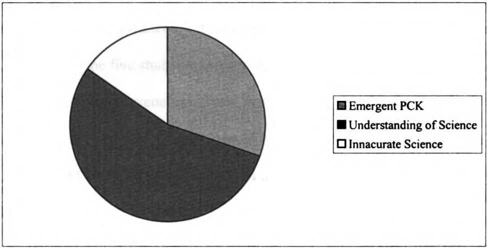
New teachers have to teach many topics that are as new to them as they are to their students. As I argued in chapter two, new science teachers teach a broad range of sciences and have uneven knowledge of these. The teachers in this study are no exception, as they all teach across the sciences, including biology, physics, chemistry, and for some, earth science and mathematics as well. In my analysis, each instance in which teachers used inaccurate concepts occurred in subject areas outside of teachers' areas of specialization. Michelle, the physics education major, mischaracterized the job of digestive enzymes, a biology topic. Andrea and Susan, both of whom studied the life sciences and had almost no background in physics, made errors in characterizing the physics of sound and light phenomenon.

A major goal of this study is to consider the influence of the TIP on teachers' professional knowledge. Accordingly, I need to produce snapshots of teachers' knowledge across time. This requires tallying, in some way, the body of evidence. Here I tally the evidence across categories of emergent PCK. However, before reducing the data, I caution the reader that the sample of observations in this analysis is small, and uneven. In particular, due to variations in access to teachers and how talkative individual teachers were, I have substantially more observations on some cases than others. What is more, my observations are scattered across a number of subject matter areas. Making precise and generalizable claims would require more attention to these complications in data collection and analysis. With this caution in mind, I have tallied the evidence by category of the emergent PCK framework below.

Figure 4.4 indicates, 55%, the majority of instances, fell into the basic understanding of science level of the framework and only 15% fell into the bottom category of inaccurate science. At the very least, then, (most of the time) teachers did not make flagrant errors in portraying science. However, they were also substantially more likely to teach without any clear sense of students' ideas about the content than they were to teach with students' ideas and experiences in mind. This more daunting feat—using science accurately and referring to or drawing upon students' knowledge about, and experience with, particular concepts—occurred in just 30% of the instances.

Figure 4.4

Proportion of Instances in Emergent PCK, Understanding of Science, and Inaccurate Science (t_1)



Teachers had limited pedagogical content knowledge with respect to students' ideas at t_1. This is not surprising: these are novice teachers and they have had few (if any) opportunities to learn about students in relationship to science. But even if they had spent a lot of time studying science instruction, they might not know much about students and how to interact with them in classrooms: science instruction is often characterized as unenlightened and far from dialogic (e.g., Weiss, Pasley, Smith, Banilower, & Heck, 2003). Focusing on novice teachers who teach across subjects and typically have at the ready few curriculum resources, we should expect nothing more and perhaps substantially less.

With this image of teachers' pedagogical content knowledge about students' ideas in mind, we can turn to t_2 data to explore changes. The workshops, mentoring sessions, and other opportunities to learn that participants encountered in the TIP clearly placed both content knowledge and pedagogical content knowledge on the table. To what extent and in what ways did this influence what the participants teaching?

A Growing Sense of Students' Ideas:

Time Two (t_2)

The t_2 data were drawn from substantially fewer observations and interviews than were t_1 data. Across the five study participants who remained at t_2, sources of data included the second subject matter interview, one fall 2003 observation, and the stimulated recall interview which resulted in 14 instances for this analysis.[31] Again I coded each of the 14 novel instances and sorted the instances into the three levels of the PCK framework.

There were two notable changes at t_2. "Inaccurate science" dropped from 15% to 0%. This change, however interesting, seems more likely an artifact of my method than an indication of teacher learning that I could substantiate with the data. I explain this below. The second change was a substantial increase in proportion of instances in emergent PCK, almost doubling from 30% to 57%. This change is more robust and serves as the focus of my analysis.

But first I explain my hesitation to claim that the drop in inaccurate science reflects a real shift in teachers' knowledge of content. While it is quite reasonable to expect change of this type given teachers' experience in the TIP—where teachers clearly had opportunities to learn "pure" content—the data are limited. One problem is that at t_1, 80% of the instances occurred in the subject matter interviews when teachers were forced to talk about subjects they had not studied since high school. There were no comparable

[31] Recall that Joaquin dropped out. Also data on Geoff is limited to stimulated recall and the second subject matter interview, as he did not participate in t_2 classroom observations. And Andrea did not participate in the summer Institute, nor the second subject matter interview.

circumstances in the t_2 data. For example, in second subject matter interview, teachers did not have to respond to any task, but were asked merely to reflect on their performance the first time they encountered the task. Similarly, there was only one classroom observation (Fall 2003) in the t_2 data for each teacher, again limiting the likelihood of teachers having to work with unfamiliar content. Thus, I shy away from claims about influence on teachers' basic understanding of concepts, as it is equally likely that, at t_2, I simply looked in fewer places where they were likely to struggle with science concepts. However, teacher learning of concepts in the TIP might be a productive line for future analyses.

The other shift in emergent PCK—from 30% to 57%—was based on more data and the observations across t_1 and t_2 retained a degree of parity. The data come in two distinct forms: instances in which teachers introduced new concepts when reflecting on their comments during the t_1 subject matter interview, and those in which teachers suggested novel concepts in their teaching at t_2. I report on these separately below.

New Evidence of Emergent PCK in Old Instructional Settings

In interviews that required teachers to critique their own past performances (second subject matter and stimulated recall interviews), teachers modified their analyses of student response and proposed new instructional ideas. In four instances, their revisions suggested emergent PCK. Avner accounted for three instances, and Andrea introduced one.

Avner revised his thinking about his lesson on eclipses, which was included in the understanding of science (but short of emerging PCK) framework at t_1. Originally in the lesson, students modeled a lunar eclipse using a quarter and a light bulb. In the stimulated recall interview, Avner and I watched two short clips of the lesson's introduction and student small group work about 20 minutes into the lesson. As we watched the video, Avner noted that students did not seem to catch onto the purpose of modeling an eclipse. They followed directions—putting the quarter and light bulb in their line of sight—but seemed unclear about how eclipses work. For example, one student explained to his tablemates that the eclipse happened "when the sun blocked the earth" eliciting no response—neither agreement nor argument—from his peers.

Reflecting on the lesson, Avner suggested that perhaps the students failed to understand that they were to develop explanations for how eclipses work, the basic purpose of the activity as Avner saw it. Were he to teach this lesson again, he proposed having students voice their ideas about what an eclipse is before launching into the lesson:

> I would leave it more open ended at the beginning—maybe just see what they think. So "What causes an eclipse? What happens during an eclipse? If you've never seen an eclipse, this is what it's like. Here are some pictures from the internet of an eclipse going by. What do you think could cause that?" Then they could try and come up with their group's theory of what was going on and try to prove it building a model. (October 2003)

Here Avner's thinking was not only informed by student ideas, but driven by them. He converted a failed hands on lesson in which students never quite got the gist of the activity to one driven by developing student theories, beginning with their naïve ideas. Clearly melding his thoughts about the content with his concerns about students' approach to it, this instance suggests emergent PCK.

Avner also reassessed his response to Eraser Clap (task four), which prompts students to explain how sound travels across an empty room. Avner's analysis of this task at t_1 was also classified as evidence of emerging PCK. At t_2, he expanded on the response, adding evidence that corroborated and extended his first response. He began by revisiting the reasoning of t_1, explaining that this problem required students to understand several concepts that are not easily explained in the context of sound energy and having students examine water waves before dealing with energy in the specific context of sound waves.

However, at t_2, he added another observation about students' ideas, explaining that students often struggle to distinguish large-scale movement (say of a car or a baseball) from the small-scale movement of waves. As he put it, "they think that waves move—that the actual water from way over there will end up way over here" (September 2003). He explained that, given this entering idea, he would ask students to describe what happens to a water molecule in a water wave which would likely elicit the large-scale movement notion from his students.

Avner's concern with distinguishing large-scale and small-scale movement of waves resonates with an observation Peter made about teaching waves during the physics workshop. Peter noted distinguishing movement of energy from other forms of movement was a classic problem in learning about waves. Peter had teachers work in pairs on an activity expressly designed to demonstrate that waves move energy. He had teachers work in pairs, using a 12-foot section of rope to create waves. With one teacher participant holding each end of the rope, he instructed one teacher to swing the rope up and down to create a wave pattern. The second teacher then held the other end still. The point, as Peter explained, was that the stationary end of the rope barely moved, but the energy pulsed through the rope and the second teacher could feel it: wave motion is the movement of energy, not matter.

Avner also revised his t_1 performance on Man's Shadow (task two). Avner observed that, at t_1 when he analyzed this task, he did not think to mention the notion that light travels. He speculated retrospectively that he had probably thought the idea too simple to bother noting. Upon review, however, he introduced the concept of light traveling, and explained that he would include this concept for students who may have had "misconceptions" about light:

> I guess when I first look at this, it's like I feel like I think a lot of people know about it from their own experiences. And maybe I need to make it more explicit…I mean definitely; people have ideas about that stuff. But obviously some people have misconceptions, too. (September 2003)

Here Avner appears to be unpacking his more expert knowledge and locating places within it that a learner new to waves might tread. This is akin to Ball's (2000) notion that teachers need to be able to decompress their knowledge to find ways to use it meaningfully to reach students.

Similarly, when critiquing her teaching of buoyancy in the stimulated recall Interview, Andrea also articulated a conscious shift in her awareness of students' entering ideas. At t_1, she had students build boats with tinfoil to examine properties of buoyancy. It was difficult to tell from the observation and our discussion of the lesson at t_1 just what Andrea hoped students would learn. She described the activity as one that would allow students to experiment with boats to determine what makes them float or sink, but in interviews and in the observation there was little sense which concepts were in play.

When we revisited her lesson six months later, she explained she would "do it totally differently," and talked excitedly about a district science professional development series that dealt with matter. The professional development leader had developed a 13-step sequence for teaching the eighth grade curriculum about matter, and he had been emphatic that teachers think about the many lower level concepts that go into the unit. This appealed to Andrea and gave her pause about how she had structured the curriculum in her first year:

> I realized after doing that, you know, no wonder why I had such a hard time—they are tough concepts! Here I am teaching them to English language learners! Many of them have been in the country for only two years! Good God! I started with the most complex level of it all and now I see. (September 2003)

Andrea planned to follow the materials she gathered at the professional development series next time around and attend closely to whether her students understand these before moving along to higher-level ideas.

An additional small bit of evidence—though short of the criteria I have set for this analysis—is worth noting. Geoff's analysis of Man's Shadow (task two) in the second subject matter interview suggests a view that some ideas may be more difficult than others for students to learn. Specifically he argues that explaining light and shadows is easier for students than explaining pitch (as in Xylophone, task four). As he put it, contrasting the two:

> [Man's Shadow] was much easier than [Xylophone] because the kids know—

it's easier to teach that as you move closer to a source of light you block the light. And then if you block the light you cast more of a shadow. I think it's easier for kids to understand that. (November 2003)

Geoff's emerging sense that some ideas are more difficult than others contrasts starkly with earlier evidence. For example, recall that Geoff's first week of physical science was one in which he proposed teaching four large, complicated concepts about matter on four consecutive days and he was surprised—even frustrated—that students failed to learn them. What is more, Geoff is a self-described "non-planner." The acknowledgement that some ideas may be more difficult than others for students to learn falls short of my criteria for emergent PCK, but suggests some positive new evidence in that direction nonetheless.

Scaling back expert knowledge to strategically build students' understanding (as Andrea and Avner do above), or simply differentiating tough ideas from easier ones (as Geoff did) reflect fundamental aspects of TIP instruction. Though ultimately the TIP instructors arrive at authoritative statements of knowledge about complex natural phenomena, this is not where TIP instruction begins. TIP instructors begin by making or having learners make very simple observations. For example, recall that Peter, the MIT-educated physicist, does not begin the Institute's Physics workshop's study of light with a lecture on the science of optics. Instead, he begins by having teachers describe what they see when they look at a light bulb. Only later does he talk (at length) about the history of scientific approaches to optics, competing models, and cutting-edge research. Similarly, recall Ernesto's electricity and magnetism workshop in begins by having teachers explore what materials in the classroom magnets "stick to." He works with teachers to establish that magnets "work" with materials with a high proportion of iron. He establishes this basic understanding among teachers before moving toward the loftier objective of manipulating electromagnetic pulses to amplify sound. Throughout the program, TIP staff model the value of *having* more expert knowledge and also *using* it strategically such that learners can begin with basic ideas before delving into complex explanations of the natural world. This does not translate into lectures – efficient ways to deliver such knowledge. Rather, expert knowledge allows the instructors to select good "hands on" tasks for students/teachers to play around with. After those explorations have stimulated thought, interest, and inquiries, TIP instructors introduce their expert understanding.

New Evidence of Emergent PCK in New Instructional Settings

While novice teachers' reanalysis of instruction may suggest emergent PCK, actual classroom teaching is another—perhaps more important—indication that participants are thinking in more sophisticated ways about teaching science. It is one thing to rethink one's intentions and plans. It is quite another to enact a new practice in complex classroom settings. There were four instances of PCK from the participants' classrooms at t_2. These were drawn from Avner (two) and Michelle (two). I describe each briefly here.

After he participated in the summer Institute, I observed Avner teach an introductory lesson for the size, structure, and scale unit (October 2003). Avner intended for students to put their initial ideas about what these terms mean on the table, engage in an activity that might stretch their entering ideas, and revisit (and perhaps revise) their initial thoughts. He organized the lesson around the *Secret Worlds: Universe Within* webpage[32] that illustrates the notion of scale with a series of photos arraying large-scale objects to microscopic objects. For instance, the first photo was of many galaxies, the next photo focused in further toward our galaxy, then the solar system, then the earth, etc. Ultimately, the photos frame a tree, a leaf, then go inside the leaf, the cell, and ultimately arrive at subatomic particles, the smallest scale.

Avner first heard about the webpage at the Teacher Institute and thought it was fascinating, but he wasn't sure how he would ever use it. Later on in September, he saw the page referenced on the TIP listserv when another teacher in the program asked for the url.[33] At the time that he was planning a unit on size, scale, and structure and figured out how he would use the webpage to introduce the unit.

I observed the lesson in which Avner introduced the size, scale, and structure unit using the *Secret Worlds* webpage. He started by writing "size, scale, structure" on the overhead, and asking students to brainstorm their ideas and experiences with these terms. After students recorded their ideas, they engaged in an activity designed to provide new insight into scale. Working in small groups, students used laptops to scroll through the photos on the webpage, noting the scientific notation used to express the images size on the bottom right of each image. Avner used this activity as a way to generate students' insights into scale. After 15 minutes of scrolling through the photos, Avner had students revisit the question, "What is scale?" Avner's strategy here to elicit student ideas, introduce novel information, and revisit student ideas was clearly informed by and focused on developing student ideas about scale, suggesting emergent PCK.

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[32] http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

[33] The Teacher Institute listserv, known as "Pinhole," is archived on-line for participants: http://www.exo.net/ti/pinhole/hypermail-04/0097.html. I access with this permission from the Exploratorium.

In another instance, drawn from the September 2003 post-observation interview, Michelle talked about a lesson in which she drew on students' thinking about radioactivity. As she explained, asking students openly about new concepts was a way of getting a sense of where they were coming from before teaching:

> Today, in my integrated science class, I had for my question of the day, "What do you think radiation is?" I was just trying to get into radioactive elements and last year . . . (whispered) *I just skipped over that.* We gave a definition, and moved on. But this time, I just wanted to see what they thought radiation was. A lot of them said some kind of gas or chemical or something like that. (September 2003)

Here Michelle suggests that she has new found knowledge that allows her to engage students in open discussions where as in her first year, she speculates, she may have simply given a definition and moved on, or maybe even skipped the topic all together.

In another instance that fall, Michelle asked her students to consider, "Why would you weigh less on the moon?" She explained that she knew students brought a range of ideas to this topic. This would help her learn where her students were coming from. As she put it "I know different ranges or levels that they can know the material at. This is me wondering, 'Well who knows this material yet and who doesn't get it yet?' It's more of a gauge of what they know and don't know" (September 2003). In both of these instances, Michelle talked specifically about prompting students to talk about their ideas so that she could learn about their thinking. These are not merely instances of asking questions; Michelle's questions are intentionally designed to elicit student thoughts about the concepts—radioactivity and mass/weight—to inform her teaching. Thus, these instances are considered evidence of emerging PCK.

In summary, the analyses suggest a substantial upward shift in the PCK framework toward emergent PCK. This is evident in both teachers' reanalysis of lessons and in their classroom practice after the summer Institute. A final point of analysis with respect to *who* shows signs of emerging PCK is in order. Most of this evidence—across t_1 and t_2—is drawn from two of five cases. Avner and Michelle, in fact, account for the majority of instances of emergent PCK at t_2. In fact, they account for all of the instances in which teachers' actual teaching indicated emergent PCK.

Conclusion

The analysis in the chapter points to two tentative conclusions and an emerging question. First, there is evidence that the TIP participants' thinking about subject matter can shift during their participation in the program. We see evidence in all but one case (Susan). The novice teachers entered teaching with a commitment to "getting the science out there." Later, after they participated in the program, and had a year of teaching under their belts, they moved toward ways of shaping the science they taught in light of learners' ideas and experiences. I claim that these new understandings are a form of PCK.

Second, although the design of this study does not allow for claims of generalizability or causation, the data suggest that the TIP might have played a significant role in creating the shift. Changes in the teachers' commitments are consistent with the characteristics of the TIP science. In the TIP, teachers had opportunities to consider their own entering ideas about phenomena (e.g., What is the "fuzz" around an uncapped lens? Do cars with bigger wheels go faster?), and afterward they created ways to elicit students' ideas when they returned to their own classrooms. Avner's reflection on the eclipse lesson, his teaching of scale; Michelle's questions about radiation and Andrea's reflection on the buoyancy lesson—these all reflect the TIP's commitment to student-idea driven science. In some instances, the new teachers even invoked their observations from the summer Institute to describe and explain their teaching such as when Avner attributed his use of the scale webpage to the TIP, and Michelle did the same for her treatment of radiation.

This shift was neither wholesale nor mature. Teachers were not building full-blown inquiry units in which student ideas drive the enterprise, nor did they follow Gallas's freewheeling science talks. They had not magically become experts at spotting students' naïve ideas, and when they did try to teach in an "Exploratorium way," their efforts were immature and ragged. They are novice teachers who, after an intensive science-induction experience, showed signs that student ideas had become important to them, teachers who embraced the idea that student ideas should be considered as they go about teaching.

But their learning was uneven, that is, some teachers appeared more ready to develop a commitment to student ideas and PCK. Michelle and Avner appeared to be the two teachers most influenced by their experiences in the TIP, or the two inclined to develop PCK. Why? In part, the fact that Michelle and Avner entered with more PCK might account for the fact that they were also the ones to develop more PCK throughout the study. But perhaps there are other answers to this question. We revisit this question in the next two chapters.

Chapter Five

Learning to Teach Inquiry

in·quir·y also **en·quir·y** *n. pl.* **in·quir·ies.** 1. The act of inquiring. 2. A question; a query. 3. A close examination of a matter in a search for information or truth.

American Heritage Dictionary, 4th Edition

Science has produced a canon of theory that reliably describes the natural world, and can predict the outcomes of many natural processes. Scientists can estimate the age of the universe or look inside components of single cells of a complex organism to code and even replicate its DNA. They can locate the chemical composition of smells and reproduce these in the laboratory. But how has scientific knowledge come be known and validated?

Scientific knowledge results from a process of inquiry, a "scientific method," Schwab's "syntax," or processes at the core of "the nature of science." Different literatures and scholars use varied language to describe the process of science. Schwab (1978) uses the language of "syntax" or "syntactical structures." Science education reformers, on the other hand, often talk about the "nature of science" or "scientific inquiry." Whatever the language, scholars focus here on the range of practices, norms, dispositions, and methods that explain how scientific knowledge is generated, tested, disputed, and verified.

The new teachers who participated in this study entered an environment in which there were multiple messages about teaching scientific inquiry (Galosy, 2005). Indeed, the Exploratorium defines science as both process and product, hence inquiry is not something separated from science subject matter knowledge, but is instead a central feature of such content knowledge. In this chapter, I inquire into how and whether the new teachers learned to use inquiry in their science teaching. As I did in chapter four, I examine teachers' uses of inquiry upon entry into the TIP, and then look for change at t_2.

The chapter is organized into four major sections. First, I discuss contemporary views and research on inquiry in science education, laying the groundwork for my analysis. Second, I describe the framework I used for this analysis, building on the conceptual and empirical contributions of relevant literatures, as well as the specific circumstances of this study. Third, I present evidence of teachers' knowledge of inquiry at t_1 and I characterize changes in teachers' use of inquiry at t_2. Finally, I draw two conclusions concerning when (and perhaps why) the new teachers take up notions of inquiry in their teaching.

Teaching and Not-Teaching Inquiry

Infusing the practices of science into the K-12 science curriculum has been a perennial goal of science educators since early in the 20th century (Rudolph, 2005). Dewey (1916) felt that the teaching of scientific thinking—not just the substance of science—was the key to undoing our societal "predilection for premature acceptance and assertion, [and] our aversion to suspended judgment" (p. 189). Dewey suggested science espoused a uniquely analytic thought process. Later at mid-century, the science curriculum took a humbler turn, as educators advanced the idea of science as a means of dealing with problems like personal hygiene (Ravitch, 2001). In subsequent decades, reforms have pushed notions of inquiry into the American science curriculum from time to time (DeBoer, 1991).

Contemporary reforms articulate a view of scientific practice that, while not universally endorsed, at least moves the field toward a consensus view. The *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (AAAS, 1993) serve as the most visible instances of national-level efforts, spelling out what science—and what *about* science—should be taught. The principle notions of inquiry in these documents converge (Akerson, Abd-El-Khalik & Lederman, 2000; Kennedy, 1997).[34] In his analysis of the standards documents, Lederman (1999) nominated six major areas of inquiry common to the standards documents. The standards agree that scientific knowledge:

(a) is tentative (subject to change);

(b) is empirically based (based on and/or derived from observations of the natural world);

(c) is subjective (theory laden);

(d) necessarily involves human inference, imagination, and creativity (involves the invention of explanations);

(e) necessarily involves a combination of observations and inferences, and

(f) is socially and culturally embedded. (p. 917)

There is also variation within the general consensus of how science should be taught in schools which includes two forms of inquiry: what the field calls "authentic"

[34] I do not suggest that academic discussions of the philosophy of science reflect this consensus. To the contrary, philosophy of science is contested. For instance Aikenhead (1997) argues that "the social studies of science" reveal science to be mechanistic, materialist, reductionist, empirical, rational, decontextualized, mathematically idealized, communal, ideological, masculine, elitist, competitive, exploitative, impersonal, and violent" (p. 220). Other portraits of science provide a very different picture (e.g., Feynman, 1999).

inquiry (NRC, 2000) and what I'll call "synthetic" inquiry. An example of the first is Steve Olson's (2004) *Evolution in Hawaii*, which describes an authentic biology inquiry lesson in which students use data to develop arguments about the geographical origins of several species of Hawaiian drosophilid flies. They analyze genetic data about these flies and historical geographic information about the islands. While student work is not on the cutting edge of science, this is an example of authentic inquiry in the sense that students look at and use data, and make arguments about real scientific subjects, in ways approximating those of contemporary geneticists.

Synthetic inquiry, on the other hand, presents students with long-settled matters (settled, that is, in the scientific community) and employs disciplinary practices as a pedagogical strategy for engaging students in learning. In this case, the actual subject is little challenged and the questions are ancillary to scientific debate, though central to classroom activity. Take away from Olson's lesson the use of authentic evidence and we can create "synthetic" scientific inquiry. For instance, students could study Darwin's finches, examining the beak sizes and shapes much as Darwin and generations of science students have for decades.

The science education literature is likely to lump both of these examples under the rubric of inquiry, but is important to bear in mind their differences. While the former reflects authentic, unresolved, or still explored problems in science, the latter draws on inquiry practices as a pedagogical strategy in contexts where science has long since ceased inquiring.

Scientific inquiry—in both senses—is the subject of to a staggering number of programs, studies, and curriculum these days. A Google.com search on "scientific inquiry" and "teaching" turns up thousands of relevant hits. The *Journal of Research in Science Teaching* published 34 articles with "inquiry" in the title in the last ten years, and *Science Education* published 20.[35]

Despite the prominence of inquiry in educational research and reform, research suggests that throughout grades K-12 students' opportunities to learn inquiry are very limited. In a survey that Weiss and colleagues (2003) administered to a representative cross-section of U.S. high schools, teachers reported that aspects of the nature of science were the intended instructional content of only two percent of secondary science lessons.

We also see a dearth of opportunities to learn inquiry at the undergraduate level. Undergraduates in the sciences rarely see inquiry in their classrooms and curriculum. The 1993 National Survey of Postsecondary Faculty indicated that in 1992 somewhere between five and 20 percent of lower-division science courses involved laboratory experiences (NSF, 1996). And when labs are used, their relationship to the relevant lectures is weak. In a large ethnographic study of science undergraduate education (n=335) from seven universities with large-scale science programs, student reports indicated a weak relationship between classes and lab work. Students characterized labs as mechanical and frequently noted that instructors were not present during lab exercises. Students reported an absence of illustrations, applications, or implications of scientific developments (Seymour & Hewitt, 1994).

[35] Inquiry science is not without its detractors. In response to the suggestion that students should experience inquiry, Klahr (2004) has argued forcefully that direct instruction in science is both more efficient and more effective. Many leading scientists meanwhile argue that science education is foolhardy in its efforts to teach inquiry and that knowledgeable use of inquiry only emerges from deep substantive knowledge of the findings of science. These scholars, then, argue for teaching inquiry to students who make it through a significant number of lower level substantive classes.

With few opportunities to learn inquiry, we should not be surprised that students and adults are woefully uninformed about it (AAAS, 1990). Consider that over half of U.S. adults dismiss evolution as "just a theory" (Newport, 2004). Evolution is the cornerstone of biology, accepted broadly as the unifying basis of the discipline. As a society, it seems we misunderstand scientific theory to be idle speculation. But theory emerges from clearly and elaborately articulated descriptions of the world that are carefully tested against empirical observation, refined, and tested again and again. In science, no theory is "just a theory" and theory is not ancillary to any scientific endeavor. This casual treatment of "just theory" reflects a widespread misunderstanding of what scientific theory is, and by extension, what inquiry and what science are about.

Even science majors express views of science that are incommensurate with inquiry. For example, Hammer and Elby (2003) argue that when physicists do physics, they are playing a "modeling game." They create models of phenomena, compare these to data to examine their fit, and refine them. Meanwhile students "view physics knowledge as a collection of facts, formulas, and problem solving methods, mostly disconnected from everyday thinking, and they view learning as primarily a matter of memorization" (p. 54; see also Elby, 1999). Consequently, students are unlikely to employ intellectual "resources" (e.g., personal experience) in science that they use to successfully to inquire and problem-solve in non-science settings.

Prospective and new teachers' views of scientific inquiry are also inconsistent with inquiry (e.g., Abd-El-Khalick & BouJaoude, 1997; Aguirere, Haggerty, & Linder, 1990; Bloom, 1989; Pomeroy, 1993; Windschidtl, 2004). For instance, Windshidtl's (2004) study of preservice teachers' knowledge of inquiry suggests that teachers enter the classroom with "folk" notions of inquiry. He studied 14 preservice secondary teachers' efforts to develop their own inquiry projects, beginning with formulating questions through presentations of research to peers. He found that teachers shared a common core of beliefs about inquiry and that few aspects of their knowledge or beliefs were consistent with "authentic inquiry." Teachers saw hypotheses as "guesses" which had little bearing on how problems are framed and examined. Theory itself assumed a peripheral role in their view of science, relegated to the end of a study as "an optional tool" one might use to help explain results. In short, teachers' views were inconsistent with the notion of science as motivated by questions, and based on empirical observations that are theory-laden.

In sum, Americans broadly—including science undergraduates—have few opportunities to learn inquiry. Further, teachers themselves are ill prepared to teach inquiry. We have a problem, but do we have a solution? What can be done? The literature suggests that if we want students to learn more science (including more inquiry), then we need teachers to have more opportunities to learn inquiry. It offers two variations on this theme: teachers can either do more inquiry, that is, experience authentic scientific practices for themselves, or they can be explicitly taught more about inquiry as a scientific process, in professional workshops or courses.

The "do more inquiry" view suggests that teacher learners acquire understanding of inquiry by practicing inquiry in long-term investigations. Studies of both adult learners of science and prospective science teachers support this view (e.g., Roseberry & Puttick, 1998; Ryder, Leach & Driver, 1998; Ryder & Leach, 1999; Windschidtl, 2004). These studies suggest that, in fact, adult learners and new teachers can take up positive changes in their views of science through deep engagement in authentic scientific inquiry.

For example, Ryder and Leach (1999) followed a group of twelve senior science students at a British university over the course of their final year. British senior science students across disciplines typically shift away from course work to a long-term independent inquiry project. The participants in this study majored in earth science, chemistry, genetics, and biochemistry and conducted inquiry projects within their respective fields. Alone or in lab groups, they did data base analysis, computer modeling, or laboratory work.

With the learners engaged in projects that varied by discipline, task, and social make-up, the researchers set out to determine how inquiry experiences influenced students' ideas about science. Over an 8-month period, they interviewed the science undergraduates, asking question like: "How do scientists decide which questions to investigate? Why do scientists do experiments? How can good scientific work be distinguished from bad scientific work? How are conflicts of ideas resolved in the scientific community?" In addition to these general questions, participants are asked to consider their views in relation to their on-going experiences in long-term inquiry projects with prompts like, "In what ways have your experiences on the project influenced your understanding of what scientists do? Describe the kinds of activities that you have been involved in during your project. Describe some intellectual challenges that you have been faced with in your project" (pp. 948-949).

The researchers found that participants' thinking about inquiry conformed to the nature and purpose of their inquiry projects. Participants who worked in lab groups drew lessons about the social dimensions of scientific knowledge as they talked through their observations and findings with peers. Those who worked in isolation tended to think of science as an individual pursuit. Similarly, students who spent their days crunching data, but did not do conceptual work, had little sense where a research question might come from. The researchers concluded that inquiry experiences strongly influence students' notions of inquiry. They noted "epistemic … demands a project makes on a student to draw on his/her views about the relationship between data and knowledge in order to progress in the project" (p. 951).

In a slight variation on the above, some scholars argue that learners should not only "do," but also study the tenets of inquiry. This view suggests that although the overt practices of inquiry may "happen," understanding the nature of these practices may not (e.g., Lederman, 1999).[36] Proponents of this view propose an approach that blends short-term inquiry projects with "explicit" teaching of inquiry.

Typically, this research works from a battery of normative statements about science ("science is culturally embedded," "science is empirically based"). The researchers use surveys like the "Views of the Nature of Science Questionnaire (V-NOS)" (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), which prompt teachers to characterize their beliefs about science in response to questions like, "After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples." Researchers administer these surveys prior to and after courses that are designed to teach inquiry "explicitly" to prospective teachers.

[36] Lederman and colleagues tend to use the term "nature of science" (NOS) rather than "inquiry." However, for the sake of consistency and simplicity here, I use "inquiry."

For example, Akerson, Abd-El-Khalick, and Lederman (2000) report on one representative study in which they analyzed change in preservice elementary teachers' understanding of the nature of science during a semester-long course in which inquiry was explicitly taught. They had students read science histories, lectured about philosophical positions, and did some inquiry activities in class. The post-instruction measures indicated substantial gains in seeing science as empirical, tentative, and imaginative or creative.

In summary, inquiry is an important part of understanding science, yet teachers and students (science undergraduates and their K-12 counterparts) often lack opportunities to learn about and do inquiry. Inquiry itself can take a number of forms, some akin to scientific practices (authentic inquiry) and some less so (synthetic, domain general). There is some evidence that with well-designed, extended, in-depth opportunities to do inquiry, adult learners can learn about inquiry. Meanwhile, another body of evidence suggests that teachers, in particular, benefit from a mixture of doing and learning about inquiry.

How might this inform the current study? The TIP, as I have argued in chapter three, is chock-full of opportunities to do mini-inquiry projects as well as "explicit" lessons about science. In this sense, the TIP itself may be an excellent setting for exploring what and how new teachers learn about inquiry when presented with opportunities to do and learn about inquiry. While this study was not explicitly designed to systematically investigate teachers' beliefs about inquiry, it is nonetheless fruitful to examine their views of inquiry as I, like Schwab and others, see inquiry is a component of subject matter knowledge. I now turn to a description of the framework I used to analyze teachers' thoughts about and instructional uses of inquiry.

Operationalizing Inquiry Science

Participants arrive at the TIP with views of inquiry that inform their teaching. And because the program places a great deal of emphasis on scientific inquiry, the role of empirical experience, and the nature of knowledge, one might expect to see some changes in their views of inquiry. For the purposes of this study, I took a grounded theory approach (Strauss & Corbin, 1998), combing the data at both t_1 and t_2 for relevant evidence. Two dimensions of inquiry were evident in the data: working with evidence and framing science as an exploratory endeavor. I expand on these here.

Working with Evidence

Scientific knowledge is derived from evidence, and framed by theory. Here I refer to "theory" as the substantive knowledge generated in a given field based on repeated data patterns and analysis, and used to account for those patterns. If theory is "king" of the scientific kingdom, then bodies of evidence are its subjects. Evidence, like the masses, is diverse, unruly, and numerous. Yet through careful control and coordination, evidence can support, validate, or diminish the standing of a theory (or relevant concepts). Given the centrality of evidence in scientific inquiry, my framework reflects three distinct, but related levels of working with evidence: evidence as illustration, evidence patterning, and interpreting these patterns of evidence.

Evidence as illustration. Schwab (1962) was critical of school science that was "a rhetoric of conclusions in which the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths" (p. 24), rather than the best possible descriptions of the natural world available at a given time. Evidence as illustration, the first rung of the evidence framework, reflects the base-level distinction between portraying science as a rhetoric of conclusions and an evidence-based practice. For example, I could assert to a friend or a student that "humans evolved from chimpanzees" and offer no evidence for the claim. Or I could support this assertion with some evidence, "look how similar their hands are to ours." Thus, the single piece of evidence is thought to illustrate the assertion.

Illustration falls well short of persuading, engaging arguments, or building patterns, but it contains in it a kernel of inquiry, albeit bearing little resemblance to authentic scientific inquiry. Single instances carry little weight in scientific discourse, which is concerned with establishing patterns (and patterns of patterns) as evidence. However, a single illustrative case is a more than the bald assertions of truth that Schwab (1962) was concerned about.

Patterning evidence. While illustrative cases serve a basic level of evidence, there are many more sophisticated ways in which evidence can be used. Standards of evidence in science go well beyond mere coordination of an idea with a single event. Theories are built on patterns in experience (Duschl, 1990). Patterning entails a large number of instances that vary in particulars, but adhere to a common set of principles.[37] When data are collected within a research project, the data are organized in ways that make them observable, in hopes that clear patterns will emerge. Depending on the type of data, researchers might use data charts, graphs, text printouts, tables, or any number of graphic

[37] Of course, patterning of evidence is not itself sufficient either, but it is an important aspect of theory building.

devices to make the data visible. Displaying the data in these ways is critical to observing patterns.

Interpreting evidence. A third and final aspect of working with evidence is interpreting evidence. Trends in evidence are *used* to support, refute, augment, or better specify a particular body of theory, but evidence itself does not carry specific meaning. Evidence does not stand alone, but must be interpreted within a theoretical or exploratory framework.

Interpretation is not just a matter of "seeing" the evidence. Psychologists and philosophers have long argued persuasively that observation is "theory dependent," that is we observe what we *expect* to observe (e.g., Hanson, 1958; Popper, 1972). Interpretation of evidence is particularly important in science, as understanding science can often be an "unnatural act" (Wineburg, 2001). That is, we take in information about the natural world constantly and from this we form ideas about what things are, how things work, and what ought to be clustered with what. Yet, these naïve definitions and explanations are often faulty (Driver et al., 1985), and learning science requires much unlearning and rebuilding new understandings through observation and theorizing about those observations. Interpretation is central to that process.

Exploration

While science can be a tightly controlled, rigorous, plan-ful exercise in pursuit of the validation of preexisting understanding, it is not always so. Science, and science instruction, can also entail more intuitive (Bruner, 1960) or freewheeling explorations of phenomena. Well-honed analytical procedures contribute to important pattern building to validate theory. And what Thomas Kuhn (1962) refers to as "puzzle solving"—fleshing out minor details to fill in well-defined gaps in advanced areas of research—can bolster the strength of a body of theory. However, in addition to routinized, clearly articulated versions of scientific work, there are exploratory aspects, and many instances in which less is known about a topic. Here questions are not predetermined. Rather, hunches and thought experiments prevail, and researchers "muck around" in a loosely structured and playful way. Exploratory activity in science, from this vantage point, moves to the formation of questions and the generation of hypotheses about how things work or how they are related.

For example, Kuhn (1962) describes the early work of "electricians," who developed theories about what electricity is and how to harness it. Working without a clear theoretical guide, one group of researchers imagined electricity was a fluid and tried to trap it inside of a water-filled glass vial. Touching a conductor suspended under an active generator to the surface of a jar of water, they hoped to trap electricity in a bottle. Initially this exploratory inquiry was both successful and—momentarily—safe. Indeed, they trapped electricity in water. Fortunately, their shoes grounded them, avoiding a tremendous shock. Shortly these investigations—again working outside of well-established theories of electricity and circuits—were altered slightly. Future tests under (unbeknownst to investigators) ungrounded conditions, resulted in several severe electrical shocks.[38]

As Kuhn's tale suggests, informal exploration also differs from hypothesis testing in that it does not necessarily entail the articulation of a (tentative) theory or idea. When dealing with the unknown, as scientists do, often the bits and pieces of knowledge

[38] Kuhn tells this story to illustrate how "speculative and unarticulated theories" (p. 61) can lead to scientific innovation. In this case, the efforts to store liquid electricity worked and eventually lead to the development of the Leyden jar, a device that grounds stored electricity so it can be handled safely.

available are inadequate. Nor does exploration require a clear method of hypothesis testing, designed to return unambiguous results (e.g., experimental design).

Exploration may also occur later in inquiry, throughout the course of a study, or the lifetime of a line of research. One might explore a range of research designs and measures (Might an outlier study be helpful? Which measures of central tendency should we attend to?). Researchers might explore data collected under a predetermined theory-motivated research design. They might, for example, generate a dozen printouts of test results (scatter plots, bar graphs, pictograms) to stimulate their thinking about where patterns exist. In short, exploration is the playful interaction of researchers with any portion of the research process in which they are neither validating nor formally testing correspondence with "truth" (as in hypothesis testing), but in which they are trying to gain a foothold on what is going on nonetheless.

Evidence and exploration are two core features of scientific inquiry. In some respects, they represent the extremes of scientific practice. On one hand, working with evidence can be quite conservative. Careful analysis, patterning, and interpreting evidence is the bedrock of valid science. On the other, uninhibited exploration of ideas, phenomenon, and methods pushes science into new terrain, generates new hunches, and casts doubt on (sometimes) well-established theory.

I now turn to the evidence to examine where and how these aspects of inquiry were evident first at t_1 and then at t_2.

A Smattering of Inquiry at Time One (t_1)

For each teacher participant, the t_1 data were drawn from across the data, including an extensive introductory interview, three classroom observations, teacher logs of professional development, one "check-in" interview, and the t_1 subject matter knowledge interview. In total, sixteen classroom observations, eighteen introductory and check-in interviews, and six subject matter knowledge interviews informed this analysis.

At t_1, evidence of inquiry in teachers' practice was quite limited. This was true across both categories (working with evidence and exploration), with the exception of evidence as illustration, the lowest sub-category of working with evidence. Here I describe the evidence across categories and participants. Given the sparseness of evidence (with a few noted exceptions), my analysis describes the data exhaustively. In addition, I describe "near misses." That is, I describe instances that *nearly* suit the category (but were close enough to comment on given the study's broader interest in looking at change over time) as well.

Working with Evidence

Evidence as illustration. There were nine instances of evidence as illustration, far more than any other component of the inquiry framework.

Recall Joaquin's lesson on friction and traction forces from Spring semester 2003 (described in chapter four). Joaquin planned a lesson that would help students understand that traction and friction are forces that allow for vehicles to move and stop. Joaquin started the lesson by placing a transparency with two photographs from the textbook on the overhead projector. One photo depicted a boy sitting in the backseat of a car with his seatbelt on, holding a glass of water. The car appeared to be moving forward down the road, the boy sitting comfortably at ease. The second photo depicted the same car, boy, and glass of water but was taken after the car had come to a sudden stop. It showed the boy's body jutting forward, his chest pressed against the now tense seatbelt, and the water spilling over the front of the glass. Joaquin led students in a 10-minute description and analysis of these photos.

"Who can tell me what the forces are in this picture?" To this prompt Joaquin's ninth graders offered a variety of answers that were consistently off the mark: "There's the engine" "Gasoline?" "The car is moving!" Joaquin followed up by reminding them that they had talked about forces the previous week and reiterated his question: "What are the forces at play?" Again he was unsuccessful. Joaquin then took another tack, asking the students to simply describe what was happening. One young man noted that "there is a car that is driving and then, in the other picture, it stops." Joaquin asked another student to expand on what the first student observed. When students hesitated to participate, Joaquin reminded them: "I just want you to describe what you see. That's all. They said the car was moving and it stopped. And they said that in the second picture the boy was put forward against his seatbelt. What else can you describe?" With this, Nancy, responded reluctantly, "You can see that the water is spilling."

Soon the class reached a description of the car, the water, and the boy. At this point, Joaquin introduced the concepts of traction and friction, asking students to open their books and directing them to the page in the forces and motion chapter where the photos appeared, below which the two vocabulary words—traction and friction (in bold font)—were defined. Joaquin asked students to read the definitions. After reading the textbook definitions, Joaquin offered his interpretation:

> Traction is the force that makes the car go forward when the wheels turn against the ground and push the car ahead. Friction is the force that works against it. It makes the car want to stop—it slows it down. (April 2003)

Across cases, anything that resembled inquiry in the new teachers' lessons generally took the form of single illustrative examples. Susan used the example of an airplane crashing through a forest to illustrate that objects tend to stay in motion unless acted on by an external force. Andrea had students observe the behavior of the moon to illustrate that its appearance changes in predictable ways. Avner noted that water waves could be observed as evidence of energy in motion. In none of these instances did teachers talk about additional examples, lead students through alternatives or counterexamples. Thus, they typically came up short of the more sophisticated notions of working with evidence.

There were also a few instances in which evidence was portrayed as even less than illustrative.

I observed Andrea's "Rainbow Chemistry" lab in April 2003, the third in a series of four lab sessions. Working with pre-mixed water and food color solutions, and following a sequence of prescribed steps, students would mix certain quantities of each color into a series of six test tubes. Students who followed directions and mixed the proper measures of each solution would be surprised when a rainbow of colors resulted across the tubes.

During the three class periods preceding it, Andrea taught lab vocabulary (beaker, test tube, meniscus, milliliter), and safe use of lab equipment, and careful liquid volume measurement. I observed a "dry run" in which the students followed the procedure for the lab using water, but not colored water. Andrea explained that this would avoid a chaotic and messy experience and better prepare students for the "real" lab. Andrea's lesson goals were: "following the procedures, measuring accurately, making sure they aren't leaking and spilling the stuff—and accurate measurement is the key thing" (April 2003).

The lesson itself was an exercise in how to collect evidence, but there was no explanatory goal in mind. At no point did the wet lab become a place to explore, validate, or question theoretical knowledge. Nor was there any sense that this was somehow preparatory for future labs in which there would be a substantive question to explore. The lab activity was more akin to an elaborate visual aide for understanding processes, points of safety, and vocabulary. The classroom interactions reflected this theory-free view of science, as Andrea led students through a careful step-by-step process of conducting the lab, but made no reference to substantive ideas. The following excerpt illustrates:

Andrea: Paulo, read number two for me.

S: [Reading] Using a black permanent pen, label six test tubes in order: A, B, C, D, E, F.

Andrea: [holding a black pen above her head in front of the projection screen] Ok, this is a black pen. On your test tube you're going to write A... through F. So you can see it. Write it big, so you can see which test tube to pick: A, B, C, D, E, and F. That's easy enough! Ok, all your test tubes are going to get labeled. All right, so we'll put a label on it. Then, (aside: Mauboro, can you get some water?) Fong Yun, can you hand me *that big t-a-l-l grad—u—ated cylinder*, the plastic one? Thank you. All right, you're going to have a beaker full of water and a *grad—u--ated cylinder* [holding up the cylinder]. Ok? So, number three, Hugo, read number three [She points to number three on the overhead projector].

S: [reading] Using your dropper, measure eight ml of water into test tube B.

Andrea: Okay, they are already filled out for you. [Students complete the tasks as Andrea introduces them and has Paolo read the steps out loud. As she and students complete the third of 12 steps, she marks a large "X" next to each of the first three steps on the overhead. Several students mark their papers in a similar fashion.]

Andrea: Okay, number four, Brenda, number four, please read.

S: [reading] Using your dropper (student struggles to pronounce "dropper").

Andrea: (to student) Your *drop-per*, right? This one? [holds up the medicine dropper] Yeah? Your *drop-per*?

S: Yes. Measure eight mm-mm… (student struggles to pronounce "milliliters").

Andrea: Milliliters . . .

S: . . . of water in your graduated cylinders.

Andrea: Okay, so I have to count on the bottom [holds up cylinder and points to lines as if counting up to eight from the bottom]. And yesterday, remember how we already talked about how to accurately measure. [Andrea draws a beaker on the overhead] If we need eight *milliliters*—let's say this is eight right here [adding a line to the beaker drawing on the overhead]. If I fill my water up like this (top of line at eight), is that eight?

The dialogue in Andrea's class was devoted to developing vocabulary, following processes, reading and following steps in the lab. It is true that teaching science can require helping students measure accurately, and even the most obvious and mundane task can take on new meaning when trying to coordinate the efforts of a roomful of adolescents. Further, in urban settings where many students struggle with issues of language, it makes sense that her teaching would focus on vocabulary. Andrea did what teachers need to do; she carefully prepared students for the methodical aspects of doing laboratory work and taught them the language of that work along the way. But as is often the case, she and her class never examined the intentions of lab work. Andrea never seemed to ask herself questions like: What might the experiment allow students to explore? Why might careful measurement matter? What would the experiment allow them to see, answer, puzzle about, explore? In this sense, the lesson conveyed a notion of evidence that was confusing. While evidence is accumulated in order to answer a question, there was no sense in this lesson that evidence collection served a goal of informing a question. It was evidence collection for the sake of evidence collection. The dissonance in this practice—collecting evidence toward no particular end—did not arise for Andrea at t_1.

Patterning evidence. Patterning evidence is the second level of working with evidence. Scientists must not merely illustrate their ideas with their favorite examples, choosing those that most handily support their beliefs. While this may be helpful pedagogical practice, it falls short of scientific practice. Scientists seek evidence in a wide range of situations and conduct comprehensive analyses in order to discern the validity of a given hypothesis or theory. They search for disconfirming, as well as confirming evidence, and they do so in methodical ways.

I observed six instances of evidence patterning at t_1. Avner produced three of these. I saw Michelle and Geoff pattern evidence in two and one instances, respectively. In Spring 2003, Michelle taught a lesson on Newton's "equal and opposite forces" that included examples such as firing a gun and feeling its recoil; pushing one's arm against a wall, the wall pushing back; pushing against the ground to move on a skateboard and the ground pushing back; gently nudging a sleeping student in class and the student pushing back. Michelle linked each example back to the idea that every force is paired with an equal and opposite force. Similarly, in the same spring, when Geoff was teaching his students about chemical and physical changes, he asked them to locate 10 chemical and physical changes in their homes and to document these in a journal. As he described the assignment, he led the class in generating a series of changes that are permanent (chemical) and changes that are reversible (physical), including ice melting, mixing powder Kool-Aid with water, preparing toast, boiling water, baking a cake. As students generated examples, Geoff classified them—writing them in a chart on the overhead projector—as either chemical or physical changes.

Michelle used quantitative data to help students ascertain a pattern in a taste and smell laboratory. In order to examine the relationship between taste and smell, students noted predictions and results as they tasted candies under two conditions (nose plugged/ unplugged). In pairs, they tested their sensory accuracy in determining taste of a given lifesaver candy under each condition. Michelle intended to tabulate the evidence for student pairs conducting the same test. As students reported their findings, Michelle realized that their investigations were not producing the results she anticipated (students reported no higher rates of accuracy with their noses unplugged than with them plugged). Given the unexpected results, Michelle quickly abandoned the exercise.

Avner developed quantitative data patterns in at least three instances, each involving Fathom, a computer program designed to give students opportunities to collect and analyze quantitative data. Avner's mentor during his student teaching had introduced him to the Fathom developer in fall 2002; the developer then asked Avner to serve as a teacher consultant. The software allows for data collection using probes to generate data (e.g., for motion, heat; salinity or basicity of solutions). It also offers an array of graphing options, which are driven by a simple interface that, with a few clicks can generate several data graphs. Avner saw Fathom as a versatile instructional tool:

> It's a tool that you could actually use trying to fit data to curves and curves to data… to run a lab experiment on using different probes and everything and put data into the stats software and see the graph and you can put lines in and move the line around to see where the best fit is, get a residual plot. [You can do] all this great stuff! (October 2002)

Avner related his interest in Fathom to his own frustrations as a science student where using data entailed complicated calculations. The emphasis on calculation, in his mind, steered he and his student peers away from making sense of the evidence. He intended to focus on trends and patterns, enabling in his own students more sense making and less rote calculation:

> For me, it was just like we did a lot of laboratories in college and you had to go home and calculate these crazy percent errors. You have no clue what it is; you just looked at the formula. You always make some mistakes about something. You don't get a sense of what it means... But [Fathom] gives you like an instinct . . . you know . . . this is what it looks like . . . You don't have to average anything, you just look at it. I took three trials here and one point is close; we could see if they are up or down or whatever... it gives you a good (picture) of what the data actually look like. (October 2002)

Avner reported using this tool regularly and described three labs in which his students worked with Fathom data. For example, in one lesson, students timed cars as they coasted down a track to generate data for, and solve, rate problems. Probes on the cars and timing gates on the track generated data on velocity and acceleration. Avner then used Fathom to display this data in a range of graphs. I'll return to Avner's patterning practices below as they also bear on his knowledge of interpreting data.

Interpreting patterns. Interpreting evidence is the act of looking at a data—a series of observations or their coded representations in a table, chart, or graph—and extrapolating a pattern, and inferring meaning. Instances in which new teachers had their students interpret such patterns were few and far between, totaling just five instances. As with patterning evidence, if we exclude Avner, we are left with only three instances. I describe these first, then describe the instances from Avner's practice.

There was one instance in the t_1 data in which Susan asked students to interpret evidence. She talked with me about a lesson in which students were expected to interpret three graphs. These depicted objects that were accelerating, decelerating, and traveling at a steady rate of speed. She explained that straight lines meant the object observed traveled at a constant speed; curved lines meant it accelerated (positively or negatively). This was the sole instance of Susan working with multiple data points to illustrate an idea.

I observed one additional instance (other than Avner's) in Michelle's taste/smell lab, which I mentioned above. As Michelle began to tabulate students' taste observations on the overhead projector, she noticed unexpected patterns. She had hoped that students would notice that their observations would be less accurate when their noses were plugged, thus "demonstrating" that the sense of taste is indeed enhanced by the sense of smell. However, when the expected pattern failed to emerge, she quickly dropped the compilation of data. Rather, she simply foregrounded the evidence that corroborated the theory she hoped to illustrate with the experiment, that is, she pointed to instances in which students' guesses were more accurate when they used both their senses of smell and taste.

From this instance, we cannot tell whether Michelle did not understand the nature of scientific inquiry—that data are never "clean" or "pure," that there are always outliers and anomalies—or whether she abandoned the activity for pedagogical reasons, that is, it would take too much time to have students understand the anomalies as well as conclude that the trends in patterns corroborated the theory she wanted them to learn. Here I include Michelle's use of interpretation, flawed as it may be, is as it was one of very few instances that dealt with interpretation at all.

While most of the new teachers portrayed little to no sense of the interpretative aspects of science in their teaching, Avner was again the exception. Avner had students look for patterns in data on several occasions. Again, these were generally linked to his work with Fathom. For example, Avner described an instance in which he hoped to use the Fathom software to study plate tectonics and earthquakes. In this unit, he would use two inquiry activities. In one, he would have students model the large-scale phenomenon of tectonic plates by having them examine the fault lines on maps, evidenced by seismic activity. He had a data source on the location and magnitude of earthquakes that students could use to plot on a map and analyze. By having students consider where activity was greatest and noting how the activity was clustered, he would steer them to see where the edges of tectonic plates are joined. Analyzing the places where activity was greatest would outline the "ring of fire"—an arc stretching from New Zealand, along the eastern edge of Asia, north across the Aleutian Islands of Alaska, and south along the coast of North and South America, composed of over 75% of the world's active and dormant volcanoes. This was one of three similar instances in which Avner portrayed the interpretive aspects of science, asking students to interpret patterns.

Overall, the role of working with evidence (or, more accurately, the lack thereof) in the new teachers' classrooms was limited, and consistent with national patterns that characterize inquiry as an infrequent classroom event (Weiss et al., 2003). Thus, the fact that evidence played such a small role in novice science lessons should not be surprising. Avner's more sophisticated uses—developing patterns of evidence, teaching students to interpret these—are an exception to the norm.

Exploration

Exploration presumes a degree of uncertainty in science. That is, we explore in order to better understand an area that is poorly understood or where the prevailing knowledge is suspect. As previously noted, we can think of two classroom versions of exploration. One is the authentic version where real scientific disputes, current or historical, are the subject of student inquiry. In these instances, we might expect to see exploration at either an "early" phase of study (in which qualitative observations and tentative hypotheses might be voiced) or later analyses (for example, generating a number of ways to look at the data). Synthetic inquiry, on the other hand, involves long-resolved scientific disputes where scientific practices and dispositions—in this case, the sense that science is exploratory—are simulated.

Across cases, evidence of exploration (whether authentic or synthetic) was thin at t_1. There were three instances in which teachers portrayed science as exploratory and two additional instances in which science labs took an unanticipated exploratory turn. I describe each.

When exploration was evident in instruction, it occupied small pockets of time within a lesson or series of lessons, which were in principle *not* exploratory. Consider two examples in Michelle's teaching. In Michelle's taste/smell lab described previously, there was a hint of exploration, albeit of the manufactured variety that does not parallel real scientific work. From the outset, the lesson was designed to model an experiment in which the outcomes were uncertain. Would smell actually enhance taste? The answer was not self-evident to her students. At least in this small way, Michelle opened the door for exploration. However, beyond this open question, there was little additional evidence of exploration in this lesson. There was not discussion of students' entering or alternative ideas about smell and taste, nor did the class explore alternative notions of the relationship between smell and taste (e.g., Could they be one in the same? How might that be explored?). Nor did the class discussion touch on why students might conduct a quasi-experimental study on to explore the smell-taste relationship in the first place. And as previously mentioned, when their analysis produced unexpected results, Michelle quickly dismissed the evidence and explained what students should have found. Nonetheless, it was a modest attempt at engaging students in exploratory work.

Exploration also began to emerge in a pocket of Michelle's daily practice of asking a "question of the day." Throughout her first year, Michelle wrote "questions of the day" on the overhead at the beginning of every class. Initially, they were designed to introduce the day's topic and allow Michelle time to take roll, following the logic of the district training where she first learned about this practice. When I observed in October 2003, the question was, "What is your favorite food?" prior to the lesson on taste buds. In a January observation during a unit on heredity she asked, "What are the four nitrogen bases of DNA?" Students wrote answers to the questions and passed them forward for Michelle to read out loud.

Over time, these questions shifted steadily from recall questions to questions of higher cognitive level that invite observation and exploration. In April, Michelle asked her physics students to think about and answer the question, "When have you accelerated today?" In May, she asked, "If you went to the moon with a scale and you weighed yourself there, why would you weigh less than you do on the earth?"

These questions ask learners to consider the content in a personal manner: students reflect on their own movements from a Newtonian perspective; they pose predictions of an actual event they would observe. The questions are also exploratory in that answers are not immediately available or self-evident. Michelle's purpose in asking the question also changed. While initial efforts were intended to keep students busy and to move them quickly into the subject at hand, later questions were also used to gauge what students were thinking about the phenomena they were exploring.

> I've done it with Physics where I ask, "What do you think a force is?" Just trying to get them thinking . . . Or, "When have you accelerated today?" Some of them just talk about going fast and you can see that they just don't know that it's a change. It's like, "You guys are sitting here at zero velocity now, as soon as you get up, you are accelerating." (May 2003)

The questions brought students' unpolished, entering ideas into the discussion prior to assertions of authoritative knowledge. Again, this is not a version of exploration that is "authentically" scientific. It is not situated in a real, on-going scientific dispute either contemporary or historical. But the synthetic version of exploration—in which students take a stab at explaining an idea without authoritative "answers" and based on their naïve assumptions or intuitions—is nonetheless worth noting.

There was a similar hint of exploration in Joaquin's lesson on traction and friction, described previously. This lesson contained a short discussion that focused on discerning the forces that were at play in a car's sudden deceleration. Joaquin asked the students to speculate about what was causing the car to stop. This invited a range of student answers that were not scientifically correct as students reasoned from their personal experiences driving, riding in cars, and seeing things on television. As unpredictable and scientifically misleading as individuals' experiences tend to be (e.g., Driver et al., 1985), they were welcomed into the analysis. In this pedagogical sense, the lesson was unpredictable and exploratory, much as authentic scientific inquiry can be.

In addition to these instances, there were two instances of "accidental" exploration. Both occurred in labs that were intended to be strictly confirmatory but which produced unexpected results. Unanticipated evidence, in even the most tightly scripted and narrow lab, can lead to exploration, not unlike the common experience for teachers of students asking a question to which they have no answer: "I don't know, let's find out" is a common invitation offered by teachers in such situations. In science class, such occasions might turn into scientific explorations. Students and teachers might ask, "What happened? How is it that we conducted the same lab procedure but ended up with results that conflict with one another (or with the predicted outcome)?" A validation-oriented lab can take an exploratory turn, as was the case in the taste-small lab and in Avner's treatment of pH level. What a teacher does on such occasions might help us understand how a teacher views the use of evidence in teaching. Is it something we need to look at carefully as it can contain gems that aren't readily apparent, or do data confirm what we knew all along?

Using a lab that is popular among many U. S. teachers, Avner and his students explored pH (acidity-basicity) of household chemicals using red cabbage juice as an indicator.[39] Students used a variety of household chemicals (red cabbage, vinegar, lemon juice, baking soda, detergent, ammonia, washing soda, club soda, 7-up, water, antacids, lye), to determine the pH of these solutions. In these and other common chemical solutions, basicity-acidity is not readily apparent and observable.[40] However, by mixing

[39] Water is both an acid and a base with equal concentrations of hydrogen ions and hydroxide ions. When the concentrations of those two ions are equal, a substance is called neutral. When there are more hydrogen ions than hydroxide ions, that substance is an acid. The opposite condition (more hydroxide ions) makes a material a base.

[40] Neutral solutions contain roughly equal parts acid and base. A common practical application of neutralization is seen when we take antacids. An upset stomach is often a symptom of abnormally high

solutions with known indicators, you can observe pH levels in resultant color changes. Red cabbage juice is such an indicator. It contains a chemical (anthocyanin), which changes color depending on the balance of hydrogen and hydroxide ions. In an acid solution (high concentration of hydrogen ions), cabbage juice turns red. In a base (high concentrations of hydroxide), cabbage juice turns blue, green, or yellow, depending of the strength and nature of the base. Avner had students mix quantities of the test solutions with a red cabbage solution to determine their pH level.

Following the initial tests that would allow students to see the predictive value of the pH indicator, Avner planned to have students neutralize their solutions. He asked them to mix certain quantities of acidic and basic solutions together. For their red acidic solutions, students added small quantities of basic solutions with the expectation that these solutions would neutralize. They were not able to produce the neutralized solutions:

> When they were trying to neutralize, it wouldn't really neutralize. And all this stuff would happen. And you know they are like, "Oh, you can never get the acid to go away!" And you are like, "Well, actually . . ." And you even show it to them and they are like, "Well, maybe you know how to make it go away, but I don't think you can!" They are just coming to the wrong conclusions! (January 2003)

In class, Avner treated these observations as student errors. He explained that, in fact, acid will neutralize, but that their solutions had been contaminated. Later, however, he conducted the analysis firsthand and had similar problems. In the end, Avner decided

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levels of acid in the stomach, for too much acid irritates the stomach lining. Antacids are basic and will bring the pH of the stomach contents toward a neutral level (pH 7).

that, in future classes, he would demonstrate this process rather than have students do the lab, since their analysis was too prone to error.

In this case, Avner's confirmatory lab presented ambiguous results. He could have treated this as an opportunity to explore these. He or his students could have generated ideas about what went wrong (e.g., human error in execution, a flawed lab procedure, flawed understanding of the reaction itself), and talked through those possibilities. Instead, Avner suggested that inconclusive evidence was to be ignored. In this, and other t_1 instances where exploration might have been embraced, the novice teachers instead pushed it aside.

While this instance suggests a view of evidence as something that confirms our ideas—not something we look at openly and critically—a "view of science" may not be what motivates Avner to gloss over the ambiguous results. There are good reasons why a teacher may ignore unexpected results in a lab and move on. For instance, one very real concern for most teachers is time. They generally have more science to teach than could reasonably be learned in an academic year (Anderson, 2004), so if labs do not help them teach what they feel they need to teach, they are smart to move along. Textbooks, curriculum guides, standards, colleagues, and teachers themselves all convey expectations for what needs to be taught and inquiry is sometimes an expectation, though it is not the only thing teachers teach.

Overall, we see limited evidence of inquiry at t_1. At the risk of oversimplifying the evidence, I summarize the prominence of each component of inquiry across cases (See Table 5.1). Evidence as illustration stands out as the most common component of inquiry. This is not be surprising, as it is also the most basic notion of working with evidence, and inquiry is more absent than present in U.S. science classrooms (Weiss et al., 2003).

We also see a good deal of variation. Avner stands out at the high end with patterns of working with evidence, for he introduced aspects of inquiry into his teaching much more often than the other teachers. Michelle and Geoff are also on the high end of the distribution. Meanwhile Andrea, Susan, and Joaquin showed low levels of inquiry in their teaching.

Table 5.1: Summary of Inquiry Views in Teaching (t_1)

Teacher/Practice	Avner	Andrea	Geoff	Joaquin	Michelle	Susan
Evidence as Illustration	X	X	x	X	X	x
Patterning Evidence	X		ₓ		x	
Interpreting Patterns	X		ₓ			ₓ
Exploration					ₓ	

X pattern of evidence x spotty evidence ₓ a singular instance __ (blank) no evidence at all

If inquiry is an integral part of science, then why so little emphasis on it in novice classrooms? Given the lack of opportunities to learn inquiry K-16 (NSF, 1996; Seymour & Hewitt, 1994; Weiss et al., 2003), it is no surprise that novice teachers would not portray science as inquiry in their classrooms. The teachers probably do not know much about inquiry themselves, not to mention the substantial organizational and social limitations that were also pressing on them.

Between t_1 and t_2, teachers spent four weeks in the TIP summer Institute where they worked extensively with science, and ways of teaching science that include notions of inquiry as evidence-based and interpretive and especially exploratory. The question then becomes: Did that experience correlate with changes in their teaching practice the following school year?

Making Way for Inquiry Time Two (t_2)

In search of changes in teaching inquiry, I listened as the new teachers critiqued current and previously taught lessons. I listened to them talk about their curriculum plans and aspirations for future units. I observed them teaching in the second year on the job. Thus, this analysis of change draws on one "check-in" interview, one classroom observation, the stimulated recall interview, and the second subject matter knowledge interview—fewer sources of data than were consulted at t_1.

Teachers' actions and thoughts indicated an uneven shift towards teaching inquiry. In particular, science as exploratory rose in prominence—to the exclusion of advances in using evidence. Where I saw teachers working with evidence at t_1, I saw more of the same at t_2. The standard use of single illustrative cases as evidence did not wane. Beyond that, Avner and Michelle continued to dabble in more sophisticated notions of data patterns. I saw Avner work with students on interpretation of evidence. However, both within and across cases, uses of evidence were neither more frequent, nor more sophisticated. Thus, the following discussion focuses exclusively on teaching science as exploratory, and area in which there was a change in the new teachers' practice.

There were 17 instances of exploration (compared to 3 at t_1). I saw exploration everywhere: in classroom observations, in teachers' reflections and instructional plans and aspirations, in their self-critiques, and in their impromptu musings about scientific topics and their instructional goals.

Here I begin by with the notion of "making room for inquiry," and point to ways teachers pulled exploration into their teaching. In some instances, they sprinkled facets of exploration or appreciation of the beauty of science into their practice. In other instances, they pursued explorations aggressively and even supplanted other goals. I also examine two discrete categories of interest: an exploratory pedagogical approach that was evident across cases, and teachers' lessons on inquiry where "teaching science as exploratory" became an explicit instructional goal. Finally, I pull back to consider what these analyses suggest about the influence of the TIP on participants' teaching of science as and through inquiry.

Squeezing in Inquiry

At t_2, teachers made way for inquiry in their classrooms as they represented the exploratory view of science. In some cases, exploration debuted as a nuance or a short segment in a particular lesson. In others, it was an aspect of science to be experienced and taught. I briefly point to instances that illustrate ways in which exploration was framed as either a new, small nuance to teaching or a major shift in emphasis.

Andrea's critique and revision of her Rainbow Chemistry lab evidenced an exploratory "tweak." At t_1, students followed step-by-step directions to mix several colored solutions of varied solubility and mass (though these characteristics were not discussed) in test tubes. If students followed directions accurately, entering solutions in the proper order into the tubes, they would produce a rainbow effect across vials. Earlier I described the Rainbow Chemistry activity to point out sometimes "following procedures" can become the point of labs while motives for inquiry (including theory-testing) lie dormant. Scholars have often argued that students experience labs as non-explanatory, even when teachers intend them to be authentic (Schauble, Glaser, Duschl, Schulze, & John, 1995). In this case, the teacher herself failed to note an explanatory goal for labs. At t_2, Andrea proposed that students compare two solutions at a time to discern which was had greater mass, which would mix, and which would sort cleanly.

> Only one person got all six [of the rainbow colors in order]. They looked at their [results] and they could see at what point they got mixed up…I think if I were going to do it again, this time it would be, "Okay, that one and the next -- do they separate?" And then the next one: that one and the next, "Do they separate?" (October 2003)

The proposed revision comparing two solutions introduces exploration into Andrea's lesson, whereas the initial Rainbow Chemistry lab did not. Students in the revised lab would determine which solutions mix/do not mix with others, and which have greater mass and might sink to the bottom. Asking students to examine and discern non-obvious characteristics of the solutions was a step toward exploration.

We might think of Andrea's shift above as one towards a controlled exploratory view of inquiry. That is, she frames the problem as exploratory in the sense that she proposes a systematic way of analyzing the properties of solutions: examine one (liquid) solution at a time. This is a familiar approach that is essential to solving many scientific problems. Gregor Mendel, the father of genetics, for example, could not have established his theory of genetics without finding a way to separate the phenotypical (outwardly observable) and genotypical (genetic) characteristics of his pea plants. Much as Andrea determined a process for distinguishing qualities of one solution from those of another, Mendel found a way to isolate and describe the phenotype and genotype for individual specimens. In either case—Mendel's peas or Andrea's students' solutions—the "inquirer" is not certain what the qualities (genetic make up or buoyancy) will be for a given specimen. Thus, the need for consistent testing. In this sense, the activity is exploratory. However, in both cases, the process is controlled as the inquirer works within a framework designed to produce a discrete, serviceable answer to well-defined problem.

Other instances indicated wholesale shifts toward exploration which, unlike Andrea's "controlled" inquiry, is open-ended and may be less concerned with explaining the phenomena than with exploring it for its intrinsically interesting and aesthetic qualities. In these cases, shifts toward exploration supplanted or overshadowed illustration or definition of a given concept. In these instances, teachers focused closely on the raw aesthetics of the phenomenon. For example, Michelle explained that she felt it was important to promote explorations irrespective of promoting definitive substantive understanding:

> I think it's not necessary to get 100% on all the concepts. But [it is important] to also have a little bit of the "How does it do that?" type of thing. Because when we were going through the Exploratorium, looking at some of those optical illusions, and trying to figure out why we were seeing what we were seeing, *we* couldn't figure it out. (October 2003)

Michelle's reasoning here suggests that if even she, a physics education major and physics teacher, is unable to explain certain optics problems, student mastery of optics concepts may not always be relevant as a goal. This was not the only instance where Michelle expressed this sentiment.[41]

Michelle's re-analysis of the bent pencil task at t_2 also reflects a significant shift toward exploration, even at the expense of teaching concepts. At t_1 on the bent pencil task, Michelle noted that student response failed to characterize the phenomena and merely re-described the prompt inserting the term "refraction." She questioned whether this indicated understanding or merely the parroting of science vocabulary. At t_2, she was less concerned about evidence of conceptual understanding. She suggested that rather than correct the student or push him to expand on his answer, she would leave the student's answer unchallenged and introduce more perceptual puzzles that involve refraction and its illusory perceptual effects:

> I don't know if I would necessarily be so concerned about that response. He basically said the light bends when it hits the water and then refraction kind of goes around; that's the type of thing where now (it's acceptable). [I'd say] "Okay, light bends when it hits the water, refraction—good job." . . . And maybe even just make it a little more interesting now. If there were a lot of perception pictures, optical illusions, that I could just show them. (October 2003)

Michelle's shift here—backing off a laser-like focus on "facts" and broadening her goals to include enticing students to explore and appreciate natural phenomenon (and perhaps develop inquiring habits of mind)—reflects a clear, consistent emphasis of the TIP. The TIP (and the Exploratorium more broadly) science is more than a body of knowledge or a "cold," cognitive process. It is also an emotional and aesthetic

[41] Of course Michelle's apparent dichotomy of instructional goals – teaching "mastery" vs. "process"— is false. Substantial research suggests that these goals are best pursued in tandem (see e.g., Lehrer & Schauble, in press).

experience, knowing science involves doing science, being excited by science, and impassioned in one's pursuit of science. The Exploratorium itself, after all, is a museum of "science, art, and human perception" which depicts musical and visual art in exhibits and probes scientific evidence to answer questions like, "Why does music give me goosebumps?"[42]

Across components of the TIP, but especially during the summer institute, staff members foregrounded the beauty and intrigue of scientific phenomenon in addition to describing scientific theories and theorizing. For example, during the physics workshop, in the context of a series of sessions on light and perception, Peter explained to teachers how it is the layers of semi-translucent silicate give pearls their beauty: the more layers of silicate, the greater the perception of depth in the pearl, and the greater the market value. During a middle school physical science workshop, teachers explored the sound qualities of harmonious and dissonant pitches with a range of musical instruments and exhibits. For example, they used the *Circular Scales* exhibit, a short one-octave keyboard that wraps around a disc to create a "continuous" octave. There teachers played the circular keyboard to explore pitches that were separated by a fifth (a pleasant sounding chord), those separated by a half-step (an unsettlingly, unpleasant, or unstable sound), and discussed the emotional impact of major and minor chords. The next day, the same teachers visited the sound column exhibit, a 60-foot-high room and striking keys to play a chord that resonates throughout the chamber and discussed the "full-body" sound sensation of these harmonious vibrations. Though all of these experiences could potentially illuminate a range of scientific concepts, or processes of inquiry, these and others were clearly focused on the aesthetic aspects of the phenomenon.

[42] See http://www.exploratorium.edu/music/questions/goosebumps.html.

"Doing it Qualitatively First"

Recall Schwab's (1978) notion that the disciplines have "primitive" origins. Schwab asserts, echoing Dewey, that the disciplines were originally derived from the "primitive" daily experience of man. This evokes images of Newton's apple or Mendel tinkering in the monastery's pea gardens. The primitive view suggests that these future giants and their world-changing ideas started as informal experiences that evoked informal theorizing. The pedagogical implication of the "primitive" principle is that daily experiences and observations may serve as a model for learning science. This notion is abundantly evident in the Exploratorium. It was also the strongest theme in the t_2 inquiry data, and was evident across teachers.

"Doing it qualitatively first" was Avner's language. By this he meant that, rather than introduce students to topics through the technical language of the discipline, he would give students opportunities to generate hunches and that these would serve as starting points, later bridged to scientific understanding. Avner was particularly fond of this idea. It was evident in his talk and teaching, and his critique of his own earlier lessons.

For instance, in Fall 2003, Avner introduced speed by asking students to "play" with ramps and balls and to generate thoughts about factors that influenced speed:

> I did this with the physics kids this morning doing ramps. At the end of the week they'll have to measure the speed. Like how much time, what the distance is, things like that. Well that's great, but one of the things is that you do it qualitatively first. And the first thing to do is you give them the stuff and let them play. And that's what I did today. I just wrote down some ideas on the

whiteboard. And they just brainstormed on the board. Of course they all observed the same thing: the steeper it is the faster it goes, things like that—but they were just playing with it. I didn't say do this–lab blah, blah, blah. (September 2003)

Later on the same day, I saw him introduce a unit on size, scale, and structure, which I described in chapter four. In this lesson, Avner had students generate their ideas about what "scale" meant as they perused photos ranging in scale of light years (galaxies) down to subatomic units. His goal was that students would put their initial ideas on the table, add to their base of observations, after which they would revisit -- and perhaps revise -- their initial thoughts.

Avner also drew on this notion in his critique of lessons he had taught in Fall 2002, during the stimulated recall interview. We observed a class on eclipses in which he had students conduct a simulation of an eclipse. A light bulb was the "sun" and a quarter was the "moon." Students held the quarter in front of one eye to block parts of bulb's light. When he reviewed this lesson at t_2, Avner was frustrated with the fact that few students were able to explain how the eclipse worked. He suggested that were he to do it again, he would begin with students' ideas. He would provide students with a common representation of an eclipse and then ask them to generate their own ideas about how an eclipse might work:

I would leave it more open ended at the beginning—maybe just see what they think. So "What causes an eclipse? What happens during an eclipse? If you've never seen an eclipse, this is what it's like. Here are some pictures from the internet of an eclipse going by; what do you think could cause that?" Then they could try and come up with their group's theory of what was going on and try to prove it building a model. And then if it works, are there other things that we could take into account? Not necessarily the teacher coming up with, "Here's what we're going to do and this is exactly how it's going to go." But more like, "What do we know and what can we prove? And what can we theorize?" (October 2003)

In sum, Avner's practice was thick with the notion of "doing it qualitatively first." In fact, among participants, Avner used it most frequently and in a range of ways. But other teachers also began using similar activities in their teaching at t_2 as well.

Recall that there was some evidence that Michelle was introducing exploration into the curriculum at t_1 when she asked students to think about when they had accelerated that day. The next spring in the same unit, Michelle's question of the day dealt with a pulley system she placed in front of the classroom. Two masses hung from the respective ends of a balanced pulley system. She asked, "If I cut one mass what would happen?" Students looked on and speculated about what would fall down, what wouldn't, and why.

Though evident across cases, some teachers used "doing it qualitatively first" in more sophisticated ways and more regularly. Both Avner and Michelle, for example, taught exploration in many different ways across many different contexts. As noted above, at t_2, the teachers were still using illustrative examples as forms of evidence as they had at t_1. At t_2, in addition, teachers used exploration in teaching more frequently.

The notion that science can be pursued qualitatively is fundamental to the TIP. Though the mantra "do it qualitatively first" was one I first heard from Avner, the practice was already quite familiar to me, having spent time around the TIP. TIP instructors provide teacher learners with numerous "cheap" demonstration materials with this purpose in mind. They want teachers to help students experience and/or observe scientific phenomenon first hand. Indeed, it is part of the TIP messages that it is only after first hand experience that teachers provide explanations or lead students to authoritative answers. They teach participants how to make musical instruments out of straws and sections of PVC tube; how to split and bend light using lenses prisms; how to build electromagnets and motors with copper wire and paperclips; how to harness the compressed air in a 2-liter bottle to launch rockets. They also worked with teachers in their schools and classrooms to show them lessons that would introduce students to science concepts in an informal, qualitative fashion. Andrea's mentor Rhonda showed her how to "shrink wrap" students using a powerful vacuum and large plastic bags as the introduction to the notion that air takes up space. The students' qualitative experience of having the bag "sucked onto" their skin was intended to elicit or prime their thinking for later discussion of the air the vacuum removed and the space the air occupied before being removed.

Teaching About Inquiry

Another place where an exploratory view of inquiry crept into instruction at t_2 was in lessons designed to explicitly teach students about science, the nature of science, or the scientific method. At t_2, three teachers (Avner, Michelle, Susan) taught lessons that were themselves *about* inquiry. These were not just lessons that implied a "sense" of scientific inquiry in the activities students engaged in or the stories of scientists' endeavors, they were lessons in which teachers' primary instructional goal itself was for students to understand the inquiry process. There were five such instances, all of which presented an exploratory view of inquiry.

For example, Michelle taught scientific method during the first week of class in Fall 2003, using a contraption she built at the Teacher Institute that she referred to as the "mystery box."[43] She used the mystery box to elicit student thinking about what science is and how it works. The mystery machine is a wooden box containing a series of hoses and a cistern. The box's "mystery" is that when water is poured into the top of the box, pink liquid comes out of the bottom. Michelle used this box in the first unit to stimulate students' thinking about science as exploratory. As she explained:

> Yes, the mystery box had a siphon inside it, so I'd pour water and a bunch of pink liquid would come out. The students had me do all these experiments, like "pour all that pink water back in!" It took the entire bottle for all of it to come back out. I poured clear [water] in—almost a liter and a half—and then it just all came out. Once the water went a little bit above a certain level, the siphon kicked in and pumped it back out. They were wondering what the heck was going on. I had them draw a diagram and they had no idea. (November 2003)

Susan, like Michelle, presented the scientific method in a new, exploratory light in Fall 2003. She used an activity she called "ice balloons," in which students asked questions about frozen water balloons, and the effects of common household items like table salt and vinegar on the ice balloons. This is an open-ended science activity in which students are asked to generate and answer questions about how to change the ice balloon (e.g., how do you get food color inside of it? How can you make it melt fast?) or to

[43] This is a well-known science teaching activity. See Carpenter and Romberg (2005).

explore the effects of household chemicals on the frozen balloon, or the hunk of ice inside of it (e.g., What happens if we put salt on it?).[44]

As Susan explained:

> We did ice balloons where you are developing questioning skills. You give them ice balloons and they come up with different tests that they want to run… You give them different things like salt, food coloring, lasers. Their question would be like, "What would salt do to the ice balloon?" (October 2003)

In two additional instances, Michelle and Avner both reported teaching the same lesson reflecting an exploratory view of science. In this lesson, which Michelle and Avner heard about from a fellow the TIP participant during the summer Institute, the teacher passes out peanuts in their shells to students, asking them to describe a particular peanut carefully. Then the peanut was mixed in with a bag of nuts and students—using the description they made—were to find their peanut. Both teachers hoped that this exercise would help students learn the value of careful observation in science. This simulation of scientific observation also has an exploratory feel. Learning to make the familiar strange, and describing a peanut in ways more detailed than we would be "naturally" inclined to do, this activity was intended to push students to think like scientists.

Without exception, where teachers taught about inquiry, they used materials and ideas acquired through the TIP. Susan's "ice balloons," and Michelle's mystery box were lessons teachers reported learning about or doing at the Teacher Institute. Avner and

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[44] This activity is featured on the Exploratorium Teacher Institute webpage at http://www.exploratorium.edu/IFI/activities/iceballoons/iceballoons.html.

Michelle learned about the peanut observation activity from a peer who made a brief presentation about it in a session of the Teacher Institute Physics section.

Conclusion

Science takes on a different face at t_2—as exploratory, personally accessible, qualitative, and rooted in familiar experience. These characteristics emerge in teachers' instructional portrayals of science across cases. And the thumbprint of TIP is all over these instances.

This analysis, unlike that of PCK in chapter four, indicates universal change across all five teachers. Participants who at t_1 portrayed very little inquiry in their teaching, moved toward an inquiry view. So did those who entered with a stronger predilection. However, like the analysis of PCK in chapter four, the degree of change was uneven. Those who entered with stronger inquiry leanings also realized greater inquiry gains. Avner and Michelle were the strongest at t_1 and both shifted substantially at t_2. They created room for inquiry through exploration, used the notion of "doing it qualitatively first" in their teaching frequently, and taught lessons about inquiry depicting science as exploratory in nature. Change in other cases was less decisive. Andrea and Susan presented hints of an exploration view. Both talked about pushing content back a bit to create space for inquiry and students' experiences with science. Andrea tweaked the Rainbow Chemistry lab. Susan taught students that science was about questioning. The evidence does not indicate a wholesale shift by any means. These teachers seem to be moving toward a view of classroom science as exploratory, but they are not sold or "done."

One final observation has to do with how and where we look for change in teachers' thinking about subject matter. At the conclusion of chapter four, I proposed that one way to explain variations in learning to point to teachers' entering knowledge: those who learn more had more knowledge to start with. Here I'll pose another possibility. It might be that these teachers simply manifest their learning in ways that make it easier to observe: taking activities or concepts from the TIP and importing them wholesale into their own practice. But wholesale enactment of TIP activities is not the only measure of impact. If could be that teachers—especially those with limited personal resources—learn smaller-grained ideas and practices. A question here, a student idea there—little bits of change may be monumental for novices. Similarly, change may not crop up in classroom teaching at all, even when teachers know new things. Andrea's "tweaking" Rainbow Chemistry was based on her reflection about teaching it the first time. Her new take may not show up in her actual teaching right away, but it is an important shift that we miss if we don't look carefully and ask good questions.

Chapter Six

Crafting a Pedagogy that Taps Into Eros

> First, each query or discussion must serve as an efficient means to arrive at a specific, intended understanding of some specified object of knowledge... Second, each query or discussion must function as an instance of movement toward understanding. It must represent that kind of attack upon the problem at hand, which would be found appropriate and proper, by a master of that field... Third, each query or discussion must function as a stimulus to the student to try the activity in question, the activity that can eventuate in the immediate understanding sought. (Schwab, 1978, p. 126)

Schwab argues that there are three interrelated aspects the teacher should keep in view as she presents her discipline to students. First, Schwab asserts students must learn content. Second, he argues that students must learn about the discipline's "syntax" or norms of intellectual practice should be fairly portrayed: students need some familiarity with the origins of knowledge. Thus far in my analysis, I have focused on what the new teachers learned about teaching content (chapter four) and inquiry (chapter five).

The third aspect—what Schwab refers to above as "stimulus to the student" and later as "Eros"—is the subject of the final analysis in this study. Eros, the drive to do and learn in the discipline, in Schwab's view is an essential component of an educative discussion, and by extension—I assert—of good teaching generally. In this chapter, I explore teachers' uses of Eros in instruction. First, I explore the concept of Eros and explain how it can be observed in science teaching. Second, I explain how I defined and operationalized Eros in this study. Third, following the pattern of analyses set in the previous chapters, I examine teachers' uses of Eros in teaching at t_1 and t_2.

Eros and Teaching

Schwab argued that central to all liberal learning was students' "Eros," their natural interests and enthusiasms that can—he would argue, should—be harnessed in schooling, much as they are in other endeavors: "Eros, the energy of wanting is as much the energy source in the pursuit of truth as it is in the motion toward pleasure, friendship, fame, or power" (p. 109).

Schwab's suggestion that motivation is an important consideration in teaching is not surprising, as all teachers struggle with motivating students, irrespective of subject matter and across levels of formal schooling. Scholars and educators approach this issue of motivation, or wanting, in varied ways.

Sometimes efforts to motivate students result in accessorizing the curriculum, adding "bells and whistles" or "fun" activities to make the bitter pill of curriculum go down more smoothly. They may see activities as motivating and believe that when kids engage in these activities they flourish (Mastropieri, Scruggs, Mantizcopoulos, Sturgeon, Goodwin, & Chung, 1998). Activities proponents draw on a "child as scientist" metaphor, emphasizing children's innate curiosity and theory-building capacity (Gopnik, 1996). Science instruction that embraces this perspective keeps students busy in processes and practices of science: measuring, observing, graphing, hypothesizing, drawing conclusions. Not all activities-based science approaches (nor their supporters) suggest that activities produce more knowledgeable students, but they will suggest that activities increase student motivation to learn (Jarvis & Pell, 2004).[45]

But Schwab makes a very different argument. He places Eros at the center of instruction, pointing to the interdependency of ideas, thinking, and interest. Students' Eros is not apart from the curriculum, but part and parcel of it. For, in Schwab's (1978) view, a curriculum is successful only if it results in "*actively* intelligent people" or those who:

> *like* good pictures, good books, good music, good movies. They *find pleasure* in planning their active lives and carrying out the planned action. They hanker to make, to create, whether the object is knowledge mastered, art appreciated, or actions patterned and directed. (p. 109)

Of course, these are not new ideas, for Dewey (1902), in his classic *The Child and the Curriculum* argues that the substance of the disciplines can be located in the willful experiences of the child. He conjoins concerns about the child's natural propensities and the subject matter, rejecting the idea that one or the other should be treated in isolation. Rather, he suggests we should view each from the vantage point of the other, viewing subject matters as "outgrowths of forces operating in the child's life" (p. 189). And in the child's experience, we should see the subject matter or, as Dewey puts it:

> [The child's] experience already contains within itself elements—facts and truths—of just the same sort as those entering into the formulated study; and, what is of more importance, of how it contains within itself the attitudes, the

[45] And some educators arrive at an activities position through misinterpretation of constructivist-informed pedagogies. This misinterpretation has a long history in education. For example, Dewey wrote *Experience and Education* (1938) in response to sympathetic misinterpretations of his earlier ideas (e.g. *School and Society* or *Child and Curriculum*). See Ravitch (2000) for an analysis of these wrong-headed, if well-intentioned, transformations of progressive ideas.

motives, and the interests which have operated in developing and organizing the subject-matter. (p. 189)

Schwab and Dewey, then, argue for a conception of curriculum that holds together Eros, scientific concepts, and inquiry. Consequently, learning to teach content includes learning content, learning how to present that knowledge to students, learning to understand science in all of its complexity (including inquiry aspects of science), and learning how to connect students to content.

Learning to engage students in the content is a core principle of Exploratorium-style instruction. The new teachers participating in the TIP were encouraged to think of ways to tap into the inherent intrigue of scientific phenomena, or the natural interests of their students, in crafting science instruction. In short, learning about science, and how to teach science at the Exploratorium was very much a matter of tapping into the teachers' Eros, as well as that of their students.

The chapter is based on my analysis of the data with an eye toward issues of Eros. In closely reading and re-reading the data, three Eros-related themes arose. Teachers spoke of connecting curriculum to students' non-academic interests, teaching with discrepant events, and situating the study of science in students' everyday experiences.

Once those themes were identified and defined, I went back to the data and located reasonably well-developed instructional representations. By this I mean instances in which teachers talked at length about a particular lesson in interviews, and in classroom observations accompanied by teachers' thorough descriptions of their intent and/or reflection on the lesson. Separating Eros from instruction is antithetical to Schwab and Dewey's conception of engaging students' interests, and thus in the analysis, I looked at instruction, locating Eros inside of it. After locating the instructional representations, I coded them for instances of Eros and analyzed these across time akin to the analyses in the preceding chapters.

Operationalizing Eros in Instruction

Before describing the framework I pause to introduce two views of science learning that inform it.

Conceptual Change

In conceptual change, students' experiences with scientific phenomenon in their day-to-day lives are thought to influence students' knowledge and thinking, often in undesirable ways. Students develop strong, but flawed theories of the often-deceptive natural world or "naïve ideas," "misconceptions," or "Aristotelian notions." Conceptual change instructional programs set about to air out these ideas, challenge them, and provide compelling alternatives that (hopefully) replace them (Strike & Posner, 1985).

A classic example of how experience can mislead the learner involves falling bodies and gravity. From a scientific perspective, gravity is anomalous in that it is an equal opportunity force: all objects at a given distance from the earth accelerate at an equal rate as they fall to the ground, independent of their mass. So a bowling ball and a feather suspended 40 feet above the ground—all other things being equal—will accelerate in equal measure, and will contact the ground at the same time. However, students' day-to-day experiences belie this. The student knows that if you drop a feather and bowling ball from your rooftop at the same time, the bowling ball will reach the ground first. All things in the real world, in fact, are not equal. The young student doesn't know about particle friction. He concludes that more massive objects accelerate faster.

In this case, the student's daily empirical observations of falling objects are further supported by observations of conventional "pushes" and "pulls" which observably vary in magnitude and in effect (e.g., If I kick a large, heavy ball and a small, light ball with equal force the second ball will travel further.). Thus, conceptual change suggests that students build quite reasonable models that lead to problematic understandings of the natural world. Only by directly confronting these ideas, conceptual change suggests, will students be able to move toward canonically correct notions, or at least add these to their current understandings (Duit & Treagust, 1998).

Participatory View

In contrast, some scholars take a participation view of science learning. They conceptualize student reasoning about everyday phenomenon as the basis of scientific thought (Penner, 2001) and continuous (Roseberry & Puttick, 1998). Thus, with reference to the falling bodies example above, this group might choose to highlight the evidence-based reasoning implicit in the analysis of falling bodies as scientific. While this reasoning may lead to a flawed substantive understanding of the world, they acknowledge the pattern seeking analytical work of our student in the above example. As Penner (2001) notes, these theorists dispute the claims of conceptual change:

> [T]raditional accounts of misconceptions overemphasize discrepancies between student and expert scientists. This overemphasis arises as a result of a research focus that has centered on the products of student learning while largely ignoring the learning process… learners' "misconceptions" are typically rooted in productive and effective knowledge that has proven useful in a wide range of situations.

> An alternative to the argument that students' intuitive knowledge needs to be replaced is to consider how learners use their current understanding as they try to make sense of the world... Such a focus leads to considering which aspects of everyday knowledge can potentially serve as the foundation for rigorous theoretical concepts. (p. 5)

With this background in hand I can now describe the analytic framework for Eros.

Teaching with Discrepant Events

Discrepant events give the learner pause, causing him to reconsider his basic sense of the world and how it works. They are the driving force in conceptual change theories of instruction (Fensham & Kass, 1988). Returning once again to the example of falling bodies, a teacher might organize instruction around a discrepant event to unseat or challenge students' naïve ideas. This requires several steps in instruction. First, she would elicit students' predictions in some way to help students become aware of their own views, which may to this point be unknown or tacit. Assuming students voice notions that are contrary to the scientific view, she would then try to disrupt their ideas with countervailing evidence. For instance, she could have students observe a feather and a 100-gram mass in a frictionless vacuum chamber. Without friction, the objects would reach the ground at the same time, posing a compelling, perhaps puzzling challenge to their entering notions. The dissonance between students' expectations—that massive objects fall faster than feathers—and the observation to the contrary, is unsettling and can push the learner in pursuit of a better theory (Kuhn & Pearsall, 2000).

The idea behind teaching with discrepant events is to create in students both (1) doubt about their explanations which don't account for the evidence; and (2) once this "softening" of students tried and true ideas is in place, to provide fruitful alternative explanations. I operationalize discrepant events as those instructional plans or events in which teachers intentionally juxtapose common observations of the physical world with others that are jarring and dissonant.

Teaching in Everyday Experience

Another instructional approach related to motivating students entails drawing on students' everyday experiences to frame science content. Students—like the rest of us—take in information about the natural world all the time. The sun rises, we watch our gardens flourish, and when are scared, say we stomp on the brakes to avoid an auto accident, we feel our necks jerk (and our hearts pound); all the while, we naturally develop "folk epistemologies" for the physical, biological, and social domains (Atran, 1998; Carey, 1985; Inagaki & Hatano, 2001). For example, Carey (1985) suggests that all children under most conditions—that is, whether they study science or not—develop a "folk biology" that includes a quasi-scientific notion of, for example, the life cycle. Children's everyday experiences provide them with sufficient "data" that they go about building scientific—or not so scientific—theories about the natural order.

Students' everyday experiences are fundamental to both conceptual change and participatory views of science learning and so framing science instruction in everyday experiences can be powerful instructional approach. In the conceptual change view, students' everyday experiences confound them. They repeatedly observe compelling empirical observations (e.g., the sun "rises") that ultimately lack important information and, consequently, students draw inaccurate conclusions. The conceptual change instructional response is to unseat or challenge these patterned everyday observations.

Meanwhile, in the participatory view, everyday experiences give rise to reasoning about the world. Though our reasoning drives us to inaccurate conclusions, proponents of the participatory view will argue, our reasoning (about empirical observation) itself is important, irrespective of the (temporary) conclusions—right or wrong—that we draw.

In this study, I operationalize everyday experiences as those contexts, experiences, and observations that we can reasonably assume are familiar to a particular group of students, if not all students. For example, we all live in a modern society in which automobiles, houses, and apartment buildings are familiar. We are all familiar with domestic pets and urban wildlife—cats, dogs, birds, rats. Similarly, we all do some things: we eat, bathe, wake up, walk about, sleep at night. These activities can serve as contexts in which to examine scientific notions.

Teaching to Nonacademic Student Interests

Schwab (1978) asks, "To what objects does the youthful Eros readily attach?" (p. 109), thus reminding us that students bring interests to school, to which they have already "attached" their drives to understand and act. Outside of school, students and teachers alike engage in a wide range of activities that, while not traditionally linked to school subjects, can provide important "hooks" for student interest in science. Some students and teachers are sports nuts who hound player data, others play video games, many love movies and popular music. Teachers can link legitimate study of the subject matter to nonacademic interests, and use these interest areas as contexts for pursuing scientific ideas and pulling students into science.

Nonacademic interests can include those topics that the teacher hears students talking about, sees them doing, suspects they'll find interesting; or they may include those things that teachers themselves find interesting and suspect that students may too. But importantly, for my purposes, these are things not traditionally linked to school subject matter but which teachers intentionally bring in to instruction. For example, Ernest Morrell (2004) talks about using the popular media to draw students into literacy. To get students to use and think about argument he may build on known examples from daytime television shows like *Judge Judy* or *Divorce Court*. In science, we can imagine that for the many students who listen to hip-hop music, the low-frequency bass lines from a popular song might be an enticing starting point for a lesson on sound waves. From the teacher's side, in chapter three, I have already described the many personal, nonacademic interests that mentors and TIP staff drew on in their work with TIP participants. Recall that Greta, the TIP staffer and surfing fanatic, organizes annual workshops on waves, in which she and teacher participants go surfing. Similarly, TIP Co-Director Peter, melds his own love for adventure travel and sport into instructional examples in TIP workshops, and does webcasts from distant lands (e.g., a webcast from the North Pole on global warming). Thus teachers' interest too may be evocative for learners, when they provide novel contexts in which to think about science.

Of course, not all well-intended efforts to tap student interest are on the mark. Schwab described the unfortunate tendency of teachers to make themselves the subjects of study.[46] We can imagine a biology teacher serving up fond reminiscences of his fieldwork and fun evenings around a campfire rather than using those personal stories to launch into a more systematic treatment of stream ecology. In other instances, teachers

[46] This is not to say that the authentic experiences of the teacher in the discipline are not important resources in instruction. In fact, Schwab suggests that the teacher provides an admirable model of mature knowledge and practice of the discipline. Further, he argues for the teacher's own grappling with legitimately difficult subjects in the classroom.

may bend too far in their efforts to engage student interests, making students' lives the subject of instruction. One can easily a lesson on low-frequency sound which starts out with popular hip hop track, devolving into chitchat about the hottest new artists and never getting to the science.

In the analysis that follows, I include only instructional representations in which actual science concepts or practices are depicted within, or linked to, non-academic interests of teachers, or (those they perceive in) students. Instances in which students and teachers talk informally about interests, or appear to use interests as window dressing for instruction are excluded.

Entering Assumptions about Tapping into Students' Eros: Analysis at Time One (t_1)

The data at t_1 come from across the entire data set and constitute 34 instructional representations from across six participants. Instructional representations are instances in which I have "thick" documentation of a teacher's instructional goal and how she acted to fulfill it in a classroom context or interview setting. This could mean instances in which teachers spoke about lessons they intended to teach or reflected on lessons taught. Thus, data are drawn from combined observations and teachers' descriptions of classroom actions, as they talked through their plans or reflected on lessons in the pre- and post-observation interviews.[47] Other data are drawn from discussions concerning the teaching of physical science in the subject matter interviews.[48]

[47] Or, in some cases, teachers conveyed their plans, reflections, and intentions in writing, or in the context of stimulated recall interviews.
[48] In some cases, teachers used this opportunity to describe *actual* teaching instances in their classrooms.

Casual references to potential representations, however, were not included in the summary of instructional representations. For example, consider Avner's passing reference to sketchy ideas for instructional representations of sound and pitch:

> I haven't done all that much on sound... the things I've done would probably have more to do with the xylophone problem; where it's like, different notes are produced at different levels of things; so you know guitar strings or air tubes and things like that. (March 2003)

This is an aside, not a well-articulated explanation of an instructional representation. Comments like this were not used in the analysis.[49]

Here I summarize the evidence for Eros at t_1. To summarize the findings, of the 34 instructional representations collected, ten included some reference to tapping into students' Eros. In the remaining 24 instances, there was no such evidence. Let us consider each form of instructional representation.

Teaching with Discrepant Events

There were two instances in which teachers used discrepant events in instruction at t_1. I observed both in the same unit in Avner's ninth grade physical science class in Spring 2003 and both followed the same process. Avner and his students were starting a unit on force and motion and this pair of labs would introduce students to the notion of

[49]Nor does the sample include instructional representations in exams, quizzes, or review sessions. While these distinct forms of instruction were commonly seen in novice classrooms and could inform the discussion of instructional representation in interesting ways, I chose not to include them. This decision reflects my interest in examining the influence of the TIP on teachers' instructional representations. As noted previously, the TIP places very little emphasis on assessment of any sort, and so while these assessments all carry with them implications for how science is represented, I chose not to review them here. Some might argue that to judge the effects of the TIP you should see how teacher present science more generally and then tease out the part that seems to be effected by the TIP. In this case I disagree. These are novice teachers and I feel that if I am to see any change it will be in places in their instruction that bear the most similarities to the TIP itself. While any intervention would hope to transfer and inform practice broadly, I felt my energies were best spent looking a near rather than distant transfer (Klahr, 2004).

mechanical advantage and tradeoffs. But a first order of business for Avner was to overturn the naïve idea that all simple machines somehow "make work easier." If nothing else, he hoped his students would come to understand that sometimes simple machines *may* make work easier (though there is always a tradeoff), but don't always. Levers and pulleys can also be used to redirect motion rather than to introduce ratios that make work "easier." To unseat their entering ideas, Avner planned to have students encounter and work their way through discrepant events.

To prime students for an event that would stir their thinking, Avner first had students predict whether two distinct pulley and two distinct lever set-ups would make lifting a mass easier. For example, the two different pulley systems were both set to lift a 200-gram mass, but one was a single pulley that provided no mechanical advantage, while the other was a compound pulley that did. The contrasting set-ups, he felt, would break students from the idea that all pulleys provide mechanical advantage. He developed a similar contrast with the lever set-ups.

Once the students committed to a prediction—and Avner anticipated that many would predict that all of the set-ups *would* make the job easier—they would conduct qualitative "tests of feel" to discern whether their perceptions were accurate. This, he reasoned, would cause students to rethink their entering ideas.

Teaching in Everyday Experience

Teachers framed science in everyday experiences in six instances. These included riding in a car, listening to music, and baking a cake and were observed in the practice of four teachers (Michelle, Avner, Geoff, Joaquin). This was the most frequent form of instructional representation in the Eros framework at t_1. I describe each instance here.[50]

Michelle (twice) and Joaquin both drew on the experience of riding in a car to illustrate different notions of force and motion Spring semester 2002. In chapter five, I described Joaquin's lesson on traction, which drew on students' initial experiences driving a car. This lesson resulted in a boisterous exchange between students who debated whether stomping on the gas pedal resulted in the passenger's body "flinging" backward or forward in response. Michelle's tenth grade physical science students looked on as she "drove" about the front of the room: walking with her arms in front of her as if clutching a steering wheel, she stopped and started abruptly, and bumped into her desk. Whipping her neck about, she "recoiled" to dramatize the effects of reactive forces. Students erupted in laughter, and volunteered their own experiences driving or riding in cars operated carelessly.

In the following lesson, Michelle extended the use of the car context in an activity involving "Alka-Seltzer cars." These were plastic film canisters, half-filled with water and "fueled" by the reaction of water with chunks of Alka-Seltzer which, when placed into the sealed canister, produce an explosion which opened the canister, sending canister and cap in opposite directions. Students varied the quantities of water and Alka-Seltzer. They made qualitative observations of equal and opposite forces, describing the distance between the canister and cap after each test run.

Recall also that Geoff and Avner both used everyday contexts in chemistry lessons. Geoff taught a lesson on physical chemical change in which students collected

[50] Some instances were described in depth in the previous chapters, so I make brief references to these, point to relevant features, and note where they were previously described. I follow this practice throughout the analyses.

examples of chemical and physical changes from around their homes (see chapter five). Students' homes provided examples that he assumed they would all be familiar with: cake batter turning into a solid cake, making ice cubes, and mixing Kool-Aid. Avner's lesson on pH-level also tested household solutions, such as lemon juice and soda (also described in chapter five). Avner also introduced students to the idea of sound waves by having students listen to amplified music. During the subject matter knowledge interview, he offered this example in response to Eraser Clap (task four) in which, he observed, the student response lacked a notion of how sound travels:

> I could set up two speakers to find the destructive interference places and the constructive interference places with the speakers. Like if you have the speakers and you line them up at certain points, they'll cancel each other out. And at that point you shouldn't be able to hear very much at all. And at other places, you know they'll add on to each other perfectly. (March 2003)

Assuming that all students will be familiar with listening to music through speaker systems, Avner intentionally incorporated this example into his teaching in efforts to engage students in the content.

Teaching to Non-Academic Interests

There were two instances in which teachers linked subject matter topics to perceived student non-academic interests. Both examples came from Michelle, and included using a roller coaster as the basis of a lesson on sound energy and drawing on examples of collisions in an N.F.L. playoff game to depict conservation of momentum.

Michelle worried that students did not understand that sound was a form of energy, and so she introduced a roller coaster analogy to help students envision what it means for energy to be transformed. To achieve this, she explained that she would:

> Start with the roller coaster and start at [the top of a hill] where it has all the gravitational potential energy. And then it transforms into kinetic energy. And then when the roller coaster is at the bottom of the hill brakes are applied, so maybe you hear a squeaking sound as it's coming to a stop. And then some of the energy is transformed into heat as well. I'd talk about the origin of the energy—it started with gravitational, then went into kinetic, then went into sound and heat. (March 2003)

In the other instance—teaching the conservation of momentum—Michelle presumed that her students were interested in N.F.L. football (after all, she knew that many of her students played for the school football team, were cheerleaders, or attended Friday night football games).[51] An N.F.L. fan herself, she prepared video clips of a playoff game between the local San Francisco 49ers and Michelle's "home" team, the New York Giants. She wanted students to understand that, when objects collide, sometimes they bounce off of one another and other times they travel in the same direction. In either case, momentum is conserved. Michelle used a videotape of football players colliding as evidence of the principles at hand. As she explained,

> I brought into class a clip of two different collisions form the 49er's-Giants playoff game.... I'm a Giants fan and they are 49er's fans, so there was some tension going on you know! We looked at two different kinds of collisions. In one

[51] We have no independent measures about whether this assumption was accurate. Given the popularity of football, it certainly seems reasonable.

the quarterback passed the ball and the guy caught it then someone came and tackled him, then both (the receiver and the defensive player) fell to the ground. They became tangled up with one another. That was an inelastic collision. Then another example is when they bounce off each other. I also had an example of that. When they get stuck together its inelastic and when they bounce off, its elastic. So in any case there is still this conservation of momentum. The momentum that the football player had in the beginning added to the momentum that the other football player is always going to be equal to their combined momentum after the collision. (January 2003)

As Table 6.1, indicates the evidence for Eros in the teachers' instructional representations at t_1 was thin.

Table 6.1: Evidence of Eros in Instruction (t_1)

Teacher/Practice	Avner	Andrea	Geoff	Joaquin	Michelle	Susan
Everyday Experience	X		x	x	X	
Non-Academic Interests					X	
Discrepant Events	X					

X pattern of evidence — X spotty evidence
x a singular instance — _ (blank) no evidence

Confounding Students and Playing on the Familiar:

Changes in Tapping Eros at Time Two (t_2)

The t_2 analysis draws on substantially less data than did t_1. The stimulated recall, check-in, and subject matter interviews, and fall 2003 classroom observations constituted

17 instructional representations, half of the 34 instances at t_1.[52] Again I combed every representation for evidence of Eros.

After getting some experience under their belts, including participating in the Exploratorium's summer Institute, I saw a notable shift toward teaching that was more attentive to tapping into students' interests or creating student interest. Whereas Eros popped up in just 10 of 34 (29%) instances at t_1, it was evident in 8 of 17 (47%) instances here. The evidence was uneven across the three themes of student interest, discrepant events, and everyday experiences. Student interests dropped out all together. Thus, in what follows, I focus exclusively on everyday experiences and discrepant events.

Teaching in Everyday Experience

There were substantially more instances in which the new teachers explicitly framed science in everyday experience at t_2. Forty one percent of science lessons used everyday experiences, more than doubling in proportion (17%) at t_1. The experiences ranged from looking in a mirror, to exploring the eye, to opening and closing one's eyes, and playing musical instruments. I observed instances in three cases: Michelle (four), Geoff (two), and Avner (one).

Michelle excitedly talked about her plans to dissect cows' eyes with her students, an activity done across the TIP summer Institute sessions. Though dissecting a cow's eye may not seem like an everyday experience at first glance, Michelle reasoned that working with a cow's eye would be quite familiar, as she put it, "I think students can relate a lot to

[52] This is due largely to the fact that an analysis of Eros was added to the conceptual framework of the study after the fact. A pattern arose in the data, and I had not structured data collection around getting information on Eros from all teachers at specific times. Future research would need to more systematically investigate the growth in new teachers' capacities and commitments to tapping into students' interests in meaningful and science-rich ways.

that--I mean they've got eyes!" (March 2003).[53] Further familiarizing this experience, students would "use" the cows' eyes, looking through the lens as she and her peers did in the summer Institute. She explained:

> We took out the (cow's) lens which was just really interesting and you even took the letters -- we wrote tiny little letters on the piece of paper and put the cow's eye lens right over it and it's like so much bigger. (March 2003)

Michelle compared the cow's eye dissection to activities she had used to teach about lenses. She was hopeful that the cow's eye experience could make analysis of light and rays meaningful to students, illustrating light through something real that students could hold in their hands.

> So even drawing ray diagrams—I mean I [had students] drawing ray diagrams and I hated it. I felt like it was totally pointless and it just didn't—you know "which way does the ray go?"— I just didn't think it mattered that much. Which way are you drawing the ray? Is it passing through the focal point? I mean it does matter and I will do that, but I think that (cow's eye) can be an application. (March 2003)

Both Michelle and Avner also described an activity in which students looked at their faces in the mirror to locate the real and virtual image on the face of a mirror. In the activity, based on their experience in the TIP physics summer Institute session, students look closely at their own face in the mirror while they walk toward the mirror looking down the line of a ruler from their eye to their image on the mirror. As they get closer to

[53] Dissection could also be thought of as a student interest, but I have confined that category to only those non-academic interests, so I do not include the cow's eye dissection there, but only in everyday experiences given Michelle's emphasis on the relevance to students' own vision.

the mirror and the ruler finally touches the mirror's surface, it is evident that the image actually exists behind the mirror.[54]

> Three people took a ruler and pointed it at where they saw their image and then they realized that it was behind the mirror. And then we went to a curved mirror and we saw that it was in front of the mirror. So, it was—that's the type of thing that I'm going to be able to do. I'm probably going to forget about a lot about [diagramming rays]—it's so much more applicable. (March 2003)

Michelle also proposed having students use illusion posters commonly found in shopping malls (those that you have to stare at in order to reveal a hidden image), again an activity she and her peers did in the physics Institute. These, she explained, would engage students in thinking about how light can and does trick them. She also proposed having students play tunes with handmade instruments in order to examine the length/pitch relationship of vibrating bodies, another activity she and peers did at the physics summer Institute.

Geoff generated two revised representations when he revisited his performance on the t_1 subject matter interviews. In both cases, he framed investigations in ways that he felt could help familiarize the experience for students. When he revisited the xylophone

[54] In short, the distinction between real and virtual images is between where an image appears to us (real), and where it would appear to exist if we backward mapped the lines of light that convey its location to us to the logical end (virtual), based on how we know light travels. Imagine a ball at a distance from a mirror in a lit room with several people looking on at the mirror (see below). They focus on the location of the ball on the surface of the mirror. As light bounces around the room off the ball in all directions, some light bounces from the surface of the mirror into the eyes of the observers, thus allowing observers to see the ball's image on the surface of the mirror. The diagram below simplifies this, illustrating only three rays that would intersect with the mirror and reflect into the eyes of the observers. The light enters the eyes of the observers having bounced (at an angle equal and opposite its angle of origin) off the mirror and intersected the eye. Yet, the mind of the observer imagines that this light has come at it in a straight-line path. By reconstructing this path (see the dotted lines below), it envisions the image in the virtual location. Yet, the "real" location of the image—the one we will default to in our day-to-day experiences—is the image on the surface of the mirror.

problem he proposed swapping the xylophone for plastic bottles filled with water and having students explore changes in pitch related to the water level.[55] As he explained,

> They sell bottled water now -- and [students] blow over the top of bottles to make sounds. So they are familiar with that. The bottle is what the kids handle everyday. I want to encourage them to go around making sounds with the bottles! (June 2003)

Geoff made a similar adjustment when he revisited Seeing the Tree (task one). Geoff, referring back to an activity he did with classmates in Math/Science Connections in the Teacher Institute, explained that he would teach students about color in white light, using prisms and gels to split and filter light into different colors. I noted that the task did not require description of how color worked, but only how the light helped the man see the tree. In response, he argued that color was a necessary part of teaching problem. Students see, and are familiar with color, though they are not familiar with light: "Why color? Well, because I think the students will not respond to just rays of light. They will respond with what they are familiar with—which is colors. They see colors of objects, they won't say, 'Oh the light shines on the tree is green'" (June 2003).

At t_1, Avner, in responding to Seeing the Tree (task one), noted the student diagram (Figure 6.1) failed to depict light reflecting. It showed light traveling from the sun to the tree and not back to the observer.

[55] The change here actually makes the problem more complex. While the length the vibrating key is not variable the "length" of the vibrating bottle varies with water level. This is further complicated by the fact that adding more water results in a higher pitch. Though the important element in the problem is the airshaft inside the bottle, which does get shorter as the pitch gets higher, you can imagine how this might be confusing.

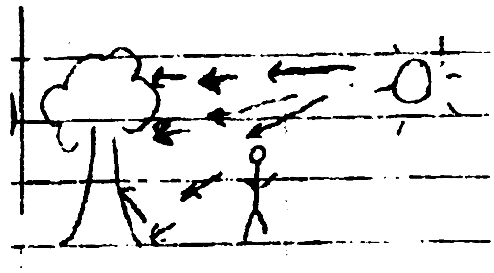

Figure 6.1: Diagram from Task One, Student Response Two

At t_2, when he revisited the task Avner concluded that the student failed to grasp the fact that in order to see objects we need light to bounce off of them and into our eyes. He suggested that one way to help students understand this is to have them simply open and close their eyes while thinking about the role of light in vision:

> "[I'd tell them] close your eyes. What do you see? Not much. That's because there's no light going in your eye and there needs to be light going into your eye." So if there has to be light going in your eye, how does it get from the sun and then into your eye? What path could it take? So just seeing that it's all coming in our eyes. (September 2003)

It is not surprising that the value of familiar settings was more salient to the new teachers after a year's participation in the TIP, for the TIP curriculum asks teachers themselves to work with observations of the world around them in new, scientific ways, and to think of ways to bring the outside world into their classrooms. In fact, most of the examples I have cited were instances in which teachers took the exact representations of ideas that they were introduced to in the TIP and used these in their own practice. The "seeing" through a cow's eye, shopping mall illusion posters, exploring real and virtual images by looking into a mirror: these were all representations that the teachers encountered in one or several sessions of the Summer Institute. In fact, the instructional moments that were richest in the use of everyday experience were ones that that new teachers took directly from materials they had been given through the TIP.

Teaching with Discrepant Events

There was one instance in which a teacher—Avner—used a discrepant event. (This is not surprising, since he was responsible for the two discrepant event instances at t_1). Recall Avner's reanalysis of Eraser Clap (task four), which I described in chapter four. This task prompts students to explain how sound travels across an empty room. Avner explained that this problem required students to understand several concepts that are not easily explained in the context of sound energy. He proposed stepping back from sound and having students examine water waves before building toward applying analysis of energy and waves to the specific context of waves.

Avner also framed this as a discrepant event. Discrepant events entail teachers eliciting students' ideas, and then confronting naïve ideas with compelling counter examples. In this instance, Avner explained that students often struggle to distinguish large-scale movement (say of a car or a baseball) from the small-scale movement of waves. Or as he put it, they enter with the naïve idea that when waves move "the actual water from way over there will end up way over here!" (September 2003). Avner explained that he would get the students' thinking "out" by asking them to describe what happens to an individual water molecule in a water wave. This would likely elicit the large-scale movement naïve notion.

Then, drawing from an activity he did in the summer Institute, he proposed a way to counter students' thinking. He would use an activity in which two students hold a rope: one holds one end steady and the other "whips" it. This would illustrate the peculiar small area motion of waves. As he explained, "We can do stuff with phone cords for instance, and wave those back and forth (demonstrating with hand, shaking one end up and down) and the other end you'll feel movement, but the whole phone cord isn't over by him or her" (September 2003).

Avner's treatment of waves, taken directly from the summer institute, was the sole full-blown discrepant event at t_2, but as I combed the data for confirming and disconfirming evidence, other—less obvious—elements arose. These are easier to see if we think about the components of a discrepant event, which include both a phenomena and a process. The phenomenon are sufficiently complex that they may lead to misconceptions. For example, waves or the seasons are examples. Students, based on patterned, but flawed observations, may think wave motion is more like the motion of an automobile than say a buzzer. Similarly, they may think that summer is hot because we are closer to the sun. These tricky phenomena are necessary if teachers are to use discrepant events in their teaching. In addition, the process of using a discrepant event is one of persuading students: luring them in by asking them to note familiar, unremarkable observations, and then surprising them by challenging the expected with the unexpected.

As I combed the data, even though I only found one occasion in which a new teacher had composed a discrepant event, there were other instances where new teachers were inserting pieces—complex phenomena or the disrupting/persuading process—into their instruction.

There were additional perplexing phenomena: Michelle's illusion served to surprise students that light could mislead them (described above). Avner and Michelle both talked about, and planned to emulate for their students, the "discovery" of real and virtual images they and peers made in the physics summer Institute (described above). These instances come up short of the discrepant event category, as they were not explicitly set up following the process of discrepant events, that is, they are not fully formed. But they maybe seen as less mature versions of this kind of instruction and could surely elicit the kind of puzzling and continued engagement intended by discrepant events.

The process side of discrepant event framing was also evident. Avner's lesson introducing the size, scale, and structure unit (described in chapter four) involved gathering students' thinking, giving them evidence that broadened or challenged their thinking, and bringing them back to those early naïve ideas. Michelle's "mystery machine" (described in chapter five) confounded students and drew them into thinking about science as puzzling enterprise, though it did not frame a particular concept about the natural world as discrepant events do.

Teaching science through discrepant events—especially the component of this approach which begins with a compelling or counter-intuitive phenomena—is common in the TIP. TIP staff dub these "provocaciones," Spanish for "provocations." The Spanish term differs slightly from the English and means to entice, or elicit interest. Provocaciones include things like getting a group of 3rd graders to commit to the idea that no single 3rd grader could lift a 180 pound teacher, then setting up a lever that would enable the child to do so. Ernesto described another provocacion during the summer institute. He told teachers about a favorite lesson on sound which he used with middle school students. He asked them if it was possible to make an aluminum rod suspended form the ceiling sound from across the classroom without touching it or striking it.

Ernesto explained that students come up with all kinds of ideas involving long robotic arms, and levers, but none which would sound the rod without striking it. After eliciting their interest in the problem, he would ask students to be silent, and standing far away from the rod, he would strike a tuning fork which—by vibrating particles at a frequency that resonated with the rod—set the rod vibrating without striking it.[56]

The proportion of instances of Eros-informed instruction at t_2 almost doubled and there is still some additional evidence—although sketchy—that the new teachers were taking small steps toward using discrepant events in there teaching as well.

Table 6.2: Summary of Evidence of Eros in Instruction (t_1 and t_2)

Teacher/Practice	Avner	Andrea	Geoff	Michelle	Susan
Everyday Experience	x/x		x/x	x/X	
Non-Academic Interests				X/X	
Discrepant Events	x/X			/x	

X pattern of evidence   x spotty evidence

x a singular instance   _ (blank) no evidence at all

Table 6.2 summarizes the evidence of each component of the Eros framework by teacher for t_1 and t_2. For each teacher, I have entered two marks separated by a slash to show roughly how their t_1 data compared to their t_2 data. At t_1, new teachers sporadically attempted to tap into students' Eros. Further, within the fairly thin evidence available it is clear again, that teachers enter their experience in content-rich induction in very different

[56] One could imagine that after establishing that pulsing air compression waves caused the vibration, a crafty teacher could revisit this initial challenge and ask whether he had actually vibrated the rod without striking it, or whether the moving air molecules had actually *struck* the rod.

places. In fact, recalling the analysis presented in chapter five, we see the usual suspects in the usual places: Avner and Michelle are on the high end of the distribution and Susan, Andrea, and Geoff are on the low end.

After the summer Institute and a year's worth of teaching, we see small gains for Avner, Michelle, and Geoff, but no gains for Susan or Andrea. Here again—as with PCK and inquiry, in the previous two chapters—the gains are evident where teachers entered with some measure of Eros in their instruction. Geoff entered with just a taste of Eros as he framed science everyday contexts at t_1. He built on this at t_2. Avner made marginal gains at t_2 with modest gains in use of discrepant events. In this case the gains were in part attributable to the analysis of discrepant events by component part (e.g., part phenomena, part process) that I described in the t_2 analysis. Michelle's gains were a bit stronger still and evident within two components of the Eros framework. Upon entry, Michelle framed the occasional lesson in an everyday context. At t_2, her everyday practice flourished as she took up a number of examples she learned in the TIP and also added other instructional examples that frame science in everyday contexts. And like Avner, we see some movement with respect to discrepant events using the analysis of discrepant events by component parts.

Conclusion

Looking back across the three analyses—teaching concepts, inquiry, and Eros-informed instruction—each time we have seen overall gains. And each time we have seen that greater gains for teachers who enter with higher measures.

Along the way I've suggested two explanations to which I'll add a third. In chapter four I proposed that we could understand this pattern as a function of prior knowledge moderating learning: more entering knowledge leads to more learning. In chapter five I proposed another explanation for the same pattern: less mature teachers may require us to "look harder" and closer to discern the evidence of change. So it could be that we simply under-observe the gains of lower performing teachers.

A third explanation we might also entertain is that factors external to the individual teacher influence what she learns. For example, recall the teacher background and organizational circumstances I described in chapter two: additional sources of induction support, correspondence between teaching load and subject matter expertise, and teachers' comfort with their student population. If we consider factors external to the teacher and the TIP, additional questions come to mind. Could it be that teachers who teach lots of physical science were more focused on learning the physical science content than those who teach a more splintered load? Perhaps teachers who had other forms of support for their professional learning in *addition* to the TIP could synergize the experiences in ways that were conducive to change whereas those who had thinner supports could not?

I explore three candidate explanations for variable learning results—prior knowledge, a method that missed "kernels" of learning, and organizational factors external to the teacher—in the concluding chapter.

Chapter Seven

Serving Pragmatic and Developmental Ends in Subject Matter-Specific Teacher Induction

In the introduction to this study I asked, "What (if anything) do new teachers learn when presented with opportunities to expand their knowledge of subject matter and the teaching of subject matter?" I explored this question by looking at new teachers in a science-rich teacher induction program and examining how they worked with subject matter in teaching. In chapter four I probed whether teachers consulted students' ideas about content in teaching. In chapter five, I examined whether/how they taught science as inquiry. And in chapter six, I considered the extent to which teachers drew upon both qualities of science, and of students' interests to develop instructional portrayals that motivate students to learn and use science.

Examining the new teachers' teaching over time, my analyses suggest that teachers can, and these teachers did, learn new ways of thinking about subject matter throughout their first years of teaching, albeit in varying degrees. But was this learning due to the influence of the TIP? And if so, what can we glean from this study to inform subject matter specific induction generally? Here I explore these questions. I begin with a discussion of three alternative hypotheses to explain the variation in learning that I described across these teachers.

Three Ways to Think About Uneven Learning Gains

Over the first two years of their teaching, some teachers seemed to learn substantially more about teaching science than did others. Why? In each of the three proceeding chapters, I alluded to possible explanations for this, including prior knowledge and organizational/social factors. In addition, as is true with all research, there are also methodological reasons that might account for the variability.

Prior Knowledge

The prior knowledge hypothesis suggests that teachers' entering knowledge was varied, and that those with greater knowledge were better able to sort through, process, and grasp the opportunities to learn about science and teaching science in the TIP, thus achieving greater gains. For instance, we could consider Susan—a biology major who avoided physical science and expressed little confidence in her knowledge of physical science—possessed relatively little knowledge of physical science. We could also assume that Avner—who took several physics and chemistry courses as an undergraduate, and expressed a high degree of confidence in his knowledge (of physics in particular)—entered with a relatively high level of physical science knowledge. The prior knowledge hypothesis says that Avner, and other teachers with strong entering subject matter knowledge, might make better use of the opportunities to learn in this induction program.

In the cases of Avner and Susan we see some evidence that what teachers know coming in may influence how they make sense of the opportunities to learn in the TIP. Consider the following excerpts from my final conversations with them in which they reflected on the value of their TIP experience. Susan saw the TIP as a place to learn "fun" science:

> I think that the underlying tone is "science can be fun"— it's a reminder to teachers. I mean I taught physics last year. Personally, it was like, "Well, how *can* you make this topic fun?" It wasn't really fun [for me] as a student. But then being [at the TIP] and seeing all the people, the instructors there that loved it, and

were able to make it really cool, made you feel like, "Oh well I can do that too!" (October 2003)

Clearly, Susan took from the TIP an idea that science can be "fun." This is not all bad—science *can* be fun. But science in the TIP is not just about fun; it is about serious, rigorous engagement in science; it is about understanding the excitement, personal relevance, exploratory nature, and openness of scientific inquiry; it is also about learning scientific facts, theories, and principles. To reduce the TIP's approach to "fun science" is to miss its' central intellectual commitments. Using intrigue, the TIP wants teachers to inspire in students an intellectual excitement that will lead to substantial learning and a drive to persist (even) when learning is not fun at all.

Now consider Avner's reflections. Avner proposed that the TIP was about providing resources—in the form of activities and questions—which do not reflect a particular value-system or pedagogical approach. In Avner's view, it is up to TIP participants to work these raw materials into instruction as they see fit:

> The Exploratorium—I don't think—takes one approach or another. Mostly what I've experienced is they give you these activities and then maybe some questions to go with them, which could be used in an activity way or could be used in as part of an inquiry style thing… But the good thing about it all is that it follows a methodology that is logical for figuring something out. (November 2003)

Avner sees the TIP as a place where he can get activities and questions, but these are not constrained to a view of science teaching as "fun," or to a particular pedagogy. The only constraint he introduces is one of a general epistemic stance: that science is about figuring things out (fun, hard, boring, activities-based, or otherwise). How one uses

TIP science, in his view, is up to the teacher. Avner's view of the TIP is expressed best in a language of professional choices: he might develop inquiry instruction, he might take an activities approach, he might lecture. The choice is his.

Avner and Susan saw different things in the TIP. Where one saw "fun" stuff to do in the classroom, the other saw a set of materials and questions that could be used flexibly. From the vantage point of the prior knowledge hypothesis, Avner's strong entering knowledge might have allowed him to sort through the layers of activities, with their affective and cognitive dimensions, to see resources that he could use. Susan, with little prior knowledge, could not. She could see the surface level "fun" stuff, but she failed to see inside of rich portrayals of science, science as an inquiry process that is intrinsically compelling.

Social/Organizational Factors

A second hypothesis that I alluded to in chapter six was that social/organizational factors at the school and department level could make for a more or less hospitable environment for new teachers picking up and trying TIP materials and pedagogy. For instance, some teachers worked in environments where Exploratorium-style teaching was welcome and supported. A senior colleague who is sympathetic to Exploratorium style science teaching and who is actively supportive—offering advice, sharing materials, co-planning—might facilitate teacher learning. Recall, for example, that Andrea's co-teacher, George, was also her TIP mentor. George and Andrea spent their weekly department meeting organizing and restocking bins of materials for each of the units they taught, many of which were taken directly from Exploratorium programs.

In contrast, some organizational factors are antithetical to TIP-style instruction. For instance, Joaquin's principal expected him to state the specific concept outcomes for each class orally to his students, and to write them on the board. Starting a lesson with a discrete, predetermined conceptual outcome is incommensurate with the inquiry approach of the TIP, thus this administrative policy comes in direct conflict with Joaquin's efforts to enact TIP instruction.

We can think of prior knowledge and organizational/social factors under the broad notion of "resources," as Galosy (2005) has suggested. She argues that teachers with personal and social resources at their disposal will make greater strides in their early learning as teachers. Teachers who enter with strong personal knowledge are better able to milk their experiences in productive ways that build on their well-developed knowledge and dispositions. Similarly, teachers who work in environments that are supportive of Exploratorium-style instruction are better able to use the opportunities to learn in ways that influence their practice.

Methodological Limitations

A third possible explanation for variability in what teachers learned related to my research design and methods, which might have been insufficiently sensitive to some relevant learning outcomes. I focused on changes in participants' thinking about *teaching science.* However, it is quite possible that teachers may have made gains in their understanding of science itself that may not have surfaced in practice. For example, had I explored teachers' personal beliefs about how scientific knowledge is constructed I may have found shifts that were not manifest in their teaching. The science that teachers portray in practice, after all, is a combination of many factors including their personal understanding of science as well as curriculum, and teachers' beliefs about students' capabilities. As a consequence of my method, this line of reasoning suggests, I have failed to see important changes in teachers' thinking. This too would explain the pattern: if my methods allowed me only to see developments in teachers' thinking that resulted in practice changes, the teachers who entered with greater capacity and skill would be more able to demonstrate their knowledge and learning than their peers with less overall knowledge. If these advances were not counted, by default I could have over-represented more "mature" manifestations of learning and missed those more modest learning gains.

In retrospect, thinking about smaller grain-size analyses leads me to question one key assumption in my study. I chose to look at teachers' use of subject matter in instruction, presuming that learning would lead to instructional change. By doing this, however, I may have glossed over other developments, for example, in how teachers personal own scientific knowledge. After all, much of the activity in the TIP was about teachers making sense of scientific phenomenon for themselves. For example, in chapter four, where I asked whether teachers began to consider student ideas about science concepts in teaching, I might have asked whether they began to think about their *own* ideas differently. It seems reasonable to think that novice teachers—perhaps especially those with less entering knowledge—would show gains in knowledge and awareness of their own ideas about concepts, and what about particular concepts has been tricky for *teachers* as learners. With a method that was more sensitive to these developments, the analyses may have produced a different pattern in which teachers who enter with little knowledge also make substantial gains, but gains that are relative to their entering resources.

These three hypotheses may serve as stimulus for future research. While I acknowledge these limitations, I stand by the overall patterns in the data that suggest teachers learned new ways of thinking about subject matter through the TIP. Of course, given the limited sample size, I cannot make generalizations about teacher learning from induction; but in the case of these participants, the patterns suggest that they acquired new professional knowledge.

A TIP Effect?

If teachers learned new ways of thinking about subject matter, as I have argued, the next concern is whether or not their learning was a byproduct of their experience in the TIP. I argue that the TIP had an independent effect on teacher learning. The study is of course limited to one program, just six teacher participants, with no comparison group. And I did not develop controlled measures of teachers' entering knowledge. So I have no clear way to distinguish what teachers might learn on the job anyway (or through other channels) from what they learned in the TIP.

Yet, even with these substantial limitations, at the end of the analyses, I argue that the study captures a causal relationship between the TIP and teacher subject matter knowledge for teaching. John Stuart Mill (1843) argues that there are three aspects of causation: (1) Covariation; (2) Time precedence of the cause; (3) No plausible alternative explanation. I briefly define each of these criteria and explain how the study satisfies each here.

Covariation. When events covary, the emergent qualities or characteristics of one event coincide with parallel developments in another (covarying) event. In this study, events in the TIP program covary with developments in teachers' practice and talk about subject matter for teaching. There is clear evidence that teachers' practices and ideas about teaching science paralleled or varied in conjunction with the examples developed in the TIP. This was evident in triangulation of the teacher and program data, as well as in teachers' reflections in which they attribute ideas and practices to their experiences in the TIP.

Specific instances of covariation were observed when opportunities to learn in the TIP were triangulated with teacher practice. That is, I can connect observations of specific teachers' experiences in the TIP with observations of the same teacher using those parallel practices and examples in their own teaching. For instance, in March 2003, Avner's mentor Harry reported helping Avner locate and set up computer motion and chemical probes in his classroom. Later in the study, Avner told me about using these probes in his teaching. Similarly, when I interviewed Rhonda, Andrea's mentor, she reported helping Andrea gather materials and prepare for an activity in which she "shrink wrapped" a student. In another interview, Andrea described teaching the activity. These and other examples leave very little doubt that the TIP had an effect, and that these changes in teachers' practice could not be the result of non-TIP experiences.

Teachers also attributed ideas, practices, and materials they used in instruction to the TIP. For instance when Michelle talked about dissecting cow eyes with her students (to examine light refraction through lenses), she made clear reference to learning how to do this lesson in the TIP. She explained that she had even gone back to the listserv, and bookmarked a follow up message from Peter, the TIP staffer who led the dissection, in which he described how to order the cow's eyes. Similarly, Avner used the *Secret Worlds: Universe Within* webpage and attributed this to two places in the TIP (a reference to this site in the summer Institute and a later message about it on the TIP listserv).

No plausible alternative explanation. Were it not for the distinctive nature of the TIP—in particular its curious and unique representations of scientific phenomenon—eliminating alternative explanations for teacher learning and changes in practice would not be possible given the study's research design. However, the distinctive "TIP footprint" was evident in teachers' talk and practice subsequent to their enrollment in the program. Notably, "snack"-sized versions of the Exploratorium's exhibits, for example, are unique to the Exploratorium and could not reasonably be observed in teachers' practice through other means. Susan, Avner, and Michelle all made reference to making PVC woodwind instruments in their teaching. Using short sections of one-inch diameter PVC with a series of holes along the top they had their students build instruments that would allow them to explore the relationship between the length of a vibrating body and the pitch it produces. This is a miniature version of an Exploratorium exhibit on pitch.[57]

Time precedence of a cause. The third condition for causality is that the causal agent (the TIP) precedes the effect (developments in teachers thinking about and instructional uses of subject matter). This condition is satisfied by the design of the study. Data collection initiated as teachers entered the classroom and preceded engagement in program activities. Further, data collection was framed around the summer institute, the "core" component of the TIP: t_1 measures preceded it, and t_2 measures followed it. With these criteria satisfied, I argue, the TIP had an independent effect on teacher knowledge.

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[57] In which museum version, museum goers interact with the *Pitch* exhibit which consists of a series of large PVC-pipes, with a 10-inch diameter and ranging in length from 7 to 20 feet. Visitors strike one end of each tube and observe that longer objects produce lower-pitched sounds.

Of course, arguing that there was a change begs the question; did the TIP make the participants better teachers? In this study, I did not analyze student learning, so I cannot directly address the ultimate measure of improved teaching (or "better" teachers). But teachers with more ideas about subject matter—what it consists of; what makes it hard, easy, or enticing to learn; how students see it—might be better equipped to do so. Certainly there is a tidal swell in current discussions of teacher preparation that argues just this (e.g., Ball & McDiarmid, 1990; Grossman & Lee, 2005; Kennedy, 1998). While student learning may be the ultimate determinate of good teaching, there is a range of things that teachers must know and do to influence student learning. I focused on teacher subject matter knowledge. This is premised on the logic that teachers need to know the subjects they hope to help students understand in flexible, practical ways. Good teachers skillfully orchestrate many kinds of knowledge and concerns to influence student learning. My argument is that the TIP made the participants better teachers by arming them with new ways of thinking about subject matter, an essential component of the complex problem of teaching. Where student learning is thought to be the measure of good teaching—and improvements in it the marker of improvement—subject matter threads throughout and interacts with most things a teacher does in the classroom.

Building and Improving Subject Matter-Specific Induction

What can we learn from the TIP that informs efforts to develop and improve subject matter specific induction? As induction efforts grow and expand, the field will need to define clearly the goals of induction, how induction influences teachers and students, and ultimately, whether the impact justifies the expense of induction programs. This study is but an early, exploratory effort to describe what teachers (can) learn about science for teaching in subject matter specific induction. While definitive answers will have to wait, this study raises some useful insights into the workings of induction, and what teachers can learn in induction. I close with a few thoughts about organizing induction to maximize impact, focusing on two problems that induction must tackle if it is to succeed in supporting the practice and development of new teachers.

The first problem is that induction—the programmatic activities, staff, and other resources—will not uniformly influence all teacher learners. Teachers enter induction programs with varying subject matter knowledge, as well as other forms of knowledge and experience. And once teachers are engaged in induction, their knowledge will change at a variable rate. Thus, induction cannot be "one size fits all." Yet, from a practical perspective it cannot feasibly be customized to fit all learners equally.

The second problem is that teacher learning may not be evident during the program, but will likely continue beyond the program's "lifespan" (as is the case with all learning). Though induction activities may last up to a few years, *when* teachers learn from those activities is not equally constrained. Learning to teach is complex and teachers (one hopes) will continue to reflect on their experiences and opportunities to learn well into the future. Promoting on going learning, and learning that transcends the specific, structured opportunities to learn in induction (e.g. workshops, mentoring sessions) is a challenge worthy of our attention.

With these specific challenges in mind—the challenge of reaching a teacher learners of variable and changing subject matter knowledge and to sustain that influence beyond the timeline of induction itself—what can we learn from this study of one program that will inform efforts maximize teacher learning in induction? In short, I argue that induction programs can maximize their ability to reach diverse teacher learners and extend programmatic influence by organizing opportunities to learn at variable "distances" from real time classroom instruction. Strategically placed opportunities to learn can enable beginning teacher learners to meaningfully explore subject matter and instruction. If induction is going to do more than support the emergent practices of novice teachers—if it is to truly move teachers' thinking about teaching in a new, positive direction—it must necessarily work on several levels. I describe three levels here: classroom-based support, school and department-level support, and induction outside of classrooms. I reserve discussion of school and department-level support for last, as it was infrequently observed in this study.

Classroom-based Support

Zeroing in on the "real time" classroom as a location of induction—where novice teachers are working directly with their students during the school day—can facilitate important lessons for new teachers. First, the classroom can serve as a location for the induction educator, for example a mentor, to assess first hand the practice and working conditions of the novice. As teacher learning is situated in daily practice and distributed across twenty-some diverse students and local tools such as curriculum (Putnam & Borko, 2000), it is important for induction educators to gauge the circumstances of novices on the ground level. This can augment the novice teachers' own self-assessment of her needs and interests, providing a strong basis upon which to build a strategic regimen of induction for a particular novice teacher.

Second, since teachers must learn to use knowledge flexibly (Ball & Bass, 2000) real time classroom-based induction can support novice teachers in dealing with events that are not predictable. For instance, to the extent that induction models novel instructional approaches, novice teachers will need opportunities to enact these with direct support. For the teacher who wants to create a discourse community—in which students analyze phenomena and engage in debate to construct explanations—students may resist efforts to think out loud, or struggle to argue in a constructive sense. Similarly, inquiry lessons hinge on uncertainty, and may turn up unexpected results or results that students do not find plausible. The specific ways in which these situations play out are difficult to foresee. They call for flexible application of knowledge, and serve as important places where classroom-based induction could play a crucial role.

Of course, personnel from an induction program will not always be available. Induction educators necessarily work with multiple teachers (if not in multiple schools) and the novice teachers' period of testing and refining new ideas about teaching subject matter will likely outlast the period of induction support. However, the absence of program staff does not necessarily preclude continued classroom-based induction support. In place of teachers, instructional tools can play an important role in extending teacher learning and supporting innovative practice of novice teachers. In the context of the TIP, all of teacher participants used the "cheap and accessible" instructional materials made available through the program. These tools not only support practice, but were inscribed with meaning that reflects their use and intention in the TIP. For example, the PVC pipe saxophone described several times in the study carries an emphasis on student observation of phenomenon—a central value of the TIP. A related idea that might support teacher learning in induction is producing "educative curriculum materials," or materials that "help to increase teachers' knowledge of specific instances of instructional decision making but also help them develop more general knowledge that they can apply flexibly in new situations" (Davis & Krajcik, 2005).

Yet classroom-based induction can also be a highly constrained environment for teacher learning, with limited facility to support innovation and reflection. Dewey (1904) pointed to the problem over a century ago, arguing that field experiences can be worthy sites for teacher education, but that alone—in the absence of instructional and learning theories to guide the teacher learner and against which the practitioner can compare her own empirical observations—they are highly conservative. Teaching itself requires a high cognitive load, which may at times limit a new teachers' capacity to attend to both her instructional duties and her professional learning. Moving away from the heat of real time practice may at times be necessary to generate practitioner reflection and careful analysis of practice. What is more, teaching and simultaneously learning novel instructional ideas can create an inordinate workload, and may exacerbate known teacher concerns about time usage. Adding classroom observations and debriefing sessions to the mix may be overwhelming.

Working Outside of Classrooms

One way to ease concerns about teacher learners' capacity to critically reflect on practice, the time it takes to learn, and the cognitive load of simultaneously teaching and learning to teach, is to provide induction at a remove from classroom-based practice. Non-classroom contexts can serve as rich environments well suited for teacher learning of concepts and practices that suggest substantial changes to the "core" of instructional practice (e.g., rethinking the goals of science instruction, introduction of innovative instructional models).

Consider a fundamental challenge that many teachers face: creating an orderly learning environment that is also respectful of students and responsive to student thinking. While most new teachers will support the idea that students should actively participate in class, most will fail to do so. Novice teachers and teachers with limited subject matter knowledge may tightly control the structure of student participation by repeatedly asking low-level, convergent questions (e.g., Carlsen, 1987). Successfully creating an orderly environment that is responsive to student thinking requires the recruitment and coordination of a broad range of knowledge. The teacher needs strong subject matter knowledge. He needs knowledge of the kinds of questions and activities that will elicit student discourse. He needs to know what to do with student ideas when they arise in class. He needs some way of tracking his students' progress. He needs to create norms for student participation.

The constellation of knowledge needed to work on this and other fundamental challenges to teaching is not self-evident. And lofty, complicated ideas are less attractive to the teacher who is locked in a program of instruction, working hard to prepare for tomorrow's lesson. If induction will help novice teacher look deeply into their own teaching and knowledge, it requires environments that create mental space and large periods of time for teacher learning. At a distance from the real time organizational constraints of classroom teaching, novice teachers will be able to engage in a broader range of considerations about how to approach teaching, to scrutinize their own knowledge about subject matter, and to consult with others about the former.

School- and Department-level Support

Finally, a third place we can locate opportunities to learn in induction is between the classroom-based and removed contexts, in the naturally occurring activities of the school and science department. The science curricular functions of schools and departments can be honed strategically to scaffold novice teacher learning. The activities include formal activities, like assigning courses and organizing curriculum, developing assessments and reviewing student results, and organizing instructional materials. They may also include informal activities; such as the happenstance mentoring that takes place over coffee among colleagues.

Working on teacher induction within the school and department level functions allows induction to calibrate with the local intellectual climate. For example, if there is a strong, coherent instructional program within a local science department, an external induction educator (such as a TIP mentor) can choose strategically how to augment the program. She may also raise criticisms of that program for the novice to consider. Similarly, if there is a strong mentoring component in house, an external induction educator could rethink how to spend his time with the novice by either replicating or diversifying the efforts of the department as needed.

Similarly, schools and departments may allocate instructional time and resources (e.g., textbooks, lab space) in different ways, which can serve as distinct opportunities for novice teacher learning (McLaughlin & Talbert, 2002). Some may work in a block scheduling structure, others may offer structured planning periods, or organize some courses in teams. Local material circumstances of a particular school of department have important implications for the specific challenges that novice teachers face and the resources they have to work on these. Material and resource allocation decisions made with teacher induction in mind could create strong day-to-day learning opportunities for novices for instance by providing fewer preparations for novices, making sure that novices teach subjects they know, ensuring that senior colleagues share their curricular materials with novices where appropriate.

This observation of the potential of schools and departments to act as sites for carefully structured subject matter-specific induction arises less from empirical observations than from a sense of lost opportunity. As I mentioned previously, all of these teachers taught multiple subjects, including subjects for which they had little preparation. Further, while these teachers' professional lives were rich with opportunities learn science and how to teach it—instruction, school- and district-based meetings, TIP-based induction, conferences, teacher networks—these were infrequently informed and shaped by a consistent logic or coherence. While the gamut of activities we observed were intended to support novice teachers, they often seemed to pull novices in different directions.

The school or district seems the logical place to pull these activities together and to shape a program of support from the range of resources available, beginning with those that are directly controlled within the school. Could the TIP shift its focus from supporting individual novice teachers to building small groups of science teaches within particular schools and departments? Toward supporting the creation of hospitable and supportive school and departmental environments, organized to cultivate teacher development? Whatever complexity this shift may introduce, it seems a proposition worthy of consideration for the TIP other efforts to develop novice teacher instructional capacity.

Conclusion

Most teachers do not have access to good, subject matter specific support in the early years of their career. Their experiences as novices might be characterized as "trial by fire" as they are handed the keys to a classroom and offered limited guidance and support to teach once they close the door behind them. And if trial by fire is the default induction practice, "trial and error" is the default method of novice teacher learning. At its best, induction counteracts or moderates both trial by the fire experiences and trial and error learning.

In contrast to teacher preparation, which is often seen as irrelevant (Baldassarre, 1997), induction may tend too easily toward narrow pragmatic concerns—simply helping teachers "live through" the first years of teaching. As novice teachers themselves are most immediately concerned with their classrooms, they may come to induction with practical questions, demanding workable solutions for tomorrow's lesson. In efforts to address these real, sometimes overwhelming, legitimate concerns, induction programs may postpone or marginalize its teacher long-term development charge, and become a "solutions" clearing house. The TIP, for example, recognizes that teachers arrive with a thirst for ready-to-go ideas, and it responds with materials, and instructional ideas that teachers can take immediately to the classroom.

However, anticipating or responding to the immediate practical needs of new teachers is a necessary, but insufficient role for subject mater specific induction. Serving up materials and ideas on demand leaves teacher development to chance. True, some teachers may be able to abstract from a series of instructional ideas and materials to build their own model of instruction. But others will not, and without a concomitant commitment to their intellectual development, they are left to mimic what they see in the materials provided or extrapolate from quick fixes they gather from mentors. Induction that will feed both of these goals—meeting the immediate demands of novices and pushing their long-term development—will need to recognize and embrace this tension. To work productively in this environment, multi-faceted induction efforts should strategically work to match program resources with both the pressing demands and long-term developmental trajectories of novice teachers.

Appendix A.1

New Teacher Getting Started Interview

New Teacher
Getting Started Interview

Tell me about your assignment this year.

- What are you teaching (subject matter, grade level)
- How many classes do you have?
- What kinds of kids are in your classes?
- Was there any new teacher orientation at your school/in your district?

Professional Interactions with Teachers/Support Staff

Do you have any official mentor in the school?
Are there any particular colleagues with whom you interact regularly?
Do you belong to a department?
Do you get any support through other groups, say for example, the union?

Relevant School Policies

Is there a school curriculum?
Do you have assigned texts? If so, what are they?
What kind of standardized testing will your students take this year?
District level
State level
How does that testing affect your teaching decisions?

Relationship with Principal

Have you met the principal? If so, what have you talked about?

Evaluation

As a new teacher, are you evaluated by your building principal?
What do you know about this process?
Are you observed by anyone? If so, how often? Are you assessed according to a set of criteria/evaluation sheet? If so, have you seen it? Who is responsible for your evaluation in the school?

Exploratorium

Tell me about your relationship with the Exploratorium.

How did you get involved with the Exploratorium?

Why did you apply for this program?

What are you hoping to get out of this program/learn from this program?

What contact have you had with the museum?

Who is your contact person?

What kinds of things have you done with the Exploratorium?

Have you met your mentor/coach? What have you talked about?

How do you think you will work together?

BTSA

Can you tell me what you know about BTSA, the California statewide requirement that new teachers are associated with a support system?

Are you involved in a BTSA program? If so, can you tell me about it?

Where?

Who do you interact with?

What does it consist of? What kinds of support do you get? Does anyone evaluate you? When and how, etc.

Teacher Preparation and Undergraduate

Can you tell about your undergraduate preparation?

College/universities attended, majors/minors, define majors (how many courses in what sciences).

Have you had any teacher education courses? If so, can you tell me about those?

What did you take? Where?

Current Concerns

As you think about your first year of teaching, what do you feel most prepared to do/ready to do/confident about?

What are you less confident about? What do you think you will need the most help with?

Is there anything you feel you need to know about the subject matters you are teaching?

About students?

About management/discipline?

Appendix A.2

Mentor/Coach Getting Started

Mentor/Coach interview
Getting Started Interview

How long have you been a mentor/coach?

How did you decide to become one? Can you tell me the story of how you came to be a mentor/coach?

What do you do as a mentor/coach?

Have them describe their job. Listen for central tasks. Probe for central "tasks" of coaching/mentoring (Are there big chunks of work that they do?). Examples might include: having discussions with their beginning teachers; observing and debriefing a lesson; co-planning and co-teaching; interactions with building administrators; anything they do at the Exploratorium, including teaching workshops, etc.

How did you learn to do these things?

Was there any training at the Exploratorium?
Did you have a mentor yourself?

What do you think makes a good coach/mentor?

Can you think about a typical problem/issue that you work with a new teacher on?
Can you describe that issue and then talk me through how you work with the novice.

What is most challenging about being a mentor/coach?

What is the most important thing that you can do for the new teachers as their coach/mentor?

You were an experienced teacher before you took on this role, is that right? If so, . . .

How long were you a teacher?
Where did you teach?
What did you teach?
Did you go through any teacher preparation program?
Did you have any mentors?

How did what you knew as a teacher help you as a mentor/coach?

What new kinds of knowledge, skill, and practices did you have to develop when you became a mentor? What new things did you need to learn to become a mentor?

Has your practice as a mentor/coach evolved over time? If so, in what ways? Can you give me an example?

What do you think are the most important things that the new teacher needs to learn? How do you help them learn these things?

New Mentors/Coaches

What do you think you need to learn, as you become a coach/mentor? Who helps you learn those things?

Experienced Mentors/Coaches

Can you tell me about a new teacher you worked with last year. What were the most important things that that new teacher needed to learn? How did you help them learn those things? Can you give me some examples?

Tell me about your biggest success story.

Can you tell me about your relationship with the Exploratorium? How did you get hooked up with the Exploratorium?

Appendix A.3

Touching Base Interview

Interview Guide – Touching base on general teaching/learning issues, support, professional development, and evaluation [to be completed by phone/email 3x per year]

<u>Teaching & Learning Situation/Views</u>
How are things going?

> *If vague response*: Probe for both strengths and concerns (What's going well, any concerns, recent improvements/difficulties)
>
> *If responses are "abstract"* ("I'm really a lot more confident about teaching science this year."): Probe for specific instances; Can you give me an example of a time when you realized______________________?
>
> *Follow-up from prior visit:* Last time when we talked you mentioned you were having difficulty with (or wanted to work on) _________________________ How is that going? Last time you said you felt very good about ____________________, is that still going well for you?
>
> *Probe for collegial support:* How are things going in the science department?
>
> *Probe for completeness:* _______________ sounds a little different than the last time we talked, any other differences?

<u>New Teacher Support</u> *(Note: Ask about all of the support programs that the NT participates in)*

What have you been doing with (BTSA/Explo/other NT programs) since our last visit?

<u>Other Professional Development Support</u>
Have you been involved with any other professional development since we last talked?

> *If there are any others mentioned:* Probe to find out more about them (who sponsors, what's involved, who participates, how they found out about it)
>
> *If any are ongoing:* Probe each time for what's happened (How about ________, have you done anything with that lately, been able to use in your teaching?)
>
> *If any involved in summer institute (e.g., TRIAD):* Probe for follow-ups and use (How about ___________, have you been able to use any of that in your teaching? If *yes*, how did that go?; *if no,* probe for why not)

Appendix A.4

Classroom Observation Protocol

EXPLORATORIUM CLASSROOM

OBSERVATION PROTOCOL PACKET

General Admonitions/Directions

- Find a place to sit where you can see and hear well.
- Prior to beginning, sketch a map of the physical arrangement of the room. Note where students are sitting.
- Since you will not be able to describe the activities and responses of all students, choose a sub-group upon whom to focus. For this sub-group, complete an "on-task" running record every five minutes.
- As you take notes, describe what is going on in the class, getting as many direct quotes as possible. Describe student-student interactions, student-teacher interactions. Avoid summary statements in favor of descriptions of what people are saying and doing.
- Indicate the time every 7-10 minutes or when the task or activity changes.
- In conversations, follow-up on what does not seem to fit. Ask questions to understand, to clarify patterns.
- Type up your observation notes as soon as possible after the observation.

The purpose of the narrative write-up is to provide as full a picture as possible of the slice of teaching that you observed. Begin by describing the context, the physical setting as well as the number of students, a summary of the tasks and activities you observed, and the curriculum content. Note what materials and supplies were evident (and NOT evident) in the room. Note other adult support available in the classrooms and the roles they assumed. If possible, note whether they are volunteer or paid. Explain what you chose to pay more or less attention to during the observation. The purpose of this part of the write-up is to provide a roadmap of the teaching you observed.

In the body of the narrative, recreate the chronology of the observation with as much detail as possible. Describe how the teacher began the lesson, what students did and said, how the teacher handled transitions, disruptions, questions, comments, how the lesson ended. The narrative should be complete enough so that someone other than yourself could use it as data with which to answer the interpretive/analytical questions below. At the end of the write-up, make a section called attachments in which you list all the documents collected that accompany the observation (e.g., lesson plans, handouts, student work samples, etc.).

If possible, complete your write-up with a "typical yet telling" vignette that exemplifies the teacher's integration of knowledge of the student, the content, and of pedagogy. What it "looks like in this classroom" when the teacher puts it all together.

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Classroom Context

Number of students _______

Number of free/reduced lunch students (from office) ______

Limited English proficient students (from office) _______

Racial/Ethnic make-up of classroom (from office):

European-American _______

African-American _______

Asian-American _______

Latino/Hispanic American _______

Special Needs Children (from office) _______

Male _______

Female _______

Community Description:

Narrative -- type of neighborhood -- e.g., industrial, commercial, residential (apartments or houses), urban/suburban/rural, etc.; history (how has it changed in past several decades); Socio-economic characteristics; Types of businesses; How connected with other neighborhoods/Permeability with other worlds (e.g., automobiles, mass transit, etc.); Do teachers live in neighborhood? Could they afford to if they wanted to? Do they want to?

Classroom Map:

(Include seating arrangements, what's on the walls, etc.)

Pre-Observation Data

Teacher Name

____

School Site/Location

____

Observer

____

Date/Time of Day ______________________________

Grade Level/Subject matter ______________________________

Time: Begin ________ End _______ Total Length _____________

Information to gather from a conversation with the teacher prior to observation (if possible)

During the observation, will you be in your own classroom or in a room you use on an occasional basis?

During the observation, will any other adults be in the class during the observation? If yes, what is their role?

Where does the observed lesson "fit in" to an instructional/curricular flow? What came before? What will come after?

What is the purpose of this lesson?

Is there anything about the make-up of the class or particular student behavior patterns the observer should be aware of in order to understand the class (e.g., ability levels, special needs, physical handicaps, behavior patterns, special language needs, etc.)" Are there special procedures in place to accommodate these?

Is there anything else the observer should know about the students, the class, the room, recent events, etc.?

Information to gather from a conversation with the teacher following the observation

Did everything go about as you anticipated? Was this "pretty typical" of your teaching/classroom?

Did you make any changes in your activities or objectives? If so, why?

Is there something I should ask you that I have not?

Is there anything you want to ask me?

Appendix A.5

Professional Development Log

Name: **Date:**

Professional Development Log

To the extent that you can, please keep a log of the professional development experiences you encounter. They may be informal (talking with a colleague, something you read) or formal (workshops, faculty meetings, coursework, etc.).

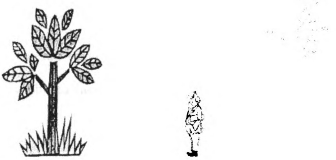
Professional Development Experience	Source	Participated? (Yes/No)/ Why	Description	Evaluation	Classroom Use?	Other comments
Workshop on light	*Explo*	*No; I don't teach light*				
Consult	*My dept chair*	*Needed help with a test I was writing on energy; wanted to make a*	*We used a model car/balloon to design questions for the test*	*Very helpful; by trying it ourselves we found out what might*	*I wrote test questions using the model/car balloon as the basis*	
Faculty meeting	*Principal*	*Yes; required*	*Nitty-gritty stuff*	*OK*	*Not really*	

Appendix B.1

Subject Matter Interview Tasks

Task One

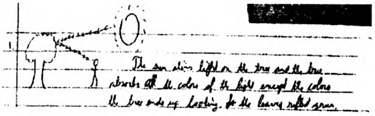
In the picture below light from the sun helps the man see the tree.



a. Draw arrows that show how the light from the sun helps the man to see the tree.

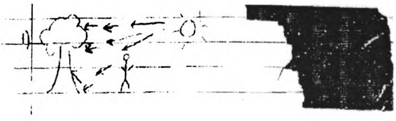
b. Explain in words how the light from the sun helps the man to see the tree.

RESPONSE 1:



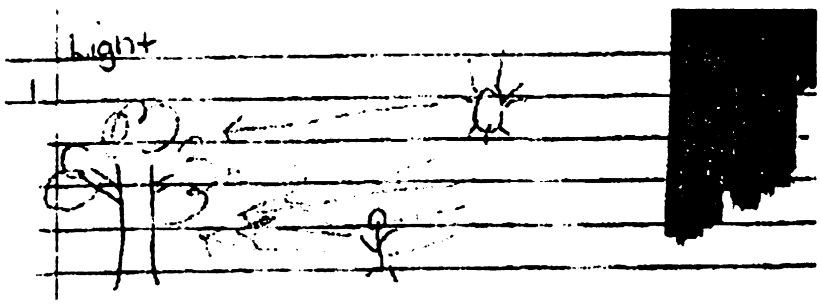
The sun shines light on the tree and the tree absorbs all the color of light except the colors the tree ends up looking, so the leaves reflect green.

RESPONSE 2:



The light helps the man (a.k.a. Bob) to see the tree because the light waves bring out the outline of the tree.

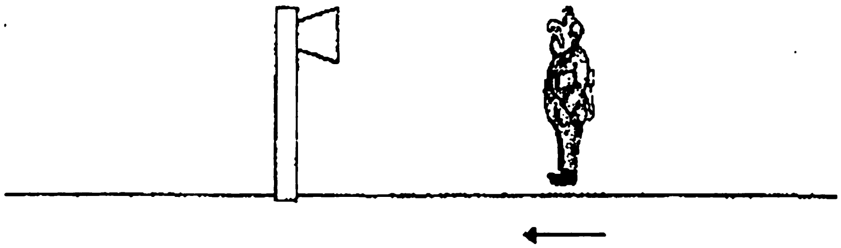
RESPONSE 3:



The sun's rays hit the tree and everything surrounding it, causing the tree to be visible to the man.

Task Two

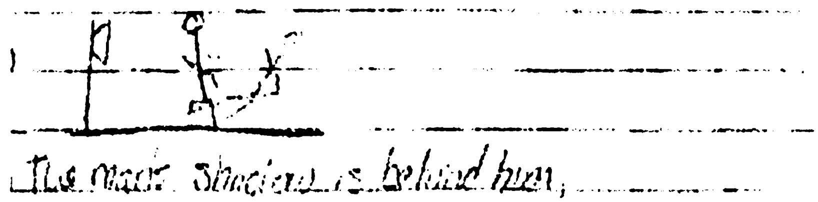
The man is facing a bright light.



a. Draw the man's shadow.

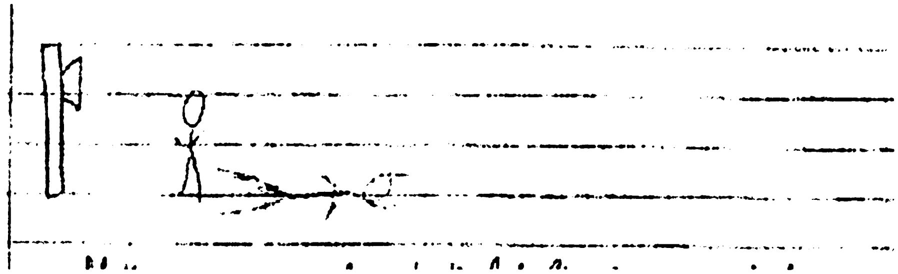
b. Describe how the shadow would change if he moved closer to the light source. Explain why it would change in this way.

RESPONSE 1:



The man's shadow is behind him. The shadow would get wider and longer as he walks towards the light. This is so because as the man goes toward the light he covers it up so there is not enough light to go around it.

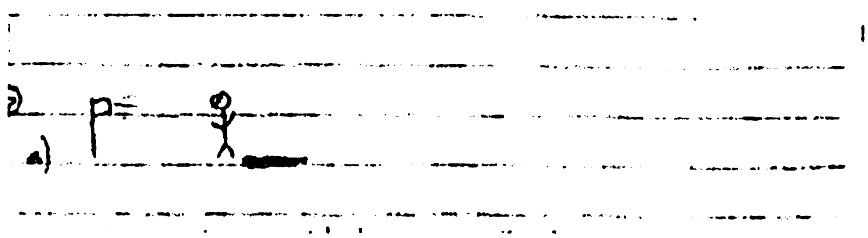
RESPONSE 2:



If the man moved closer to the light his shadow would become wider and longer.

This happens because he would be blocking more light the closer he is to it.

RESPONSE 3:



The shadow would become smaller because the light would cover more areas of the man.

Task Three

Alberto took a transparent plastic cup, filled it with water, and placed a pencil in the cup. He noticed that when he looked at the pencil where it entered the water, the pencil appeared to be bent. Why do you think the pencil appeared bent?

RESPONSE 1:

The pencil looks broken because the light is refracted in the light. Light travels differently through water than air.

RESPONSE 2:

The pencil appears to be bent due to refraction. The light hits the water and bends or refracts around the pencil.

RESPONSE 3:

The pencil appeared bent because of refraction. The light waves changed angle because of the change in medium. The light waves changed angle because of the change in medium. So the pencil appears bent when going from air to water.

Task Four

As student stood in front of the class and clapped two chalkboard erasers together. Her classmates heard a "thud" when she did this. Draw a picture and explain how the students heard the clapping of the erasers?

RESPONSE 1:

The vibrations of the erasers clapping together move the air around the erasers in vibrations, causing sound waves that travel to unsuspecting ears.

RESPONSE 2:

The resistance that the two erasers put on each other created an energy that couldn't go anywhere – but it had to – so it went into the sound waves that the classmates heard. Some energy also went into heat.

RESPONSE 3:

A thud was heard by the students because both erasers wanted to keep moving in the direction they were going in and when the forces collide they made a thud.

Task Five

The xylophone is a musical instrument made up of short and long keys. The xylophone is played by striking the keys with a mallet. When the short keys are struck, it creates high pitches. When the long keys are struck, it creates low pitches. Why do you think the short keys produce high pitches, and the long keys produce low pitches? Draw a picture and explain.

RESPONSE 1:

-The longer keys have more surface area so the wave is more spread out creating a slower frequency.

-The shorter keys have less surface area therefore the sound waves vibrate back and forth much quicker, creating a higher frequency.

RESPONSE 2:

When you strike the short one it creates small, fast vibrations causing a high frequency therefore a high pitch. The big, long keys create long vibrations for the low pitch, low frequency sound.

RESPONSE 3:

A higher sound is made from the short keys because there is less matter for the sound waves to go through, so the frequency is higher.

Appendix B.2

Annotated Excerpt from Subject Matter Analysis Memo

Note: The following is an excerpt from the subject matter task analysis in which I characterize the content in task 1, describe conceptual errors evident in the student responses to it, and summarize evidence of one teachers' performance on that task.

Task Content Description: Sound

First, we need to characterize sound: what is it? Sound is merely the aural perception of vibrations – the "shaking" back and forth of an object in space. Thus, we have a physical component (the "shaking") and a physiological component (our aural perception). This task emphasizes the *physical* component by framing the problem as one of sound traveling – from the erasers in front of the class to the students in the classroom. So, while the task asks the student to account for "hearing", they are primarily responsible for characterizing sound and its transmission across space and not the physiological component. My framework here follows this bias, placing more emphasis on the physical component than the physiological.

When objects vibrate, particles "bump into one another." Initially the particles of the erasers themselves begin to move back and forth quickly, and then the air particles surrounding them do so. These nearer particles when set in motion, disturb their neighbors in a similar fashion, and so on, and so on – each particle shaking its' neighbor in an outward-expanding chain until the particles against the students' eardrums are set into vibration against the eardrum. Earlier I used the analogy of a pebble dropped into a still pond causing an outward-expanding ring of "ripple" waves to characterize traveling light. This analogy works equally well here to characterize sound waves. They too travel outward in an expanding fashion.

Sound is transmitted in a unique way which students – and perhaps teachers – are known to confuse with other models of "travel" that are more familiar to them. Often when students characterize sound traveling their notion of "travel" is like that of a car or train (cites). That is, they seem to believe that particles – like cars or trains – move across large distances in space. In the case of the task, they might envision "sound" or particles moving from the area surrounding the erasers *to* the ears of students in the classroom. Another common error related to the transmission of sound is the tendency to think of sound as the actual *striking* of items – the erasers colliding, a pencil hitting a desk, a drumstick striking a drum. Such a model fails to account for vibrating particles that "link" the source of the sound with the ear and aural perception.

Thus, the content of this task can be broken down into four parts. First, sound is a vibration. Second, sound moves across space as particles "bump" one another. Third, these particles vibrate in a relatively small space. Fourth, eventually the chain reaction of vibrating particles may reach ears: eardrums are shaken which we perceive as "sound."

Following this I analyzed the evidence for each student response with respect to the framework and then I did the same for each study participants' response. For example, here is what I wrote about Michelle's response to Eraser Thud:

Michelle provides explicit knowledge of just one concept, while the other three concepts are not evident in any form. Michelle used only the vibration principle, as she noted,

> The first student is talking about vibration of particles and that's how we hear. That's how the sound waves are. Because she's necessarily talking about – the first student is talking about vibrations of air molecules.

Michelle vaguely suggests that explaining "what sound waves are and how they are created" would be a wise instructional move. Michelle's analysis of this problem, based on student response two, is curiously lacking in content from the framework. This might be seen as a function of the peculiar student response she was analyzing. The student response, which we will return to later, was rooted in the language of mechanics. Michelle went to great lengths to try to discern what the student understood. In the process she speculated about mechanics, and abandoned the content of sound. Thus we should be cautious in interpreting her performance. Perhaps Michelle was simply "taken in" by the student response and lost track of the objective: to analyze the student response and suggest ways to help students understand the sound phenomenon depicted in the task.

Here I have completed a rather unsatisfactory task: describing what Michelle *did not do*. She did not, with one exception, use the concepts in the framework. Of course, we have seen other teacher responses that evidence little or no knowledge of framework concepts (concept misuse, tacit agreement or otherwise endorsing errant student responses, self-admission of misunderstanding). However, this instance stands out as unsatisfactory because the respondent seems to be talking about a fundamentally different thing than the framework and task suggest. I will return to discuss what Michelle *did* discuss later.

Appendix B.3

Summary of Teachers' Knowledge of Task Concepts Time One (t_1)

	Concepts/Case Study Teacher	Andrea	Avner	Geoff	Joaquin	Michelle	Susan
1,2	Light travels						
1,2	--outward from source						
1,2	--in a straight line						
1,2	--diverges as it travels						
1	Light reflects						
1	-- off of opaque objects	XXXXX					
1,3	Light enters observer's eye	XXXXX					
2	Opaque objects block light/shadow				--NA--	--NA--	--NA--
2	Proximity/size				--NA--	--NA--	--NA--
3	Light bends at media boundaries	--NA--	--NA--	--NA--			
3	Two locations of the pencil	--NA--	--NA--	--NA--			
3	Recalibration/perceived location	--NA--	--NA--	--NA--			
4	Sound is vibration	--N/A--		--N/A--			--N/A--
4	Particles "bump" neighbors	--N/A--		--N/A--			--N/A--
4	Particles vibrate locally	--N/A--		--N/A--			--N/A--
4	A chain-reaction of bumping	--N/A--		--N/A--			--N/A--
5	Pitch, subjective experience		--N/A--			--N/A--	
5	Objects vibrate at particular freq.		--N/A--			--N/A--	
5	Pitch/length		--N/A--			--N/A--	

	Clear evidence of understanding
	Ambiguous/partial evidence of understanding
XXXXXXX	Evidence of contradiction/errant knowledge
--N/A--	No evidence of understanding/misunderstanding/no response

Appendix C

Within Case Memo Example

October 23, 2003

Instructional Innovation: Tradition, critique, and alternatives (Michelle McCoy)

Of all the case study teachers, Michelle was the most enthusiastic about her experiences at the summer institute. Her talk about the institute was riddled with novel insights into subject matter, innovative ideas about how to represent ideas to students, assertions about the value of the institute to her thinking, and plans to make particular changes to her practice that reflected her new knowledge. Among these ideas Michelle described activities related to teaching light. Before the institute, Michelle's instructional repertoire for light was quite limited. She relied heavily on a singular, conventional representation of light in her teaching known as ray diagramming.[1] After the institute she described an array of representations, considered these in relation to ray diagramming, and critiqued ray diagramming from the standpoint of its' instructional merits.

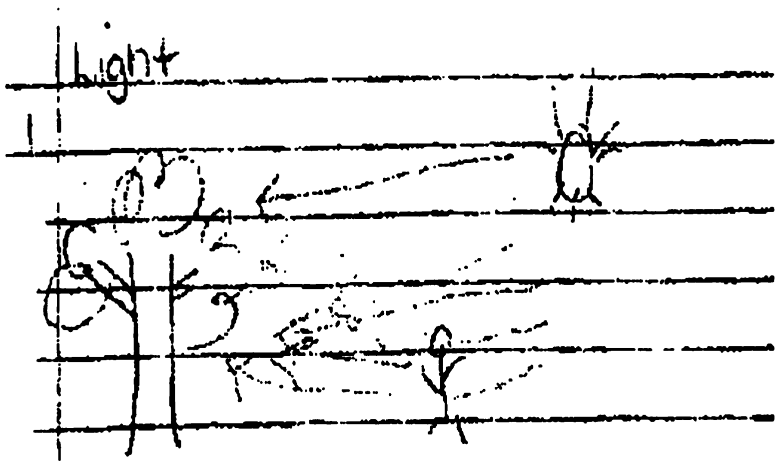
I divide this memo into two sections. First I provide a brief chronology of Michelle's teaching of light at three points in time between March and September 2003. At the first point – prior to the institute -- she relies on one representation. In the second – a few days into the physics institute – she refers to an additional representation. Lastly,

[1] Ray diagrams are often used to describe the behavior of light in particular circumstances (e.g., when shone through gas and liquid media, or lenses, prisms). They make light and the path it follows "visible", allowing the illustration of principles of light behavior. Unlike "real" light rays, with diagrammed rays we can measure angles of rays, and point to clear disjunctions where they bend. We might think of diagrams as a disciplinary short hand that facilitates communication about, and analysis of, the behavior of light and the canonical principles of light in physics.

in September, after the institute she describes two alternative approaches to teaching light. She also discusses them in relation to her initial approach – line diagramming.

Michelle's thoughts about teaching light, March 2003. I conducted the first subject matter interview with Michelle prior to both her first experience teaching light and to participation in the summer physics institute. As I noted above, at this point Michelle relied [solely] on the line diagramming method to represent light to her students. In addition she proposes an alternative instructional method, but fails to articulate it clearly.

During the initial subject matter knowledge interview, Michelle was asked to analyze a student's attempt to characterize the behavior of light (see task 1 content memo). She noted two flaws in the student response. First, the response indicated "swooping" or bending light rays where light rays should properly be represented in straight lines. Second, it failed to show reflection. These are two basic principles of light that, rightly, Michelle expected in a correct response (see the drawing below where rays bend down past the observer from the sun toward the tree).



To rectify these student errors, Michelle proposed two instructional interventions. First, she proposed having students diagram rays. As described above, a conventional ray diagram would give students practice at drawing straight light rays and model instances when light will reflect, and when it will bend. She also attempted to describe an alternative representation:

> Like if you have a mirror that's half your height, you can still see your whole body. So, try to use that to show that -- ok, even though if there's light reflecting. Basically light reflecting off your feet and basically everything and then that light that's reflected, what you are seeing. So the mirror basically might give me a better idea about being able to draw those diagrams um, and then maybe even um, even though, even though the mirror isn't all the way down to their feet -- it might give them an idea that light is being reflected. And that's what they are seeing.

Michelle's description of this alternative is quite muddled. The specifics of the demonstration and particular ideas it would demonstrate were unclear in her description.[2] As she talked, she seemed to convince herself that she did not have adequate command of this alternative strategy and ultimately abandoned it proclaiming she would "probably have a tough time" teaching students principles of light that might supplant the "swooping" rays and add the concept of reflection to their understanding.

At this point – prior to her first time teaching light-- Michelle has few ideas about how to represent light to students. What we might call her "representational repertoire" seems to consist almost exclusively of ray diagrams. However, she expresses at least a vague awareness of alternative ways to represent light for students and a desire to do so.

And when I was preparing (before) to explain real and virtual images I was not even sure how to go about doing it because I had to look at the ray diagram to look at what I was seeing. So it's supposed to be in front of it? You know I wasn't like getting it.

Though she alludes to an additional representation, at this point she neither explicitly critiques ray diagrams, nor does she express a coherent alternative to that common representation of light. In April, just a few weeks after our pre-institute subject matter interview, Michelle took her first stab at teaching light to her physics students. Not surprisingly, she relied heavily on ray diagramming. Michelle's reliance on ray diagramming is not surprising given that diagramming rays is the standard representation physics majors learn. Predictably, in her first attempt to think about how to teach light, she relied heavily on diagramming rays, the pedagogy she had witnessed as an undergraduate herself (Lortie, 1975; Grossman, 1990).

A new way to "see" light, June 2003. We talked with Michelle in June, just a few days into the summer institute. We asked Michelle to reflect on the workshop sessions she thought would be influential in her teaching. She described an activity she participated in earlier that day. The activity was designed to illustrate how light behaves in producing images on flat mirrors, a standard concern of physics courses and textbooks. Smooth lenses and mirrors, depending on their shape can produce images in different ways, by bending and reflecting light rays. Understanding how images are produced entails determining where the light goes, and consequently, where images "are" versus where

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[2] …The Math/Science Connection workshop at the Institute actually did this demonstration. See notes.

they are "perceived." Previously Michelle had only known this problem as a "line diagram" -- not a phenomenon she could point to or recognize in an authentic context.

AWS: Are there particular things that you've so far that you think will influence your teaching?

MM: Even just today. Taking those mirrors, using rulers -- to the plane mirror -- and trying to target where people are seeing the image. Three people took a ruler and pointed it at where they saw their image and then we realized that it was behind the mirror. And then we went to a curved mirror and we saw that it was in front of the mirror. So, it was -- that's the type of thing that I'm going to be able to do -- I mean I'm probably going to forget about a lot about diagramming rays – [the mirror demonstration] is so much more applicable.

AWS: Is it just different ways to represent the same ideas? Is that what it is?

MM: It's just more of a physical explanation rather than (in a monotone, mechanical, "uninspiring" tone) *taking your ruler, and drawing parallel lines, having it go through a focal point* -- I didn't think they got anything out of that. So, and also I didn't focus at all on perception because I didn't know much about it at all. And now that I have an idea about that, I'd probably do a little bit more with that.

At this point Michelle demonstrates new knowledge of at least one additional way to represent light instructionally. She clearly describes the procedure she used in the workshop – "sighting" the line of light with a ruler. This allows her to "see" a phenomenon in a way that was much more clear and persuasive than she had previously.

Multiple representations, September 2003. During the last twenty days of the workshop, light was a central topic of study as teachers worked on the museum floor, and in the classroom to examine, "test", and discuss light and ways of teaching light. In addition to the yardstick/mirror activity described above, teachers used a variety of materials and engaged in a number of activities to learn about light and ways to teach it. Among other things, they examined photographic optical illusions, created illusions with spinning discs, conducted experiments with "light boxes", dissected a cow's eye, examined light interference patterns, and shared their own thoughts about teaching light among themselves.

In September Michelle noted two representations she learned at the summer institute that were particularly influential in her own thinking. These were the yardstick/mirror representation described above, and the cow's eye dissection. Michelle's reflection on the activity blends description of the instructional representation she has in mind, critique of ray diagramming, and expressions of her enthusiasm about teaching light with these new representations.

> [At] the Exploratorium they have all those mirrors; like that curved mirror and plane ones. We weren't drawing ray diagrams, but we had meter sticks and they said, "Point to where you see your image" and we got closer and closer and they weren't pointing at the mirror at all; they were pointing at a spot behind the mirror! They got to the mirror and they still weren't on their image yet or they got to their image and they weren't at the mirror yet.

This representation conveyed both a way to communicate about the content and a new insight into the content itself:

I mean and real and virtual images was just like a lost cause. I didn't even get it. I didn't know what the difference was between real and virtual (when I was just) drawing it. [Her college teachers] were just like, "oh yeah you're going to see the image right there."

Michelle reflected on her first experience teaching light. In retrospect she noted that she was frustrated by her inability to help students understand and "see" real and virtual images. Further she attributes her frustration to her own lack of understanding – in a "real" sense -- of the phenomenon.

so many students were asking me, like, "so that's virtual?" "Well yeah... it's like behind or in front of..." And you know I just I had now way of convincing them that it actually was a virtual image.

Yeah you can point at what you are seeing; you get closer and closer and -- there it is…And then we go and we're drawing them for real and we're pointing at it. "Oh there it is!" And you just kind of see it. It just makes more sense; it all fits together.

Michelle was also enthusiastic about the cow's eye dissection. In the workshop teachers dissected cow's eyes and used these as lenses. For example, they placed the … As she described it:

We took out the lens which was just really interesting and you even took the letters -- we wrote tiny little letters on the piece of paper and put the cow's eye lens right over it and it's like so much bigger.

I want to get cow eyes. (To JG) You were there for that day. I want to do that. And I think that just makes a lot -- I mean the refraction is interesting and Snell's law works well. But I was having a tough time with the equipment that I had trying to show how light was bending. I mean I put the pencil in the glass and it was good, but just as far as your own perception and light in general -- how it looks different for everybody -- and I think I learned a lot about the eye in general. Which I think would be really neat to bring into refraction.

So even drawing ray diagrams -- I mean I was drawing ray diagrams and I *hated* it. I felt like it was totally pointless and it just didn't -- you know "which way does the ray go?" I just didn't think it mattered that much. You know which way are you drawing the ray? Is it passing through the focal point? I mean it does matter and I will do that, but I think that (cow's eye) can be an application. I mean I was taking problems out of the book and they were drawing the ray diagrams, but now this time I would use the cow eye lens and draw the ray diagram. You know just something more physical that they are seeing instead of -- I mean we spent like two days drawing ray diagrams from just problems in the book. And by the time it was over I just thought it was a waste of time really. I mean they got something out of it, but more just the technicalities I think. So that would be -- I mean I know that as soon as I start of light I know what I'll do. I've got the little thing marked in my email for where to go for the cow eyes. I'll order them in advance. It came out on Pinhole. That's what I want to do to start that chapter, or really that whole unit. I think it would just be -- I just know a lot more about the eye now. And I think students can related a lot to that -- I mean they've got eyes!

Appendix D

TIP Saturday Workshops 2002-2003

Date	General Workshop	New Teacher Workshop
September 14, 2002		Orientation
October 12	Introduction to Ethnomathematics	Planning Ahead, or Swimming vs. Treading Water
October 19	It's Here! The Math Explorer	
November 2	Convection	Lab Safety and Organization Time, Paper, and Sanity Management
November 9	The Periodic Table: It's Elemental Biological Monster Moleculres	Provocaciones
November 16	The Best of Earth Science	Teaching Box I – Earth Science
November 23	Evolution: Hits from Summer 2002	Science Homework for Young Experimenters
December 7	Square Wheels Snack Building	The Emergency Box
December 14	What Makes You Sick?	Kicking Off the New Year
February 15, 2003	Energy, Work, & Heat	Did I Teach Them Anything?
February 22	DNA Cars, Carts, & Newton's Laws	What's This & What Can I Do With It?
March 1		CMSESMC Math & Science Conference
March 8	Science & Math at the Zoo Art, Science, & Human Perception	Shopping For Science
March 15	California Academy of	Making & Using Power

	Sciences – Geology	Supplies
March 22	Math & Science Across Cultures	Testing
April 5	Cells	Map Reading & Orienting
April 12	Zone Plates, etc.	April 12 Positive Communications
April 26		Middle School Geometry
May 3	Astronomy Day	
May 10		Geology of Marin County

BIBLIOGRAPHY

American Association for the Advancement of Science. (1990). *Science for all Americans: A Project 2061 report on literacy in science, mathematics, and technology*. Washington, DC: Author.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Abd-El-Khalick, F., & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching, 34*, 673–699.

Aguirere, J. M., Haggerty, S. M., & Linder, C. J. (1990). Student teachers' conceptions of science, teaching and learning: A case study in preservice science education. *International Journal of Science Education, 12*, 381–390.

Aikenhead, G. S. (1997). Towards a first nations cross-cultural science and technology curriculum. *Science Education, 81,* 217–238.

Akerson, V., Abd-El-Khalick, F. & Lederman, N. (2000). Influences of a reflective, explicit, activity-based approach on elementary teachers' conceptions of the nature of science. *Journal of Research on Science Teaching, 37*, 295-317.

Anderson, C.A. (2004). Science education research, environmental literacy, and our collective future. *NARST News 47*(2), 1-5.

Atran, S. (1998). Folk biology and the anthropology of science: Cognitive universals and cultural particulars. *Behavioral & Brain Sciences, 4,*547-69.

Ball, D. L. (2000). Bridging practice: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education, 51*, 241-247.

Ball, D. L., & McDiarmid, G. W. (1990). The subject matter preparation of teachers. In R. Houston (Ed.), *Handbook of research on teacher education* (pp. 437-449). New York: Macmillan.

Bloom, J.W. (1989). Preservice elementary teachers' conceptions of science: Science, theories and evolution. *International Journal of Science Education, 11*, 401–415.

Borko, H. & Livingston,C. (1989). *Cognition and Improvisation: Differences in Mathematics Instruction by Expert and Novice Teachers.* American Educational Research Journal, 26(4), 473-498.

Bruner, J (1960) *The process of education*. Cambridge, MA: Harvard University Press.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: The Massachusetts Institute of Technology Press.

Carlsen, W. S. (1987). *Why do you ask? The effects of science teacher subject-matter knowledge on teacher questioning and classroom discourse.* Paper presented at the Annual Meeting of the American Educational Research Association.

Carter, K., & Richardson, V. (1989). A curriculum for an initial-year-of-teaching program. *The Elementary School Journal*, 89, 405-419.

Chinn, C., & Hogan, K. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching, 37*, 109-138.

Clement, J. (1982). Students' preconceptions in introductory mechanics. *American Journal of Physics, 50*, 66-71.

Colbert & Wolff (1992). *Surviving in urban schools: A collaborative model for a beginning teacher support system.* Journal of Teacher Education.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions.* Thousand Oaks, CA: Sage.

DeBoer, G. (1991). *A history of ideas in science education: Implications for practice.* New York: Teachers College Press.

Dewey, J. (1902). *The child and the curriculum.* Chicago: The University of Chicago Press.

Dewey, J. (1916). Method in science teaching. *General Science Quarterly, 1.*

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. *Cognitive Science*, 6, 37-75.

Driver, R., Guesne, E. & Tiberghien, A. (Eds.). (1985). *Children's ideas in science.* Milton Keyne, England: Open University Press.

Duit, R., & Treagust, D. F. (1998). Learning in science - From behaviorism towards social contructivism and beyond. In B. J. Fraser & Tobin, K. G. (Eds.), *International handbook of science education, part 1* (pp. 3-25). Dordrecht, Netherlands: Kluwer Academic Press.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development.* New York: Teachers College Press.

Elby, A. (1999). Another reason that students learn by rote. *Physics Education Research: A supplement to the American Journal of Physics, 67*(7), S53-S60.

Feiman-Nemser, S. (2001). *Helping novices learn to teach: Lessons from an exemplary support teacher.* Journal of Teacher Education, 52(1), 17-30.

Feiman-Nemser, S. & Parker, M. (1990). *Making subject matter part of the conversation or helping beginning teachers learn to teach.* The National Center for Research on Teacher Education (pp.1-17). East Lansing, MI: Michigan State University.

Feiman-Nemser, S., Schwille, S., Carver, C., & Yusko, B. (1999). *A conceptual review of literature on new teacher induction.* Washington, DC: National Partnership for Excellence and Accountability in Teaching.

Fensham, P. J., & Kass, H. (1988). Inconsistent or discrepant events in science instruction. *Studies in Science Education, 15*, 1-16.

Feynman, R. (1999). *The Pleasure of Finding Things Out.* Perseus Books, p. 320.

Fideler, EF. & Hasselkorn, D. (1999). *Learning the ropes: urban teacher induction programs and practices in the United States.* Belmont, MA: Recruiting New Teachers, Inc.

Fuller, F., & Bown, O. (1975). Becoming a teacher. In K. Ryan (Ed.), *Teacher education: The seventy-fourth yearbook of the National Society for the Study of Education.* Chicago: University of Chicago Press.

Gallas, K. (1995). *Talking their way into science: Hearing children's questions and theories, responding with curricula.* New York: Teachers College Press.

Galosy, J. (2005). *Between a rock and a hard place: Learning to teach science-for-all in an urban district*, unpublished doctoral dissertation, Michigan State University, p.395.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter knowledge and their impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge.* (pp. 51-94) Dordrecht, Netherlands: Kluwer.

Gopnik, A. (1996). The child as scientist. *Philosophy of Science, 63*, 485-513.

Grossman, P. L. (1992). Why models matter: An alternative view on professional growth in teaching. *Review of Educational Research, 62*, 171-179.

Grossman, P., Schoenfeld, A., et al. (2005). *Teacher subject matter.* Preparing teachers for a changing world: What teachers should learn and be able to do. L. Darling-Hammond and J. Bransford. San Francisco, John Wiley & Sons.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12*(1), 53-90.

Hanson, N.R. (1958). *Patterns of Discovery.* Cambridge: Cambridge University Press

Hewitt, P. G. (1989). *Conceptual physics.* Boston: Scott, Foresman, and Company.

Huling-Austin, L. (1986). What can and cannot reasonably be expected from teacher induction programs. *Journal of Teacher Education, 37*(1), 2-5.

Inagaki, K. & Hatano, G. (2001). *Young children's naïve thinking about the biological world.* Hove: Psychology Press

Ingersoll, R. M. (2004). Four myths about America's teacher quality problem. In D. Miretzky & M. A. Smiley (Eds.), *103rd Yearbook of the National Society for the Study of Education, Part I.* (pp. 1-33) Chicago: University of Chicago Press.

Ingersoll, R.M. (2003). *Is There Really a Teacher Shortage?* University of Washington: Center for the Study of Teaching and Policy. Available at: http://depts.washington.edu/ctpmail/PDFs/Shortage-RI-09-2003.pdf

Jarvis, T. & Pell, A. (2004). Factors influencing elementary school children's attitudes toward science before, during, and after a visit to the U.K. National Space Center. *Journal of Research in Science Teaching, 42*, 52-83.

Kennedy, M. (1998). Education reform and subject matter knowledge. *Journal of Research in Science Teaching, 35*, 249-263.

Kuhn, D., & Pearsall, S. (2000). Developmental origins of scientific thinking. *Journal of Cognition and Development, 1*, 113-129.

Kuhn, T. S. (1962). *The structure of scientific revolutions.* Chicago: University of Chicago Press.

Lederman, N. G. (1999). *Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship.* Journal of Research in Science Teaching, 36, 916-929.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching, 39*, 497-521.

Lehrer, R., & Schauble, L. (in press). *Scientific thinking and science literacy. In W. Damon, R. Lerner, K. Anne Renninger, & I. E. Sigel, (Eds,),* Handbook of Child Psychology, Sixth Edition, Volume Four: Child Psychology in Practice. Hoboken, NJ: John Wiley & Sons.

Lieberman, A. & Wood, D. (2003). *Inside the National Writing Project: Connecting network learning and classroom teaching*. New York: Teachers College Press.

Luft, J. A., & Cox, W. E. (2001). Investing in our future: A survey of support offered to beginning secondary mathematics and science teachers. *Science Educator, 10*, 1-9.

Luft, J. A., Roehrig, G. H., & Patterson, N. C. (2003). Contrasting landscapes: A comparison of the impact of different induction programs on beginning science teachers' practices, beliefs, and experiences. *Journal of Research in Science Teaching, 40*, 77-97.

Ma, L. (1999). *Knowing and teaching elementary school mathematics*. Mahwah, NJ: Lawrence Erlbaum Associates.

Mastropieri, M. A., Scruggs, T. E., Mantizcopoulos, P., Sturgeon, A., Goodwin, L., & Chung, S. (1998) "A place where living things affect and depend on each other": Qualitative and quantitative outcomes associated with inclusive science teaching. *Science Education, 82*, 163-179.

McDermott, L. C. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37*(6), 24-32.

McLaughlin, M., & Talbert, J. (2002). *Professional communities and the work of high school teaching*. Chicago: University of Chicago Press.

Miles & Huberman, (1994). *Qualitative Data Analysis*. Thousand Oaks, CA: Sage.

Mill, John Stuart. (1843) *A System of Logic, Ratiocinative and Inductive*. London: Parker and Son.

Morrell, E. (2004). *Linking literacy and popular culture: Finding connections for lifelong learning*. Norwood, MA: Christopher-Gordon.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

National Science Foundation. (1996). Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology. Washington, DC, National Science Foundation: 76.

Newport, F. (2004). *Third of Americans say evidence has supported Darwin's evolutionary theory: Almost half of Americans believe God created humans 10,000 years ago*. Gallup [2005, March 11].

Odell, S. J. (1986). Induction support of new teachers: A functional approach. *Journal of Teacher Education, 37*, 26-29.

Olson, S. (2004). *Evolution: A supplement to teaching about evolution and the nature of science*. Washington, DC: National Academies Press.

Penner, D. E. (2001). Cognition, computers, and synthetic science: Building knowledge and meaning through modeling. *Review of Research in Education, 25,* 1-35.

Pomeroy, D. (1993). Implications of teachers' beliefs about the nature of science: Comparison of the beliefs of scientists, secondary science teachers, and elementary teachers. *Science Education*, *77*, 261–278.

Popper, K. R. (1963). *Conjectures and refutations: The growth of scientific knowledge*. New York: Harper & Row Publishers.

Popper, K.R. (1972), *Objective Knowledge*, Oxford, U.K.: Clarendon.

Putnam, R. & Borko,H. (2000). *What Do New Views of Knowledge and Thinking Have To Say about Research on Teacher Learning?* Educational Researcher, 29, 1, p. 4-15.

Ravitch, D. (2000). *Left back: A century of failed school reforms*. New York: Simon & Schuster.

Romberg & Carpenter (2004). Powerful practices in mathematics and science: A research-based multimedia product for teachers, professional developers, administrators, policymakers, and schools of education. National Center for Improving Student Learning and Achievement.

Rosebery, A. S., & Puttick, G. M. (1998). Teacher professional development as situated sense-making: A case study in science education. *Science Education, 82*, 649-677.

Rudolph, J. (2005). Epistemology for the masses: John Dewey and the scientific method American schools. *History of Education Quarterly, 45*, pp.

Ryder, J., & Leach, J. (1999). University science students' experiences of investigative project work and their images of science. *International Journal of Science Education,* 21, 945-956.

Sanchez & Valcarcel, (1999). *Science teachers' views and practices in planning for teaching.* Journal of Research in Science Teaching, 36, 4, p.493-513

Sanford, J. S. (1988). Learning on the job: Conditions for professional development of beginning science teachers. *Science Education, 72*, 615-624.

Schauble, L., Glaser, R., Duschl, R. A., Schulze, S., & John, J. (1995). Students' understanding of the objectives and procedures of experimentation in the science classroom. *The Journal of the Learning Sciences*, *4*, 131-166.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3-103), Cambridge, MA: Harvard University Press.

Schwab, J. J. (1978). *Science, curriculum, and liberal education: Selected essays.* Chicago: The University Of Chicago Press.

Seymour, E. & N. Hewitt (1994). *Talking about leaving: Factors contributing to high attrition rates among science, mathematics, and engineering undergraduate majors*. Boulder, CO, Bureau of Sociological Research, University of Colorado.

Shouse, A. W., Galosy, J. A., & Wilson, S. M. (2003). *External evaluation of the Exploratorium teacher induction program.* Unpublished manuscript.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*, 4-14.

Smith, T. M., & Ingersoll, R. M. (2003, April). *Reducing teacher turnover: What are the components of effective induction.* Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Strauss, A. & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Strauss, A. & Corbin, J (1998). *Basics of qualitative research (2nd ed.).* Thousand Oaks, CA: Sage Publications Inc.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 211-231). Orlando, FL: Academic Press.

Thompson, M., & Paek, P. (2004). *Study of the impact of the California Formative*

Assessment and Support System for Teachers: Summary. Princeton, NJ: Educational Testing Service.

Tsai, C. C. (1999). "Laboratory exercises help me memorize the scientific truths": A study of eight graders′ scientific epistemological views and learning in laboratory activities. *Science Education, 83*, 654-674.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*, 673-695.

Veenman, S. (1984). Perceived problems of beginning teachers. *Review of Educational Research, 54*, 143-178.

Wenham. (1995). *Understanding primary science ideas, concepts, and explanations.* London: Paul Chapman.

Weiss, I. R., Pasley, J. D., Smith, P. S., Banilower, E. R., & Heck, D. J. (2003). *Looking inside the classroom: A study of K-12 mathematics and science education in the United States.* Chapel Hill, NC: Horizon Research.

Wilson, S. M., Galosy, J., Shouse, A. W., Spindel, A., Snyder, J., & Berry, B. (2001). *External evaluation of the Exploratorium teacher induction program.* Unpublished manuscript.

Wilson, S. M., Shulman, L. S., & Richert, A. E. (1987). "150 different ways of knowing": Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring teachers' thinking* (pp. 104–123). London: Cassell.

Windschitl, M. (2004). Folk theories of "inquiry": How preservice teacher reproduce the discourse and practices of the scientific method. *Journal of Research in Science Teaching, 41*, 481-512.

Wineburg, S. S. (2001). *Historical thinking and other unnatural acts: Charting the future of teaching the past.* Philadelphia: Temple University Press.