THE MEDIUM IS THE CULTURE:
A CASE STUDY OF ELEMENTARY SCIENCE EDUCATION

By

Paula Jeannette Lane

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Teacher Education

2002

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ABSTRACT

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In this case study, two teachers arrange students in small groups called "Coaching Teams" to learn science. These groups are unique in that they remain constant for the academic year, and are comprised of two 4^{th} graders, one male and one female, and two 5^{th} graders, one male and one female. The 5^{th} graders are "experts" to the process since they were members of the same class the previous year. The 4^{th} graders are "novices." Science lessons and Coaching Team activities were recorded on video tape over one school year. Eight focus students, members of two Coaching Teams, were interviewed after small group work studying air pressure and light. Findings highlight the dynamic of teaching, content, and small group work to help create a culture of learning. The Coaching Teams prove to be much more than small groups interacting with science phenomenon. The structure of these cooperative groups, supported by rigorous tasks and teaching that weaves elements of student and teacher talk, allows for independent learning and thought by the students. The case study provides rich material to inform educators about the complexities of science education and discourse dependent practices.

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ACKNOWLEDGMENTS

Thanks very much to my stellar committee; Jenny Denyer, Helen Featherstone, David Labaree, and Kathy Roth. Lynn Paine was an inspirational director and advisor. I could never have done this work without a host of other people providing endless support and good vibes. Both graduate school and the dissertation have been life-altering experiences and I am grateful for all the lessons learned. A very special thanks to Karen Miller for essential "pre grad school" support making all the rest possible. Thanks to Kevin Phipps for the ride to Michigan, and for making me miserable enough to want to leave where I was in California and move away. During graduate school I would have been lost without Kathy Roth and Elaine Howes, WISE women of substance, who keep teaching me how to advise, mentor, and be a good human being. Jocelyn Galzier earns the highest regard for everything from editing and writing tips to all the best things friends can do for you when you are under pressure and about to collapse. Many other friends were essential to my progress and final completion through all kinds of correspondence, gifts, and visits—Ursie Tocher, Mary "Smacker' Andriole and her family, Francene Trengrove, Teresa Fasola, Gerry Orgeron and Patrick Menser, Wendy Whan, Dara Sandow, Kara Lycke, Puja Batra, Conni Crittenden and Bob DeLind, Jesse Byron Markay for John Wooden and Harold Bloom, and many other pals I can't begin to list here. I am very grateful to my parents, sisters, nieces and nephew for always believing in me. Of course my greatest love and gratitude go to David Stocking who sacrificed almost as much as I did in pursuit of this advanced degree.

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Chapter One

Genealogy of the Case Study

> Nobody ever said reforming science education would be easy…the whole business of educational reform becomes much more difficult and complex as it moves from abstract statements to actual classroom practices. Underlying this point is a simple truth. Reform requires people to change… (Bybee, 1997 #431, p. 41).

> Researchers following the innovations into schools could only marvel at the extent to which teachers continued to do what they always did.
> (Olson 1982)

Budding Questions

In my first full-time teaching job I was assigned to a combination 3rd and 4th grade classroom. I had this position for two years, so I was able to observe the 3rd graders complete the 4th grade. One 3rd grader, Gianni, was a quiet, handsome, athletic boy, tall for his age. He was also an enigma to me. He never had a pencil of his own, though when he needed one, some other student provided it. The inside of his desk was a mess, yet he magically produced his social studies text or math assignment when asked. He was not a strong student, but he managed to get his work done. What was going on here? How was he doing it[1]?

As I paid closer attention to the students in class (and less to my own chaotic novice teaching) I began to find answers to my questions about Gianni. It was actually rather simple -- a group of girls took care of him and they proceeded to do this caretaking through 4th grade as well. Gianni had his own harem, and this was only the third grade.

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[1] One day in the lunchroom Gianni's kindergarten teacher told me that when she had Gianni as a student, she suggested to his parents that his counting skills needed some improvement. She told the parents they could help their son by having him do things like count out the silverware for setting the dinner table, or other such domestic chores with counting embedded in them. To the teacher's surprise, Gianni's father informed her that no son of his would ever set the table.

I'd be willing to wager that he made it through the rest of school in the same way he made it through 3rd and 4th grade, with female students more or less taking care of him.

Perhaps this was the beginning of my interest in gender roles in education. As a middle school science teacher in subsequent years, I saw social dynamics played out in a significantly different drama, one in which females dumbed themselves down when placed in mixed-sex groups. Although caretaking was still demonstrated by some girls, as I had observed in Gianni's class, it was the girl's apparent attitude not-to-know-or-care about science concepts that caught me by surprise. At this point in time, I was consciously trying to implement reforms as suggested by AAAS calling for science for all Americans (American Association for the Advancement of Science 1989).

I decided to conduct my own teacher action research project to learn about gender and teaching in middle school. I started with the students themselves. I asked all my 7th and 8th graders to complete a survey seeking their opinions on our science class, student dynamics, gender roles, lab activities. I ended with a question: Do you think single sex classes would help you learn science?

Anyone who has taught middle school probably knows how my diverse, inner city, multi-language students responded to this last question. They all <u>hated</u> the idea. They told me repeatedly they needed to learn from the other sex, that they needed to know how to talk to the other sex, that separation of the sexes would make school, and science class, really boring, and that separation was, generally, a bad thing. So much for my idea of single sex science classes to eliminate the gender roles I thought society had persuaded females to play.

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Since I conducted that first piece of really bad research (the survey for the girls was printed on pink paper and the boy's version was blue), I have spent a great deal of time trying to understand what the dynamics of gender are in the classroom and how it is manifested in individuals and groups. I considered the role of the teacher, the nature of the task and the community of learners that help define what is and is not acceptable in a classroom. I have tried to look both broadly at gender in schooling, and deeply at the particular interaction of gender and science education.

Starting with my personal interest in gender roles and moving toward the larger issue of the paucity of minorities and women seeking degrees in higher education in math and science, I have studied gender and science in education in graduate school and after. I don't pretend to have found any kind of panacea, or any single treatment, technique, or practice that might remedy the inequities. But in my dissertation, I take a close look at one practice, "Coaching Teams," employed in a local upper elementary science classroom. I think the practice offers hope for changing science education. I believe there is significant reason for teachers to consider implementing this practice with their own students. But I also believe this study makes clear the necessary interaction of several components in teaching. There is no single thing or "it" to help kids learn significant science concepts. We need to consider content, task, teacher and organization of lessons, to fully grasp what any single practice might offer. We need to look at the classroom culture.

Maturing Notions

When I began graduate school I was certain of only few things. One of these beliefs was that I did not want to study unsuccessful practices or bad teaching. I wanted to find the best t

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to find the best teacher I could and try to understand what motivated her, how she developed her practice, and what she considered the essential elements of strong teaching. Everyone I asked directed me to the same person and I was delighted to find that such a teacher existed just a few miles from the University. Soon I came to meet Conni Crittenden and her teaching partner of 8 years, Bob DeLind. Conni and Bob are teachers in the East Lansing area, known for their strong science program.

My study is based on Conni and Bob's classroom of fifty 4th and 5th graders. Over three years I spent time at the school as a University instructor, sometimes in their particular classroom, observing student teachers or helping University seniors with weekly field observations for their methods course. The data collection for my dissertation took place during one school year.

Prior to my dissertation study I spent time interviewing Conni about her life and her experiences in science education as part of a pilot study on science educators. She won the Christa McAuliffe Fellowship Award in 1995, and The Presidential Award for Excellence in Science Teaching in 1998. She was selected the Outstanding Science Educator of the Year from the Impressions 5 Science Museum in 1995, as well as being a finalist for the Michigan Science Teacher of the Year Award from the Michigan Science Teachers Association. Perhaps the most significant finding from my initial study was Conni's firm belief that the Coaching Team was the single most important aspect of the approach to science instruction she and Bob enacted. Her conviction was the genesis of this dissertation study: a close analysis of Conni and Bob's Coaching Teams.

Unlike conventional cooperative small-group strategies, Coaching Teams are a unique practice designed by Conni and Bob. The teams are cross age and kept together as a unit for a

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as a unit for a complete academic year. All teams are comprised of both boys and girls. (A sustained discussion of the Teams is found in Chapter 4.)

Their class, nicknamed "The Farside" after the Gary Larson comics, served as a starting point for my dissertation, and the questions I wanted to explore. I wanted to better understand gender issues and group dynamics, learning in science and best practices in science education at the elementary level. After Conni's suggestion that Coaching Teams were the most successful component of her practice, I decided to study this learning structure to help me think about issues related to equitable teaching. My first questions were rather basic; Just what was this "Coaching Team" arrangement and what was significant about it? Did it, for example, conform to other cooperative group learning practices or was there something unique about these groups? How are marginalized students affected by Coaching Team practice -- did it help or hinder those students in learning science concepts? Were standard gender roles sanctioned? What were the teachers doing to facilitate science learning in groups? Over time, I began to wonder what it would be like to participate in a small group for science lessons and to be with the same students for an entire school year.

I wanted to know what it was like to experience these Coaching Teams from an individual student's perspective and from my own perspective as well. This was important to me because of my previous teaching experiences and questions of pedagogy related to equity in science classrooms. Thanks to the cooperation of teachers, students and parents, the setting was ideal for a study of upper elementary students learning science in small group settings.

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After collecting data and examining it from the students' and my perspectives, I came to rethink key arguments in the debates about science education reform. If we look closely at the teaching in this room, we have an opportunity to reconsider assumptions about National Standards, content, cooperative learning and what supports student learning. My analyses took me beyond the basic questions I started with which were limited to a study of Coaching Teams. Through listening to students and observing their actions together, while simultaneously trying to understand the environment these students participated in, I came to think of the Coaching Teams as a demonstration of a unique culture. Fortunately the qualitative approach I had employed to study the Coaching Teams prompted me to more widely study the classroom context. In addition to collecting data on the Coaching Teams, I was also recording teacher actions, lesson details, and learning outcomes. Because of such an approach, and as my analyses of the data developed, I came to see my original questions as too narrow. This study was not about the Coaching Teams per se, but it was about a classroom culture that was affected by the existence of the Coaching Teams. This study answers the question, what are the engaging elements of teaching and learning in this classroom and how are the Coaching Teams a part of the whole?

Analysis of the data I collected allowed me to answer many of the questions I had originally considered but it pushed me past some of the details of practice to the nuances of cultural activity. I've tried to illuminate both the particulars of the classroom activities and magnify the less visible aspects of the culture. These findings might be useful in

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redirecting the conversation about groups and their place in the science education national reform agenda.

Case Study Rationale

As a former classroom teacher I have always believed teachers have a great deal of power to reform the system. I also believe teachers often do not learn of, and are not supported in, the best practices as outlined in research on teaching and learning. Teachers are somehow often left out of the loop on research until the final moment of implementation of a new practice or curriculum. They have few opportunities to think about what reform might look like in practice and few portraits that help them see the complexities of the many dimensions of teaching. To counter this fact I found a classroom where a well-respected pair of teachers instituted a unique practice for teaching science, and they believed this was the single most important aspect of their program.

My goal was to learn enough about this room to be able to develop a rich case study of the teaching and learning that went on there. I wanted to know if this special model might have value in the discussions on National reform of science education. The practice, named "Coaching Teams" by the teachers, involves students learning in small cooperative groups for science education. A case study approach would allow me to focus my attention directly on the teachers, the students and this classroom practice.

Benefits of a case study approach for this research are many. First, the data can "focus on naturally occurring, ordinary events in natural settings, so that we have a strong handle on what "real life" is like," (Miles and Huberman 1994). I chose to spend an extended period of time—a year—in the room so as to be able to witness events as they naturally occurred

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naturally occurred and to see things—introducing new content, students assigned a task, a unit in its entirety—occur repeatedly. By sampling two Coaching Teams, other students in the class, and the two teachers I could study the interactions, learning, and experiences of the students participating in small groups for science education.

The qualitative nature of the case study would allow for a flexible final analysis. I based the analysis on an inquiry approach that supported interpretations (Creswell and Shope 2002). From the beginning of the study I knew I was interested in the confluence of teaching, student small group work, content and learning. I knew I did not want to watch single events and have them represent the whole. As much data as possible was collected regarding science instruction, individual lessons, student feedback, conceptual understanding, student work, and teacher intent. The following is a table of all the data collected for the case study.

Type	Description	Quantity
Video tapes	Recordings of instruction of both teachers and two Coaching Teams as they completed science tasks—entire unit on air pressure recorded.	30
Interviews	Teachers (2). Eight students in the two Coaching Teams after each science lesson on the topic of "light," plus one exit interview each (56). Other students in the classroom after science lessons (20).	78
Student work	Complete science journals from eight target students in two Coaching Teams.	8 sets
Focus lessons	Complete unit on light was recorded in 8 episodes.	8
Other	Whole class pre and post tests on the topic of "air pressure" and "light." Anecdotal records.	

Figure 1: Data Collected Between January and July 2000

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Vignettes proved to be very useful in understanding Coaching Teams as "pockets" of rich data recorded on video tape (Miles and Huberman 1994). As Erickson noted, vignettes are a "vivid portrayal of the conduct of an event of everyday life, in which the sights and sounds of what was being said and done are described in the natural sequence of their occurrence in real time," (Erickson 1986). The study of the data was grounded in constant comparative procedures (Creswell and Shope 2002) and discourse analyses (Cazden 1988; Schiffrin 1994) .

I began to connect what I knew of the "Coaching Teams" strategy with discussions in the literature and at conferences related to "science literacy for all" -- the rallying cry from reformers in the late 1980s, early 1990s (Rutherford, 1990 #224). By using small group learning structures in their classroom, that were multi-age and that remained consistent over the academic year, perhaps these teachers had struck upon a method for science instruction that would, actually, allow for all students to learn science concepts. Perhaps these teachers had found a way to encourage female students and other marginalized students in the field of science. Conversely, maybe the Coaching Team arrangement was nothing special after all and had nothing to do with whether the students learned science concepts. Looking closely at the whole picture of teaching and learning science in this classroom had many potential interesting outcomes.

Questions About Learning

Chapter two is an analysis of the learning demonstrated by students in ""The Farside"." This chapter addresses the most obvious question to be considered before any other questions might be asked—did the students in this classroom learn any science? In this chapter I explore the pre and post testing results as well as evidence supporting the claim that studen

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claim that students in the Coaching Team setting, did, in fact, learn science concepts around the topic "light". The chapter concludes with a discussion about the nature of learning suggesting we think of learning more like images of waves and less like a model of a staircase. My study is organized to explore these possibilities.

Questions About Teaching

Chapter three is a study of what Conni and Bob did to create an environment which results in consistent success in student learning. In other words, this chapter foregrounds the teaching. In this chapter I attempt to uncover the special and engaging elements of dynamic teaching in the classroom. Process and content skills are discussed for their existence together instead of the usual separate teaching objectives found in state and district curricula (Michigan Department of Education 1991). The analysis begins with a review of the National Teaching Standards. By closely examining the particular approaches to content instruction in Conni and Bob's teaching, I advocate a new concept, what I call the Hybrid Model for teaching science which blends styles of teaching.

Questions About Coaching Teams

In chapter four I introduce the students observed most closely—two Coaching Teams of four students each. Vignettes are chronicled and analyzed that help explain student participation as science learners in Coaching Teams. Here I discuss literature supporting small group work for learning science and examine how Coaching Teams distinguish themselves from what today conventionally counts as group work.

The national reform documents for science education (and other subject matters as well) call for students to learn in small group settings. As the quotes from these texts provided bel

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> Using a collaborative group structure, teachers encourage interdependency among group members, assisting students to work together in small groups so that all participate in sharing data and developing group projects. (National Research Council, 1996 #346, p. 36).
>
> In doing science, it is often helpful to work with a team and to share findings with others. (American Association for the Advancement of Science, 1993 #343, p.15).
>
> The use of multi-age grouping can lead to significant changes and deserves serious attention, (American Association for the Advancement of Science, 1998 #344, p.119).
>
> The collaborative nature of scientific and technological work should be strongly reinforced by frequent group activity in the classroom (Rutherford, 1990 #224, p.189).

Coaching Teams contain several unique components. They include autonomy, longevity and muti-ageness for the small groups. A final discussion ensues considering Coaching Teams as their own evolving cultures.

Questions About Individual Students

Chapter five links issues of gender and science education through a discussion of how the Coaching Teams support the development of both males and females as science knowers and doers. Two students are highlighted from one Coaching Team. This chapter is my attempt at keeping the research closely connected to individual students. I suggest that we see the influence the students exercise on each other as a kind of "Reciprocal Cross."

In Chapter six I make explicit the problem of trying to study one aspect of classroom practice, such as Coaching Teams, in isolation from teaching and content. What began as a study of a small group learning strategy, and the associated details such as the lesso

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as the lessons taught and the teacher actions, became a more comprehensive study of the reflective nature of the various components. My study evolved from the specific questions of the role of the teacher and the nature of the science task students were asked to perform, to a study of a particular kind of classroom culture.

Before beginning the analyses however, I provide one lengthy example of one Coaching Team in action. My period of observation for the complete study was one year. During that time I saw many examples just like the one below, illustrating how students spoke to each other, the type of tasks teachers asked the students to engage in, and how children came to understand science ideas. I chose this particular instance because it is full of the type of interaction I came to believe was common in this culture.

Four Students Grapple with Air Pressure

I chose to analyze "The Farside" classroom because I believed it was rich with possibility for studying students learning in small group settings. As I began to collect data on the Coaching Teams I was buoyed by the quality of discussion I overheard among the students and I was encouraged by their behavior toward one another. It was both the cognitive component, the "eidos," and the group spirit, the "ethos," that were so impressive. In the course of my year with Conni and Bob, I hoped that by recording multiple science lab events I might capture moments, here and there, that might portray something essential about the students as they were communicating about science concepts, though I was never sure precisely what it was I was looking for.

No single recorded lab event demonstrated all the qualities catalogued in my final analysis of the case study—except one. On March 15th, I recorded Coaching Team One on digital video tape as they participated in the small group discussion phase of a lesson concerning

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concerning air pressure. I was fortunate to find that this single session was a particularly fertile event in which all the important elements of the small group work of this case study were encapsulated. What follows is a description of the setting for this episode and a synopsis of the specific fourteen minutes in which four students, two fifth graders and two fourth graders, try to make sense of scientific phenomenon.

Group Background

In October these four students began their Coaching Team or small group experience and they worked together at least twice a week on science experiments. The fifth graders, Emmalee and Sam, were in this class last year and are "experts" at the science Coaching Team set-up in this setting. Sarah and Matt are fourth graders, the "novices" who have only the past six months to draw on as a model. Generally the group works well together, determines what needs to be done rather quickly, and seems to enjoy performing the science tasks.

The seating arrangement, determined by the four team members, remains constant class after class, lab after lab. Each student sits equidistant from the others at round 6 foot tables. Arbitrarily starting with Emmalee, next is Sarah, then Donovan, then Sam. This means the two fifth graders are side-by-side, as are the two fourth graders, and the girls sit next to each other as do the boys. The students weren't instructed to sit this way, but most groups around the classroom opted to have girls next to girls and boys next to boys when they work in their Coaching Teams.

Lesson Context

During the hour preceding the relevant fourteen minutes, the students have been observing teacher demonstrations "in-the-round." The science lab is located in a part of the school building formerly used as a media center. There is a carpeted circular arena with two steps along the rim. Here students sit comfortably while they watch teachers conduct demonstrations, write on the overhead projector, or they might participate in whole class experiences such as "the Electron Dance" in the center of the circle. On this particular day the teachers provided the students with three different demonstrations to observe associated with atmospheric pressure.

First, the students watched Mrs. C, one of the two teachers in this multi-age classroom, try to "karate chop" a meter stick balanced on the side of a heavy industrial table. A single piece of newspaper covered half the stick on the table. The remaining portion of the stick extended out past the edge of the table ready for the "chop." It took Mrs. C several attempts before she successfully chopped the meter stick in half with her bare hand. This bit of comedy led to a discussion of atmospheric pressure measured in mathematical terms. The students calculated the area of the newspaper (23 in x 27 in = 621 sq. in). They considered the value of air pressure on earth, which is roughly 15 pounds per square inch. Then they calculated the actual pressure of air on the paper (621 sq. in. x 15 lbs./sq. in). It was the considerable weight of the air that helped pin the meter stick down on one side so Mrs. C could break it in half with her "chop." The initial demonstration in this "air pressure extravaganza," as it was called by Mrs. C, took about 25 minutes to complete and included questioning by the teacher, comments by students, analysis with the calculator, model drawings by the teacher on a large flip chart, and students writing in their science journals.

The second demonstration centered on a vacuum jar containing chocolate candy bunnies and lavender marshmallow "Peeps" candy bunnies. A hand pump was attached to the jar in order to remove air molecules. The air removal took much longer than anticipated, so the third demonstration began while the "bunnies in a jar" experiment continued with a student operating the hand vacuum pump instead of the teacher.

In the final air pressure activity, a student volunteered to be placed in a large clear plastic bag. Only the student's head stuck out at the opening while all his other body parts remained snugly inside the bag, and he sat on the carpet. Mrs. C tried to remove all the air from the bag by attaching a large industrial vacuum hose to the neckline of the bag and turning on the machine. The vacuum sucked the air out and Spencer was "shrink wrapped." This task was accomplished very quickly; from beginning to end it took about five minutes. After the laughing and commentary from students died down, the teacher asked questions and probed for students to make connections between the "Karate chop" and "Spencer in a bag."

As students began to speculate aloud as to what exactly happened to Spencer, Mrs. C returned to the bunnies in the jar. Students were directed to observe closely. While holding the jar for all to see, Mrs. C walked around the circle of students who were seated on the carpeted steps so that they could look at the bunnies up close. Next, she asked the students to write their observations and to predict what would happen when she let air back into the jar. What students saw was that the bunnies were larger and the outer "skin" was cracked.

The three air pressure demonstrations lasted a total of forty-seven minutes and when they were concluded, Mrs. C asked the students to get up from the carpeted area and proceed to their assigned Coaching Team tables for small group discussion. The groups were directed to confer in their teams in order to forge explanations of what happened in each demonstration and then to record the explanations in their journals.

Coaching Team One Goes To Work

It took Coaching Team One less than a minute to get to their assigned table, sit in their usual places on four legged stools, and open their science notebooks. Observing such behavior one is struck by the way in which the group seamlessly transitions from whole group to small group activity. Immediately upon sitting down Sarah states that they should start writing in their notebooks and she begins a brief exchange with Sam sitting across from her. Sarah says "I think I'll start like we did before—Today we..." and Sam says "Yes, today we, uh, watched bunnies im-PLODE." (This comment is significant because the bunnies were actually getting larger, as will be explained, and Sam will hold on to this erroneous notion until the very end of the Coaching Team discussion.) It is easy to see the students' excitement and enthusiasm for their task. Donovan is propped on one elbow, and Emmalee is likewise leaning in toward the center of the table. All four children are directed toward each other or the center of the table—they definitely look like a group of individuals who are familiar with one another and who feel comfortable working together. They laugh and make a few jokes about Spencer and the bunnies. It is Emmalee who gets the group back on task. She is the more serious member of the group, earnest and focused, a no-nonsense type of student. Her comment is an attempt at an explanation of the bunnies expanding and cracking in the vacuum jar.

Emmalee: When we sucked the air out it opened the pores and the air got out (pause), I don't know.

There is a break in the group talk, Sarah writes in her journal, Donovan looks on, Sam does some fidgeting. Then Sarah mimics Mrs. C trying to get the hand pump to work on the vacuum jar and the other members of the group laugh. Sam tells Sarah, "That's a good idea." It is not clear what he is referring to. When anyone speaks the other members of the group pay attention and turn their heads slightly to look at the person more directly. At this point in the episode, only a minute has passed since the students sat down and opened their notebooks to write.

Sam: So (pause) uh--

Emmalee: Can you guys think of any other experiments?

Sarah: There's Spencer and the bunnies...but we did something before Spencer...

Emmalee: We did...

Sam: Ruler!

Sarah: Ruler!

(It should be noted that the students in this group were very aware that they were being video taped during this session. I continued to record this group during science events through May 30th of that year and the observed behavior was consistent. Students always began quickly, stayed mostly on task, shared ideas, worked cooperatively and listened to each other.) After one minute and twenty-one seconds into the small group work, Mrs. C rings a bell, as a signal for everyone to stop talking and listen to her. Coaching Team One stops talking and each member turns to face the teacher standing up front.

Mrs. C: Every table needs to look this way. EVERY Coaching Team...You need to go through all of the demonstrations that we did and as a group decide what it is that's happening and what your conclusion is, explain it, and write in your journals in about ten minutes. So you are going to have to get right on task, and everyone needs to be included, and needs to understand what's going on and we will be checking back with you. (A student asks a question and Coaching Team One turns their heads back to the center of their table, to each other.)

Emmalee: We already went over this (tapping her science journal page where she has notes on the newspaper and meter stick demonstration) and its because she smoothed it out (Emmalee uses her hands to show smoothing out and Sam is looking right at her so she turns her gaze toward him while Sarah and Donovan appear to listen more passively than Sam) and all the air came out from under it.

At this point, Sarah has been listening patiently, but appears anxious to talk about another task, Spencer in a bag. She helped name the experiment as it was happening during the whole class segment and has something of a proprietary interest. She also seems intent on moving past the newspaper demonstration, perhaps because it is one of the more difficult experiments to comprehend and explain. Sarah is a fourth grader who exudes confidence and self-assuredness. She is obviously very verbal and always eager to contribute in the small group setting. She displays a vibrant sense of humor, and seems to have a good sense of herself as well.

Sarah: Spencer in a bag, he couldn't move because—

Emmalee: Spencer in a bag (laughing).

Sarah: That's funny, I named that (laughing). I went, Spencer in a bag. And then he couldn't move because the air pressure was hard on his--

Emmalee: Tight on (She puts her arms across her chest and bends over as Spencer did when he was in the bag). The air was so tight on him it made a seal (the use of "seal" replicates the terminology the teacher had used regarding vacuums during the bunny discussion).

Sarah: There's no, um, air in the bag, so it just went straight around him, there was more air pressure pushing on him--

Emmalee: He kinda like shriveled up because--

Sarah: He couldn't move because of all the air pressure on top of him.

During this exchange the two girls are looking at each other. Donovan is writing in his notebook and Sam is looking on intently, also writing at intervals. Now, Emmalee turns to her right to talk directly to Sam, as if to convince him of her point about the air pushing on Spencer, he nods and she continues while Sarah looks on.

Emmalee: The air pressure was pushing on him, trying to get in so he looked like that (arms across chest).

Sarah: If you did that for a long time, I bet that it would probably (eye brows raised, leaning on one elbow, backing off a bit from her adamant stance, lowering her voice as if to question this point herself) kill you.

Emmalee: If you put your head in there (nodding), DEFINITELY!

Sarah: Yea, but I mean, it's like, it would—

Sam: Yes, long enough (crossing arms on chest)—

Sarah: Your heart, if it happened long enough it would probably, your heart would burst--

Sam: Yes, it would probably be really hard—

Emmalee: You could lose your circulation.

Through this discussion Donovan has been looking from speaker to speaker, writing in his notebook, leaning forward and seems intrigued by what his peers are saying. Sarah is suddenly lost in thought, staring at the center of the table, hand to mouth, pondering something. This time it is Sam who brings the group back to the task at hand. He is the calm, understated sort of student. Sometimes in the group, he acts older than his years, and he seems to have a perception of the team as a whole unit that is unusual. He can stand his ground, share, or be quiet while others talk, each with minimal effort. Sam anchors the group by understanding what is worth worrying about during complicated labs and knowing when the group ought to seek help from the teachers. It was in character for him to step in with a leader-like comment next.

Sam: Yeah, okay. So our conclusion for the Spencer thing is, um, --

Sarah: That he couldn't move because the air was so, the air pressure was so, um, hard outside it was – I don't know how to put that but I understand it.

Sam: I understand things, but it's hard to put down.

For almost a full minute, the four students write silently in their journals.

Sam: And then the conclusion for the bunny thing is all the air was taken from—the—

Sarah: From—the—

Sam: From—the—

Sarah: From the container

Sam: Yeah--

Sarah: (To Sam) And then so the bunnies started to like crack and everything cause they were sure blowing up like what happened to Spencer.

Sam: (To Sarah) The thing is they were kinda getting bigger also so they can't really be shrinking

Emmalee: (To Sam) Well, see they'd be--

Sarah: No, but they got so their insides were growing—

Sam: Oh yeah.

Sarah: --And that's what made the skin crack.

Emmalee: (Stating the obvious to Sam) But WHY were they growing?

Sam: Yeah.

During this exchange Donovan has been following along, looking at whomever is speaking, sometimes nodding, and sometimes wearing a confused expression on his face. The group falls silent for a few seconds.

Sarah: Maybe, but it seemed like if you sucked all the air out they'd get so big it would fill up the whole container but I don't exactly know why.

Sam: That'd be funny if Mrs. C pumped that long enough that they were getting like huge.

Sarah: I know and they'd be like hey—

Emmalee: (inaudible…) maybe open the jar—

Donovan: Maybe it has something to do with marshmallows.

This last comment, which was a first for Donovan in this session, occurred at 4 minutes and 50 seconds of the small group processing time. Though he has been quiet for nearly five minutes, his timely suggestion shows he was completely alert and aware of what the other students were saying. His comment is appropriate and clever—perhaps the bunny demonstration has an explanation related to the nature of the marshmallow candies themselves, something nobody had mentioned. On the other hand, Donovan's comment is somewhat unrelated to the other comments made to this point. The other students giggle at the idea.

Donovan is a quiet and relatively immature fourth grader. Sometimes he appears to be lost in his own world. But he is a smart kid who comprehends and thinks deeply about some topics. He seems to want to make a contribution to the whole group while simultaneously listening and learning.

Emmalee: Okay, so--

Sam: I've actually, uh, microwaved a "Peep" (candy) before (Emmalee, Sarah and Donovan sit expectantly looking at Sam), they get huge (pause). So what's the, our conclusion?

Emmalee: So first, they pumped the air out--

Sarah: The same thing that happened to Spencer—NO—it's not the same thing because that had a seal (again, "seal" is used referring to the previous explanation concerning vacuums and other well-known experiments relative to air pressure and vacuums).

Emmalee: It's not like Spencer got bigger.

Donovan: (in a mocking, joking tone) Spencer got BIGGER!

Sam: If anything, he got smaller, scrunched up.

Emmalee: Yeah.

At this point in the video tape it is striking how each of the four students wears the same struggling, perplexed expression on their face. Sarah looks around, Donovan's eyes dart from person to person as if to say "don't you know the answer" and Emmalee puts her hand to her mouth in a puzzled way.

Emmalee: Maybe the—

Donovan: (To no one in particular) Bunnies could shrink—

Emmalee: Bunnies stretched when, when we took out all the air, they were trying to, trying to, I don't know.

Sam: (Rather irritated) I don't know!

The students have been working on the air pressure problems and the whole class demonstrations for five minutes and thirty-eight seconds. They have hit a wall and seem to be getting frustrated or bored or both. Donovan is looking around at another table of students, Sarah has slumped back in her chair away from the table, and Emmalee and Sam are both smiling, almost giving up. Then Sarah makes a claim to clarify and de-anthropomorphize the marshmallow bunnies.

Sarah: Candy bunnies do not breathe. We know that for a fact.

Sam: Yeah.

Sarah: Unless Mrs. C was trying to pump them up (she mimics repeated blowing into some imaginary small item cupped in her hand as if to blow life into it).

At this moment the student teacher (ST) in this classroom enters into Coaching Team One's space, placing herself between Emmalee and Sarah and she asks "What are you doin' there?" Donovan says "their heads were popping" but this is really said to nobody in particular. Emmalee, Sarah and Sam all try to share something at once; Sam wins the floor. Both he and Sarah now mime tiny CPR-like pumping movements with their forefingers on their imaginary bunnies located on their open notebooks. They are breathing life back into the "Peeps."

Sam: Mrs. C, about bringing a "Peep" back to life with CPR.

Emmalee: It's the same thing like on TV…

ST: Oh, like those infomercials. Now what did you guys find out?

Sarah: That we know what happened to Spencer and the ruler, but we can't figure out the bunnies.

ST: What similarities do the ruler AND Spencer, shrink wrapped—

Sarah: Pressure!

Donovan: Air pressure!

Sam: But the pressure was like all pushing on the bunnies so they were starting to like—

From this exchange it is easy to see Sam's fundamental misunderstanding regarding the bunnies in comparison to Spencer in a bag. Sam is still holding on to the idea that removing the air from the bag that was around Spencer is equivalent to removing the air around the bunnies. But everyone at the table knows there is something fundamentally different between these two examples, but they aren't quite able to characterize it. They are struggling with the fact that the bunnies are in a vacuum container. Sarah is sure of herself and in order to clarify, shares next.

Sarah: The pressure wouldn't be pushing on the bunnies because there is no pressure in it.

And Emmalee articulates the difference between the two examples with her next comment.

Emmalee: But see, Spencer, kinda got smaller and the marshmallows got bigger.

Sarah: Yeah.

ST: Spencer got smaller?

Emmalee: Spencer didn't physically get smaller but he looked smaller.

Sarah: But Spencer had air pushing on him but the bunnies didn't because of that --

Emmalee: So Spencer was inside, and the vacuum sucked, pulled out all the air, so that the air pressure was pushing on him so much that he got (inaudible), and he couldn't move, but—

Sarah: Maybe Spencer couldn't move, the bunnies could?

ST: Maybe if they were alive, do you think they could have? I wonder.

Emmalee: If there's no pressure it doesn't--

Sarah: I wonder…

Donovan: Well, we'll never know.

Sarah: I wonder if we pushed so much on the bunnies, like it was in space or something, they would float up, like (sitting upright and spreading her arms as if she were floating, weightless and in a sing song voice) do do do do (trying to replicate science fiction music sounds)?

Donovan: (Directly to Sarah) That's what I thought was going to happen – they were going to float.

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Now the ST moves on to another Coaching Team. Because Sarah has demonstrated her "what if" and shared this idea of floating, Donovan remembers (one presumes) the prediction he made during the whole class demonstration.

Sam: (Getting the group on task, again) The reason for it—

Sarah: Do-do-do-do-do (singing and continuing to demonstrate little bunnies floating, and laughing at herself)

Sam: Sure there is a way to do that.

Emmalee: Okay, so why would they be (inaudible), there's no pressure on them, so (inaudible)

Sam: I think that the shell was starting to get pushed in and that's why it seemed to get bigger because it was getting pushed in and then the marshmallow or whatever was in it started spewing out it's like it's getting so tight it's squeezing it and everything out of it.

Sam still holds on to the crushing notion of the bunnies in the jar, as his earlier comment about "implode" showed, though that isn't the accurate scientific explanation for the skin cracking or their increase in size. He continues to misunderstand the nature of the vacuum jar and the associated examples given during the demonstration concerning pressure increasing at the bottom of a swimming pool, and decreasing as a plane climbs in elevation and why pressurized cabins are essential for humans to fly in airplanes. Eight minutes of small group discussion time have passed.

Emmalee: But if there is no pressure pushing on you, would that make you expand? It seems like it wouldn't.

Donovan: I don't know (yawning).

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Emmalee: If not it seems like it might kinda be. Like you would lose your form.

Sam: Yeah (yawning).

Emmalee: So there is no pressure pushing on them (looking over her shoulder to where the bunnies are in the jar on the table).

Sam: They were—I don't know. Don't have a clue. Um—

Emmalee: (To Sam) If you sucked out all the air would that open like not pores but whatever of the marshmallows so they'd be getting, trying, not trying—

Donovan: Were they heated?

Emmalee: (Ignoring Donovan's comment)-- to get more air, but, it would be opening up the pores so that the air would be going in?

Sam: (To Emmalee) Yeah.

Emmalee: But that doesn't have anything to do with Spencer in a bag. Pulling out all the air—(pause)—you know that the air is going in somehow, to the rabbit, to make it puff up.

The students have been relating facts previously grasped, discussing logical schemes, and considering possible alternative explanations. For the most part, they have kept to the task, and listened intently to each other. Almost ten minutes have transpired and many concrete issues have been asserted and they form the basis for the discussion. Donovan keeps trying to offer ideas that are quite imaginative ("maybe it has something to do with the marshmallows" or "were they heated up?"). Sarah and Emmalee index observable phenomena: bunnies don't breathe, they puffed up because air got into them. This group has earnestly tried to understand what they observed by building on one another's comments and offering the best ideas they can come up with. Personal experiences are

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experiences are added (Sam has microwaved "Peeps" before) as are humorous notions of floating bunnies in space or performing CPR on candy bunnies. The students often gesture with their hands to clarify their explanations.

At 9:53 another student comes over to the group to say "Hi" to Sarah—these fourth and fifth graders are probably at their limit for discussion without further help from the teacher. It seems unlikely, at this point, that giving the students more time will have any positive effect. They have gone as far as they can. But Sam continues to try to make sense of the bunnies and refers to Emmalee's comment that air had to be getting into the bunnies for them to puff up.

Sam: But there isn't any air in the thing.

Sarah: No. Air could be going in to push it up because there's no air in it.

Sam: So you're taking all the air out of it.

Sarah: Well, how do we know the bunnies got bigger?

Sam: We don't. I don't even think they did get bigger, I think their shell started to like crack and tried to get smaller so the insides squished out and making it APPEAR to look bigger.

Donovan stood up at this point, moved around his seat, and readjusted himself, his notebook and his pencil. Emmalee is sensing that time is running out for the group work and she asks:

Emmalee: Do we just want to go with that?

Sarah: No, but it doesn't have anything to do with Spencer.

Emmalee: Well, it kinda would.

Sam: I don't know.

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Donovan: Science – never—(inaudible).

Sarah: Maybe, the air, cause there's no air in it, the bunnies they just like there's no air totally, so the bunnies already had air in 'em before they went in, so it's probably sucking the air out and while it's doing that is doing that it probably kinda sucked the bunnies apart (Her arms move up, she makes a monster image of a big bunny, then she growls).

Sam: Yeah (nods, smiles).

Emmalee: Nah.

Sarah: That could work and then it splits down the middle 'cause it had to pull out.

Emmalee: So they're sucking out all the air and they—

Sarah: Slowly.

Emmalee: Burst.

Sam: PULLING all the air (in reference to the teacher demonstration portion of the lesson where Mrs. C insisted that the students use find a word other than "sucking" to describe vacuum action).

Sarah: PULLING.

Sam: Not pulling, I mean, not sucking.

Sarah: They pulled all the air out and there had to be some air in the bunnies cause different size molecules.

Emmalee: So their skin would crack?

Sarah: Because, because it was like pulling them this way (and she pulls on her own arm, says "help").

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Donovan gets up, moves around his chair again.

Emmalee: The bunnies got bigger because, uh, can they really get bigger?

Sarah: The skin ripped and then the insides went bleahk (she gestures her insides coming out), maybe they had air in them too (referring to the organs or whatever is inside a bunny) and go bump-UMP, bump-UMP (laughing) and sucking, pulling the insides out to get all the air.

Donovan: Their heart was pounding so fast it burst it through.

Sarah: I thought they were going to shrivel up (referring, presumably, to earlier whole class predictions) like little (inaudible).

Sam: I've actually seen that trick before. Mrs. C had like a different pump.

Emmalee: I think it's the same thing only it's not electric.

Sam: From a long time ago when my sister was in the class. Mrs. C did it with a "Ding Dong."

Everyone smiles and looks up at Sam.

Emmalee: Mrs. C did it with a "Ding Dong?"

Sam: Yes. Those little snack cake things? It puffed up and then it shrank.

Sarah: I don't even like "Ding Dongs." It would be funny if it exploded.

Donovan: What if it got so big it exploded?

Emmalee: (To Donovan) Well, the skin would start cracking, peeling off.

Sarah: (Emphatically) Because it got pulled—psshhhhhh (making the sound of escaping air). I have to do sound effects.

Emmalee: So if the air was pulling it kind of apart wouldn't air be getting, wouldn't the cell be getting some air, and some air is getting sucked out and some air is trying to get to the marshmallow.

Sarah: Yes, "Don't let 'em take me. Don't let 'em take me!" No they all grab the bunny air molecules (she is laughing and smiling). That wouldn't make sense though.

Sam: So, I know the "Peeps" have to have some little spaces in them, little air pockets—

Emmalee: So when the pump was trying to pull out all the air, when there was air pulling the bunnies bigger so some air got out but air was still trying to get into the bunnies.

Sam: Yeah. I guess.

Emmalee: It seems like if the air was pushing it wouldn't they get smaller?

Sarah: The air pressure was unequal, we know that, inside than outside. It was pushing on the jar.

Emmalee: I don't think it would affect the bunnies at this point.

At 14:20, the teacher rang the bell for the second time and Sarah and Emmalee began writing in their journals. The ST spoke to the class and this lesson concluded with the discussion to be resumed at a later time. For now, the students had to clean up and go to lunch.

Further Analyses

The transcription above provides a portrait of one group of students working as a Coaching Team discussing three demonstrations offered by their teacher. The topic was atmospher

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atmospheric pressure. After analyzing the transcript and studying the children on the video tape, several points became evident.

The flow of the discussion is exceptional. The students listen closely to their peers at the table and readily build a conversation around each other's ideas. Rarely are comments made that seem to come out of nowhere. In addition, vocabulary is linked from the teacher talk to the small group talk (the use of the term "seal"). Other recorded lessons demonstrated similar direct language connections (see Appendices R-U). The genealogy of a particular usage could often be traced within a lesson and between lessons.

Besides language links, there are many instances where the students bind concepts, either related to the unit topic, or related to other topics and units. In this case, Sarah, Donovan, Sam and Emmalee make references to knowledge about humans and other living things, such as animals, and what might happen should the similar conditions prevail as the candy bunnies endured. The four students added personal vignettes to the mix, as when Sam refers to his own history with microwaves and marshmallow candies and/or when Emmalee mentions a past experience of Mrs. C and an electric pump.

The very fact that the students questioned each other is also remarkable. The students frequently pose questions or formulate explanations cast as questions. Sometimes these questions are answered between members of the small group and other times they remain unanswered. But it is easy to see how these probes help propel the group along and force the students to think hard about the concepts under scrutiny.

Another strength of the Coaching Team revealed here is the group's active engagement around ideas. Students argue animatedly with each other and display imp

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impressive confidence. They stick up for their ideas, and persistently construct explanations through the course of the small group time segment. In this example, Sarah refines her ideas over the entire 14 minutes. Students appear to grasp ideas in a pattern that is decidedly non-linear. They do not suddenly "get it," nor is anyone completely lost about what the substance of the lesson and the underlying principles the teachers obviously were trying to impart. It is evident that the move to a highly sophisticated level of understanding (one at which a learner can distinguish the nuances between "Spencer in a bag" and "Bunnies in a jar") is a process more like overlapping waves rather than steadily ascending stairs.

The picture painted above which shows the quality of learning and the nature of the small group work in the ""Farside"" classroom is illustrative of the practice in the classroom year round. The students exhibited the same patterns of talking and listing to each other every time they met in their Coaching Teams. The teaching that frames the student work along with the multiple examples of students' engaged in Coaching Teams forms the bulk of my dissertation. The case study illustrates how Coaching Teams have culture, a direct result of the larger classroom culture.

Chapter Two

Properties of Light: Challenges of Physics Concepts in the Elementary Grades

Introduction

The knowledge we are trying to impart in elementary science education falls into two categories – content knowledge and process knowledge. Content knowledge can be described as the actual ideas, concepts and facts of the discipline. Process knowledge might be described as the manner in which the content is learned, discovered or studied. For instance, Newton's Laws are concepts. In order to study this content we need knowledge of methods for data collection on moving objects, friction or drag coefficients, as well as skills necessary to engage in inquiry about the subject. Content is what is to be learned and process is the manner in which the content is to be taught -- observing, data collecting, inferring, summarizing, hypothesizing, measuring, testing, etc.

What makes teaching science concepts so difficult anyway?

Among the three basic categories of sciences content—earth, life and physical--physics is generally considered the most rigorous of all. Light and its properties (how light behaves, what light consists of, how light travels) is especially challenging to teach to children in elementary school. If a teacher merely wanted students to memorize facts about light, such as that light travels at a particular speed, then teaching about light might not be so hard. But because the ultimate goal of science teaching ought to be a grasp of concepts, not just the development of a mental database of memorized facts, teaching about light is a formidable task.

Another difficulty with teaching and learning science content is that concepts are often counter-intuitive (Tobias 1991). As Duschl explains, "The educational path to understanding the nature of science is a path that requires an epistemological break with common sense, or what I refer to as a boundary crossing from sense perception 'folk explanations' to theory-driven science explanations," (Duschl 2000). It seems logical for instance, that the phases of the moon are caused by the earth's shadow, because the shape of some phases is crescent-like. We would expect such to be the case because the earth is round. This is not, however, the explanation. The phases of the moon have nothing to do with the earth except that we see the moon from our position on earth[2]. Nonetheless, children and adults often explain the phases of the moon through the "shadow from earth" theory.

Teaching and learning about science is rendered even more difficult because phenomena to be studied are often impossible to see, touch or feel. In the field of life science, for example, viruses, microbes, and cellular activity require very specialized equipment to observe. The same is true of astronomy. Both cellular and planetary activity remain, for the most part, elusive and abstracted topics because of the almost unimaginable sizes or the fantastic distances we have to grasp in order to fully comprehend the content.

For many elementary teachers then, the difficulties of teaching concepts proves too great to overcome. Most elementary teachers don't bother to try to teach much science and if they do, it is generally restricted to rote learning of "facts." Teachers

[2] The phases of the moon are caused by several factors including the relative positions of the earth, moon and sun, the rotation of the earth on its axis every 24 hours, the rotation of the moon around the earth once about every 29 days, and the reflective property of the moon as the sun's light shines on the surface of the earth's only satellite.

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themselves often have a limited understanding of science because they are products of the same kind of teaching in their own educational experience and are generalists (Asoko 2000). "Many of them have found their own education in science uninspiring and uninteresting and approach the teaching of it with apprehension, particularly those aspects which they have never studied or which they found difficult," (Asoko 2000). Thus, science in elementary school ends up as an amalgam of disparate, unrelated facts like the names of the planets or the parts of a cell. The contexts in which science takes place, how concepts are shaped, and how meaning is made of experiment results, are missing (Duschl 2000). Walking into almost any elementary school in the United States and searching for evidence of rigorous science instruction will leave an educator frustrated. If science is taught at all, it is usually superficial and fact based. The teaching and learning of fact based science yields products limited to mobiles of the planets in our solar system or models of volcanoes spitting up chemical reactions generated by mixing baking soda and vinegar – a chemical reaction that is completely unrelated to the scientific explanations of volcanoes, lava or magma in earth science. Models, such as the mobiles, and their associated tasks, don't help a learner gain much in the way of conceptual understanding of the central ideas associated with astronomy or volcanology. Yet, it is easy to understand why this occurs – teaching students science concepts is hard work.

Room 17: "The Farside"

There are, however, some shining stars in the field of elementary science education. For my study I found a multi-age classroom where two teachers of 50 fourth and fifth grade students were not afraid to teach difficult science in a sophisticated conceptua

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conceptual manner. Both teachers had substantial science content knowledge. Science was taught often and always with enthusiasm and substantial pre-planning. At the same time the teaching was frequently messy, the student work difficult and the concepts quite complex. By this I mean, lessons extended beyond the allotted time, students broke equipment, children misbehaved during lessons, and the classrooms and labs were usually noisy and busy – maybe even chaotic. So the site for the study was not problem-free, nor was it a model in which every student learned every concept perfectly, as the teachers would have hoped. It was, however, a place where engaging conceptual science teaching was undertaken and usually met with a high measure of success. Given reform calls in science education, such a classroom is important to study as the images it offers are what reformed science for kids look like.

In this chapter I explore content taught in this particular classroom and catalogue some of the associated misconceptions held by students. This foundation will enable a determination of the extent to which students grasped content and concepts for the eight subjects in my study. Finally, I will end the chapter with several questions this case study raises that challenge our current thinking of didactic teaching, learning theories, cooperative learning practices, and the national standards in science education. These questions lead to further insights about what it means to study learning in relation to science education. The subsequent chapters explore possible responses to these questions.

Content: Light

Discussions about student learning in science regularly omit two essential elements, namely, what are the details of the content to be taught and what did the students k

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students know about the content before any teaching took place. Often, there is no correspondence between what the learner knew before the teaching events began and what she or he knew after they were completed. Without knowing what students usually get wrong about an idea, and how tenaciously they hold to misconceptions, as Sam does in the vignette in Chapter One titled “Four Students Grapple with Air Presuure” (Fensham 2000) in relation to what the canon tells us is right, there isn’t any way to appreciate the degree of any learning that has taken place. Science is a conceptual discipline requiring counter-intuitive knowledge in order to be fully grasped, so science teachers need to have a sense of just how difficult the concepts are to learn and just how far a learner must travel to become scientifically literate about the concept, if they are to become any wiser about the process of teaching science.

In this case study, most data was collected relating to the teaching and learning about light. Student pre and post-tests, student drawings, student lab notebooks, video tapes of student groups engaged in science tasks, and student interviews were compiled. Before assessing what was learned by the fourth and fifth grade participants it is essential to understand what could be learned about the topic – what were the concepts associated with light a student might come to understand. How does a scientist define light and what part or parts of that definition should elementary students know and understand?

What does a physicist know about light?

And what should children learn about light?

“For the physicist, light is an entity that propagates in space from a source, that interacts with objects it encounters in its path and then produces various perceptible effects (warming, a contrast between zones differently illuminated or which reflect light differently). It possesses a certain number of properties: in homogeneous space, it propagates along straight lines; its speed of propagation is finite, i.e. light always takes a certain amount of time to travel from one place to another; it can disappear, partially or

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totally, when it crosses a material medium, and is conserved as long as it dos not encounter any absorbing medium," (Guesne, 1985, p.10).

Such a definition of the properties of light might be translated into some version of the following list of facts that would subsequently become objectives to be learned in the elementary grades:

- Light is a form of radiant energy to which our eyes respond.
- Light travels in a straight line.
- Light travels at a speed of about 186,281 miles per second, which is very fast and significantly faster than sound travels.
- White light is comprised of all colors, and individual colors are determined by their differing wavelengths.
- There are many sources of light, both natural and artificial.
- Not all light can pass through all substances.
- Shadows are the result of blocked light.
- Reflection occurs off a smooth or shiny surface at the same angle it hits the surface – angle of incidence and angle of reflection.

Units of instruction about light might focus on the concept of light as energy. Or, they might focus on light and color, light and shadows or a single aspect of light as necessary for plant growth or the act of seeing by animals.

Misconceptions of Light: What the Students Don't See

We know children do not enter classrooms void of concepts about light. In fact, many students have strong beliefs about what light is, where it comes from, and its effects (Driver, Guesne et al. 1985; Driver, Asoko et al. 1994; Driver, Leach et al. 1996). However, what students know about light is not usually "scientifically" correct. Though there are t

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there are undoubtedly idiosyncratic notions held by some students, misconceptions have been found consistent among children when interviewed (Shapiro 1994). What the child knows about light is often contrary to what a physicist knows about light. For instance, children generally identify light with its source and/or its effect, but rarely understand that light is an entity in space (Guesne, p. 11). From this, we might conclude that students hold ideas of light as something to be seen in a light bulb or in the sun, or, that light is found on the ground or on a wall because it got there from some light source – but not that light is in the space in between. Students' less sophisticated views of light do not allow for any explanation of light moving nor would they help explain shadows (Guesne, p. 12).

Similarly, researchers have discovered that students do not understand light as reflecting off any surface other than a shiny one, like a mirror. When asked to compare a mirror and a white piece of paper, each with a flashlight shining on it, students said that only the mirror caused a reflection (Guesne, p.20).

Several other researchers found that students hold a host of misconceptions about light. Piaget was the first to write about a phenomenon where students generally think light and vision occur from the eye to the object, not the reverse (1974, p.103). La Rosa, Mayer, Patrizi, and Vincenti (1984) suggest that students who do believe that light moves from source to object may use an analogy that includes a means of connection from the source to the object, like a wire or road. Fetherstonhaugh & Treagust (1990) noted that three quarters of the students in their survey sample held the idea that visible rays of light are reflected not from the source to the object to the eye but through the person's act of looking at the object. Watts (1984, 1985) noted that most children view light as necessa

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necessary to illuminate objects, and that light remains around objects whether the observer is present or not. Additional work has been done to expose student's continued misconceptions of shadows, darkness, color, and light on surfaces (Shapiro, 1994). This body of work on students' misapprehension regarding light illustrates the point that teaching this topic -- helping students understand the properties of light – is no easy task. Previously held misconceptions stand as an obstacle to an understanding of light in the same way a physicist understands it.

Claims of Student Learning About the Properties of Light

This chapter is about learning in science in a particular classroom. With some working knowledge about the properties of light and the varied ways in which children misunderstand them, we can now appreciate what the students in the case study had to overcome in order to develop a more sophisticated knowledge of light. We can now compare what the students first knew and what they came to understand through participating in the science unit.

Students' views were as expected at the inception of the unit--naïve--and frequently erroneous as compared to the scientific canon. They demonstrated the types of misconceptions relating to the concept of light as reported in the literature.

By the end of the unit, however, the students in this study demonstrated a sophisticated knowledge about light – in line with what physicists would claim is correct – compared to their previously held naïve views. There is abundant evidence that students altered their notions in the course of instruction. Misconceptions were altered and individuals moved closer, if not right on, to canonical views of light.

Evidence: Pre and post drawings

Figure 2 summarizes the analyses of features about light from the pre and post drawings[3] created by fourth and fifth grade students when asked to draw a picture of any light source with any other object either inside a room or outside on the playground. The expressions demonstrate factual and conceptual knowledge about light.

The chart is arranged with the student's identifying code letters on the left side and the delineation of "pre" for the drawings made before any of the lessons on light took place, and "post" for drawings made after the unit was complete. Seven features are listed across the top of the chart and relate to the specific content ideas in a unit on light for elementary students.

Features 1, 2, 3 and 4 (F1, F2, F3, F4) are related to rays of light as drawn by the student. A naive conception-based drawing regarding light might show no rays, whereas the more sophisticated drawing (and hence, the more sophisticated conceptual understanding) would include rays drawn from the light source to the object and then stopping. Short rays that do not extend all the way to an object show an understanding of light in the form of rays, but not necessarily the more advanced understanding of light traveling unencumbered infinitely, unless blocked or absorbed.

Feature 5 is concerned with shadows. If the student understood that a shadow is caused by an object blocking light rays, and that shadows and rays are connected to the big picture of light, then the presence or absence of a shadow in the drawing would yield insight into the student's thinking.

Feature 6 refers to labels. At the beginning of this chapter, there is a brief explanation of the distinction between content and process skills in science conceptual

[3] Pre tests were conducted on 4/13/00, 4/14/00, 4/18/00, and 4/19/00. Post tests were conducted on 5/25/00, and 5/30/00. In addition, see Appendix A-P.

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understanding. Labels are a standard, ever-present characteristic of scientific drawing of any value, for without labels, drawings can't impart much information. The presence of labels in the students' drawings provides evidence of more highly developed process skills in science understanding. Examining the quality of content understanding and ignoring process skills is to develop an incomplete picture of what students knew. Observing, recording information/data, making and revising predictions – these are all part of the learning contained in any science program. In this case, labels demonstrated what the children were learning about the process of science, in addition to content. Use of identifiers showed that students internalized the necessity to mark their drawings so that another person might understand what was illustrated – that the process of doing science incorporates communicating ideas to others. Some would argue that the process skills learned in science, are, in fact, a type of content in and of themselves (Millar and Driver 1987).

The last feature (F7) concerns the reflecting or bouncing light ray concept. This is the most sophisticated aspect of the drawings (Wenham 1995) and represents student understanding of the reflective property of light. Only one student, ML, showed that she/he understood this aspect of light through these drawings.

Numerical values given to each student are relative to that student. By scoring the drawings for features in a pre-teaching context, and then after the unit was taught, it is easy to see whether a student performed at a higher level after the unit of instruction. A difference score of zero indicates no change, a positive score shows an increase in understanding and a negative score shows a decline, from the pre test.

Student	F1: Rays short (+1)	F2: Rays extend or are long (+2)	F3: Rays miss-ing (-1)	F4: Rays stop at object (+1)	F5: Sha-dow pre-sent (+2)	F 6: Labels of rele-vance (+...)	F7: Reflec-tion or bounc-ing rays (+2)	T O T A L	Diff-erence or learn-ing?
SS:pre		+2		+1		+1		+4	
SS:post		+2		+1	+2	+2		+7	+3
ML:pre		+2		+1		+3	+2	+8	
ML:post		+2		+1	+2	+4	+2	+11	+3
EM:pre	+1					+2		+3	
EM:post	+1			+1	+2	+3		+7	+4
CP:pre		+2			+2	+3		+7	
CP:post		+2			+2	+3		+7	+0
ST:pre		+2			+2			+4	
ST:post		+2		+1	+2	+3		+8	+4
DH:pre		+2				+3		+5	
DH:post		+2		+1	+2	+3		+8	+3
EA:pre			-1					-1	
EA:post		+2		+1	+2	+3		+8	+9
SD:pre			-1		+2	+1		+2	
SD:post		+2		+1	+2	+4		+9	+7

Figure 2: Light Pre and Post Drawing Analyses

This figure reveals the change between what features the eight students (SS, ML, EM, CP, ST, DH, EA, SD) were able to draw at the beginning of the unit and what they drew at the end of the unit. All students, except CP, showed modifications in their drawing, in the direction expected. For CP, there was no variance between the pre and the post drawings.

Perhaps these total scores reflect a more realistic view of teaching and learning than typical standardized measures. After any given unit of instruction there are likely several students who do not move in their conceptual understanding of the topic and many who do. EA and SD showed large changes in what they were able to draw at the end of the unit compared to their performance pre-test. ML, the only student demonstrating some understanding of the reflective nature of light, had this understanding at the beginning of the unit so this quality was not learned during instruction. For every unit of instruction there are a students who possessing sophisticated aspects of the topic prior to any lesson in the current science class.

Overall there is material evidence that something over the course of the unit resulted in most students gaining a more developed understanding of light. Students moved from a naive conception to a more sophisticated comprehension of light as demonstrated by analyses of pre and post instruction drawings.

Evidence: Student Interviews

Recorded interviews serve as another measure of student learning. The students, in their own words, made plain much of what they knew about light. No student could give explanations and descriptions of how light behaves that would match a physicist's description. But no student was altogether ignorant of light properties either. To varying degrees, students in the study knew that light came from many sources, moved somehow, was related to shadows, could bounce off objects, and was necessary in order for humans to see things[4]. By the end of the unit, students could better articulate how light behaves, demonstrating an evolved understanding of scientific specifics as well as exhibiting a

[4] It should be noted that some students may have had experiences with the properties of light in earlier grades, but this physical science content is officially not taught until upper grades (4 and 5) in this school.

greater confidence in what they knew. For example, two questions asked during interviews at the beginning of the unit on light, and again after the unit was completed, provided the following comparisons. These particular comments were chosen because they are representative of all comments made by students who were interviewed.

Question #1: "What is light?"

Student: SD	Pre: It's...I don't know, rays of something that we see by. The, something that we see by, I guess.	Post: Light is like, it's like kind of an energy but it, it's waves of something that, it's what we see by, pretty much. It's how we see things because light bounces off objects and so, and then the light bounces back to your eyes so you can see it.

Student: EA	Pre: I don't really know what light is.	Post: Well, I know light is something you can see by. I don't know exactly what it is. I know things about it but I don't know exactly what light is...I don't know if light is matter or anything like that but it can bend if it goes through some glass or water. It travels straight.

Though neither student perfectly articulate issues such as whether or not light is matter (an extremely advanced notion), their final comments show a building of ideas, an expanding view of what light is, moving toward a more complex and more sophisticated understanding.

Question #2: "Does light move?"

Student: SD	Pre: Uh, I'm not sure. I think it might in some way if you use kinda like a mirror or something like that to kinda change its direction.	Post: Kind of. It, it does move from one place to another but it doesn't like bend or anything. It, it can be bended by like a mirror or something which would make it change directions. Or a lens that, that would change, make it change directions

		also.

Student: ST	Pre: Yes. Like if you had a giant light bulb and you just let it sit there, the light would go to, like wherever it first touches.	Post: Yes. It's like. Light moves in a straight line and like really, really, really, really fast. Like, really fast.

Student: ML	Pre: I'm not really sure but I think, I have a theory. The light stays in one spot but it sends some of it over to another spot and they just keep on doing that. So it's lighter in a place where there's more light, and there's, and if there's not a lot of light, it's not very light at all.	Post: Yes, it travels by bouncing off objects and by hitting, reflecting, and that's how light moves.

Student: EM	Pre: Yeah, like the sun. The sun travels from west to the east, and it does move certain like moves.	Post: Yeah, it like travels, in a straight line.

It is clear the students move from an inaccurate, simplistic conceptualization, toward a more accurate, intricate view.

A comparison of what students said reveals that learning did, in fact, take place between the beginning and end of the unit. The growth in student understanding of the properties of light is not extraordinary, but shows how students are connecting ideas from different lab experiences[5] and creating or editing their own original notions getting closer to the more canonical views of the concepts related to the properties of light.

Evidence: Students Comment on Lab Experiments

Beyond the foundational questions posed by the researcher, students were asked to relate the significance of the lab experiences they had participated in during the unit on

[5] Analyses of student language recorded during interviews, compared to language from the teachers recorded during science activities and lab experiences shows a great deal of cross over, with students adopting the language of the teachers. In addition, see Appendix R-U.

light. The fourth and fifth grade students explained the importance or main point of each of the learning events by speculating on what either of the two teacher's wanted them to learn. These narratives provide a more illuminating illustration of what the children understood from each event. What follows are brief descriptions of some of the learning tasks from the unit on light and some students' explanations of the salient points they absorbed from participation. Comments are taken from the eight target students in Coaching Teams One and Four, and were selected for depth and details. Not all students were as articulate as these students, or the responses were redundant.

1. Lab: "Light Thru Holes"

(Students worked in four person Coaching Teams to shine a flashlight beam through an array of note cards that had a single hole punched thru each. The goal of the task was to get the light beam to shine through as many cards as possible and to find a single "hole" of light shinning on a last card or "target.")

Student SD: I think that what they were trying to teach is us that when light, well, [because] light travels in a straight line [if] you hit the card at an angle, it wouldn't go zoom (thru the hole) and it wouldn't bend up[ward]...so I think they were trying to demonstrate that light only goes in a straight line.

Student CP: The purpose was to teach us that light travels straight and that it, it can't bend and if you want to hit something [with the beam], and there's a small hole, then you have to get it like perfectly lined up.

2. Lab: "Measuring Light"

(Students held a flashlight 3, 5 and 7 cm above a sheet of ¼ inch graph paper. They drew a circle around the perimeter of the light beam shinning or reflecting on the paper at each height. As the light got higher, the perimeter drawings got larger.)

Student EA: That showed that the higher like the source of light is, the bigger surface area it covers. And the duller, the higher it goes, it also gets duller.

Student ML: I learned that light gets bigger the farther away you get it cuz it has more time to spread out. That's what I thought I learned.

Student ST: That was to prove like the farther away the light is, the surface area is bigger but it gets dimmer. So that was kinda proof.

Student SS: Like the lights on a car, when it gets dark out, they go far and as [the light] comes out of the bulb, it goes like that – it spreads out across the road so you can see it and that's kinda what we were doing when we were holding [the flashlight] up higher.

3. Lab: "Opacity and Light"

(Students brainstormed 10 or 12 items to test and see if a flashlight beam would pass through each. They were directed to predict and then test if the light passed through each item fully, a little bit, or not at all (these conditions were later identified as "transparent," "translucent," and "opaque" respectively).

Student EA: I think that kinda taught us that like some objects are transparent and it's really easy for light to kind of pass through.

Student ML: Light doesn't travel through everything. We had a couple of surprises. We thought the light would travel, I thought the light would travel through like the overhead screen but it didn't.

Student ST: That was just to prove what light can go through and what it can't and it taught us like, if it couldn't go through, well, light could go through water so that was kinda proving what materials light can and cannot go through.

4. Lab: "Penny in the Cup and Spear Fishing"

(Students watched a penny in a cup as water was poured into the cup. Viewing from a certain off-center angle the penny suddenly became visible due to refraction of light through water. For the spear fishing task, a fish tank was used with a spear-like item and students tried to hit the "fish" (partially air-filled balloon) secured to the bottom of the tank. Connecting the "spear" with the "fish" can only be done by aiming the "spear" while taking into account refraction of the light through the water.)

Student ST: [We learned] how light can bend and make it look like it's somewhere else. Cuz when we were spear fishing, it, we thought it was, we thought the thing was bigger. I mean, a little bigger and a little like floating up more so everybody aimed it straight at it but you really had to aim below it cuz that is where it really was.

Student SS: When the light hit the water, it went in the water kinda and it reflected off of it so it looked like the stick was broken in two.

5. Lab: "Candle Trick"

(Students observed a display arranged by the teachers. In this "trick" there is a lit candle in front of a sheet of clear Plexiglass with an unlit candle behind. Both candles are visible from the front view and both appear to be lit, though only the front candle is. The teacher proceeds to try to burn a pencil, his hand, other objects in what appears to be the back lit candle – but this is only an illusion created by the lit flame reflecting off the Plexiglass making the second candle seem lit as well as the front candle.)

Student ST: Well, there's a mirror trick we did and we had a candle lit in front of Plexiglass and a candle behind it that wasn't lit and Mr. D matched it straight up so it looked like both candles were lit but we didn't know that because the light from the candle was bouncing off the Plexiglass and coming to our eyes and since it worked like a mirror, but since we could see through it, it looked like the other one was lit but actually we were just seeing the reflection of the one that was lit. So, it looked like that from every angle.

Through drawings, interviews and descriptions, the students in the study demonstrated that they learned about the properties of light and enhanced and refined their original understandings. No student understood light at the conclusion of the unit in exactly the same manner they understood it at the beginning of the unit. Every student grew in their knowledge of light. Some misconceptions are evident in the beginning of the unit and not all misunderstandings are eliminated by the end of the unit (see Appendix A-P). But the concept of light and how this phenomenon behaves were better understood by the students through the teaching and learning of the unit. The many tasks the students experienced as well as the discussions that occurred in class, to make sense of these events, helped students gain conceptual understanding of the phenomena.

Learning Science Across Time

It became abundantly evident to me during my time in the ""Farside"" that learning occurs over small sometimes barely perceptible increments. Learning was not linear in a step-by-step process but rather in fits and starts, even regressing at times, as illustrated by the Vignette described in Chapter One. Students often held to misconceptions and lower level strategies for problem solving when presented with more sophisticated methods. The events presented to students, their engagement with tasks, and the overall approach to teaching and learning were social constructivist in nature. Science education as suggested by learning theorists and philosophers John Dewey, Jerome Bruner, and Lev Vygotsky is standard treatment for the students in the ""Farside"," (Dewey 1900/1902; Dewey 1938; Bruner 1960/1977; Bruner 1966; Vygotsky 1978; Vygotsky 1997). Tobin, too, I believe, would recognize the type of science teaching and learning in this classroom as an example of social constructivism in action (Tobin and Tippins 1993).

Learning is perhaps too often discussed, and assessed, in discrete terms, as if a student either understands something completely or not compared with an earlier arbitrary time. The "Ah-Ha" moment is part of popular culture. "People commonly believe that creative new ideas come suddenly, as a kind of bolt from the blue or inspiration—but evidence indicates that the process of creating new ways of thinking is long and slow, depending on lengthy processes of microdevelopment of component skills," (Fischer and Yan 2002).

Microdevelopment refers to the "process of change in abilities, knowledge, and understanding during short time spans," (Granott and Parziale 2002). The development of the methodologies of microdevelopment is relatively recent and viewed by some as so radical and novel that it represents "a significant paradigm shift," (Lee and Karmiloff-Smith 2002). Microgenetic methods were designed to provide insights regarding the incremental steps taken by learners as they acquire knowledge "particularly steps taken just prior to apparent progress," (Goldin-Meadow and Alibali 2002).

In an article included in a recent volume edited by Nira Granott and Jim Paraziale (Granott and Parziale 2002), Robert Siegler applies microdevelopmental technique to demonstrate its potency as a methodology. In doing so, Siegler also supports observations I made in "The Farside" regarding the pattern in which learning seemed to take place and in the effectiveness of the teaching of Conni and Bob. The advantage of a microdevelopmental approach is that it helps explain how change occurs, how students learn in diverse contexts, and illuminates what the characteristics of more successful learners are (p. 36). Its reliance on observations of development over short time-frames more accurately represents learning than does traditional "state oriented" longitudinal studies. (Granott and Parziale 2002 2)

Learning as Waves, Not Staircase

Microdevelopmental analysis makes clear that a "staircase model" of development (as posited by Robbie Case, for example, in <u>The Mind's Staircase</u> (Case 1991)) is not an accurate representation of the way that learning progresses, even though most teachers and curriculum development reflect such an outlook. Siegler proposes an "overlapping waves theory" to describe the process wherein students adopt a variety of strategies to perform tasks and problem solve (Siegler 2002 32). Previously held, less advanced strategies continue to be utilized long after the child has been exposed to more advanced strategies (p. 33). Strategies are adopted, utilized, not utilized and then picked up again at various times, even in quick succession. This multiple, adaptive variability in strategizing is demonstrated across all ages (p. 34-36).

Siegler's study sought to examine an approach he called "self-explanation," judgments about the "causal connections among objects and events." While even very young children have the capacity to make this type of association, "math and science teachers frequently lament the fact that their students can execute procedures but have no idea why the procedures work," (p. 37). Siegler had ample evidence to draw an inference that self-explanation and learning were positively correlated, but he used microdevelopment to determine if there was a causal connection (p. 38). His testing contrasted students provided only with feedback as to whether an answer was correct or not, a second group of students who were given feedback and then asked to explain their own reasoning process, a third group given the correct answer and asked to explain how they thought that answer was obtained, and a fourth group asked to explain not only the correct answers, but incorrect ones as well.

In all phases of the experiment, before, after and during instruction, (Case 1991) variability of reasoning was evident, especially in the "explain-correct-reasoning group," the group demonstrating the greatest learning. Siegler points to microgenetic method in its accrual of dense data over short time periods, as the key to the "trial-by-trial analysis of change," (p. 40) and in the way that a detailed examination of how a request to explain produced the resultant accretion of learning (p. 41). Requests to explain answers "led to an initial period of cognitive ferment," but the utilization of multiple strategies led to consistently correct explanations (p. 51)

> In all cases, learning sees to involve children moving from incorrect approaches to a state of high uncertainty and variability, and then to a period in which the uncertainty and variability gradually decrease as children increasingly rely on more advanced approaches (p. 52)

Among the findings that Thelen and Corbetta reach are that "systems exist in time" such that a behavior is the product of all the patterns that preceded it. As a consequence of this factor, systems "may be sensitive to seemingly small changes in one or more elements," that is, for instance, that learning takes place in a nonlinear fashion. A microdevelopmental approach calls for the collection of data at smaller time scales which allows for an analysis of what goes on between the times of traditional testing (p. 62).

Kurt Fischer and Zheng Yan applied microdevelopmental analysis to the notebooks of Charles Darwin as he struggled with the theory finally published as the On the Origin of the Species, (Fischer and Yan 2002). Based on the work of Howard Gruber, Fischer and Yan examine the process of learning and thinking a new point of view, a task they believe best accomplished with microdevelopmental tools. They see microdevelopment as involving "combining, differentiating and reorganizing specific skills in particular tasks and contexts as well as generalizing them," (p. 296).

The particular insight offered by Fischer and Yan relevant to the ""Farside"," is the variability of skill level over short periods of time. Lesson analysis and repeated vignettes throughout this case are evidence of students learning concepts in this fashion. Often people drop to a low level; they seem to regress. In order to build new skills or to change old ones to fit a new task, "people must move backward to a lower level" (p. 299). In their examination of Darwin, they found him developing important concepts and then failing to sustain them, requiring a rebuilding of the same concepts (p. 315).

Notebook Data and Learning

Students in the ""Farside"" never came up with a theory of evolution, but they did use notebooks to record observations and posit explanations for what they saw.

Notebooks held clues to what students were learning and what the teachers were teaching. Students wrote vocabulary words and definitions, procedures and findings, conclusions and explanations. They included predictions throughout their record of science experimentation. Student journal text is recreated below in Figure 3.

Unit/Topic	Text	Analysis
States of Matter: Liquids	Frozen Rag -rag soaked & wrung out placed in the freezer -Prediction: I predict that when it comes out it will be Frozen-and as stiff as a board -After rag was removed: I was way off it wasn't frozen just partly	Description Prediction Observation Conclusion
States of Matter: Polymers	Goo Yuk -Is Goo Yuk more like a solid or liquid? -Prediction: I think it is a solid. -Observations: It looks like a liquid but it feels like a solid. The top of the Goo Yuk is cold. It feels like dough.	Prediction Observations
States of matter: Gas	Butane Lighters -Observations: making bubbling noise, feels like ice, it looks like it is freezing, looks like a liquid but it is a solid -I think that the molecules were spinning because of the heat. The head of our room temp. & hands made a difference. The more heat the faster of a change.	Observations Explanations
States of matter: Polymers	Slime -The molecules are linked together and the molecules are in a clump when we pulled the slime, it broke quickly. The slime doesn't bounce much. Silly Putty -The silly putty is in a clump, isn't as goey as the slime. The silly putty absorbed the borax. When we pulled the silly putty it took a while. Bounces good.	Observations Comparison
Air pressure	Bobbing along (Cartesian Divers) -When you let up he goes back up again -The air is equal on all sides -Squeeze the bottle and the bobber will go down -Observations: We think there is equal pressure on all sides, is greater pressure on the outside and lighter pressure on the inside so when you squeeze you are adding pressure and then there is unequal pressure so he goes down -More: Squeezing the bottle made "Bob" take on more water. Water in the bottle rose. When water in "Bob"	Observations Explanations Conclusions

	rises, he dives. -Conclusion: When you squeeze the bottle the pressure pressing on the top of the water and "Bob" so "Bob" goes down	
Light	Candle Observation: -The candle on the other side wasn't even lit. I think they are different colors. -Explanation: because the glass is blocking the candle and Mr. D has to set up the unlit candle exact, because light travels in a straight line that's why he has to move the unlit candle exact	Observation Explanation

Figure 3: Student Journal Text (EM)

The use of journals in this classroom is not unique to the ""Farside"." These texts are just one more layer of the science program that support student learning in small increments over time. The content of individual student journals is evidence of children attempting to make sense of phenomena through observations and explanations. Journals alone cannot teach science, but together with engaging tasks, small group interactions, and dynamic teaching, children can piece together concepts that form the basis for future understandings at a more sophisticated level.

Conclusion

Microdevelopment, as a methodology, supports the previous analyses using interviews, journals, and observations, to reach the conclusion that students in the ""Farside"" learned the properties of light. The teachers, employing constructivist tasks for learning about light, offered a particular type of experience for the fourth and fifth graders.

Current reform agendas in science education at the state and national levels support a "big idea" picture of education. Conceptual understandings, not memorization of facts, are what teachers ought to encourage in their students (National Research

Council 1996). Yet, learning concepts or "big ideas" such as "light travels in a straight line," or "light reflects off a surface at the same angle it hits the surface," is not easily achieved from a single interaction or event. These are not just isolated facts, but ways of thinking about a phenomenon, concepts about how the phenomenon behaves. Though epiphanies or big "Ah-Ha" moments can happen for all learners, it is more often the case that something is understood a little at a time. The bits and pieces of a concept, understood at different rates by different learners, add up to a unique "total" understanding over time. As seen in this study, few students know nothing about light and few would understand what a physicist knows about light even after experiencing a constructivist elementary education unit (see Appendix A-P). Never the less, the class as a whole and individual students, shifted in their understanding of a complex phenomenon—light. They deepened their understandings in fits and starts. For many, learning about light was not a smooth unbroken trajectory, or was it the result of a single epiphany. Yet, learn they did, in waves rather than steps. How did this occur?

Given the goal of conceptual teaching and learning in science education today, what are some ways teachers are going about this challenging task? In the classroom where light was taught and where children enhanced their understandings of the properties of light, the teachers did many things to cultivate this learning. It is no surprise that these award winning educators have managed to obtain supplies ranging from consumable products like cotton balls to high-tech equipment such as electronic magnifying gear, and that they implement them in absorbing and cutting edge practice. This setting seemed like a great place to study science education. In fact, it provided an opportunity to examine science teaching and student learning in a unique context – the teaching was complex, the lessons difficult, and the student structure for participating in science events was a non-standard group structure called Coaching Teams. Subsequent chapters attempt to shed light on these three aspects of the science program implemented in one classroom and how they might lead to new visions of what science could be, what elementary classroom teachers might aim for, and how students might engage with scientific phenomenon and each other, all as they foster conceptual understandings in science.

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Chapter Three

Stirring the Brew in the "The Farside" :

Invoking national teaching standards then adding a dose of reality

Bob DeLind and Conni Crittenden are two dynamic, creative educators who cultivate and tend a renowned elementary science program. This is not to say they make teaching science to 50 fourth and fifth graders look easy--it isn't and it doesn't. Spending even just a little time in their classroom, an observer can't miss the focus and energy required to do what they do-- planning lengthy units and lessons, pulling together appropriate demonstrations, finding the materials necessary for their students to be active learners, conducting workshops, collaborating with others in their school, district, and state—the list goes on. These two teachers are science geeks, but they draw on their other interests in painting, drawing, sports, weaving, and cooking to create an atmosphere singularly conducive to growth.

In this chapter I will explore the role Connie and Bob play in providing opportunities for science learning. I start by considering the Standards. I consider some of the received notions about didactic pedagogy, and its relation to the role of inquiry in science education. More precisely, I test the idea that good science teaching--teaching which results in strong science learning for students--should be void of didactic practices. I also question the emphasis on inquiry in science education at the elementary level and how inquiry based instruction is implemented, particularly whether inquiry should be originate in the initiative of the student or whether that inquiry ought to be at the direction of the instructor. I examine whether the National Standards can actually serve as a practicable text for teachers in the real world and if the Standards are a panacea for the ailments of science education as it is currently practiced. Lastly, I offer a picture of an alternative version of teaching science based on my study of Conni and Bob and reveal a conception of teaching that might not fit with the most current views of "best practice"[6].

The Teaching Standards in Science

The National Science Education Standards (National Research Council 1996) is the predominant set of principles utilized for instruction by the science education community. Known as "The Standards," these guidelines are drawn upon by other educational organizations to judge effective teaching in their respective fields as well. The National Science Teacher's Association (NSTA), the Association for the Education of Teachers of Science (AETS), and the National Board Certification of Teachers (NBPTS) list similar principles to categorize the "knowledge, skills, dispositions, and commitments" teachers of science ought to possess. The Standards, though widely accepted as the basis for sound science education practices, have been criticized for several of reasons, predominantly for a lack of attention to issues of equity and multicultural student populations.[7]

Chapter Three of The Standards outlines six teaching principles. Each is illustrated with an elaboration of more specific methods in which teachers are to carry out

[6] "Best practice" is used herein as it is used in Best Practice: New Standards for Teaching and Learning in America's Schools by Zemelman, et. al. where the authors declare on page vii "We borrowed the expression, of course, from the professions of medicine and law, where "good practice" and "best practice" are everyday phrases used to describe solid, reputable, state-of-the-art work in a field. If a practitioner is following best practice standards, he or she is aware of current research and consistently offers clients the full benefits of the latest knowledge, technology, and procedures."

[7] See Rodriquez, A. J. (1997). "The dangerous discourse of invisibility: A critique of the National Research Council's National Science Education Standards." Journal of Research in Science Teaching **34**(1): 19-37, Lee, O. (1999). "Equity inplications based on the conceptions of science achievement in major reform documents." Review of educational research **69**(1): 83-115.

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that particular standard in their practice. Figure 4 compiles the details of what a teacher should know and be prepared to implement according to The Standards.

Teaching Standard	Elaboration of The Standard
Teachers of Science… Plan an inquiry-based science program for their students.	Doing this, teachers …develop a framework of yearlong and short-term goals for students. …select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students. …select teaching and assessment strategies that support the development of student understanding and nurture a community of science learners. …work together as colleagues within and across disciplines and grade levels.
Teachers of Science … guide and facilitate learning.	Doing this, teachers …focus and support inquiries while interacting with students. …orchestrate discourse among students about scientific ideas. …challenge students to accept and share responsibility for their own learning. …recognize and respond to student diversity and encourage all students to participate fully in science learning. …encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.
Teachers of Science … engage in ongoing assessment of their teaching and of student learning.	Doing this, teachers …use multiple methods and systematically gather data about students understanding and ability. …analyze assessment data to guide teaching. …guide students in self-assessment. …use student data, observations of teaching, and interactions with colleagues to reflect on and improve teaching practice. …use student data, observations of teaching and interactions with colleagues to report student achievement and opportunities to learn to students, teachers, parents, policy makers, and the general public.
Teachers of Science … design and manage	Doing this, teachers …structure the time available so that students are able to engage in extended investigations.

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learning environments that provide students with the time, space, and resources needed for learning science.	...create a setting for student work that is flexible and supportive of science inquiry. ...ensure a safe working environment. ...make the available science tools, materials, media, and technological resources accessible to students. ...identify and use resources outside the school. ...engage students in designing the learning environment.
Teachers of Science... develop communities of science learners that reflect the intellectual rigor or scientific inquiry and the attitudes and social values conducive to science learning.	Doing this, teachers ...display and demand respect for the diverse ideas, skills, and experiences of all students. ...enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community. ...nurture collaboration among students. ...structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. ...model and emphasize the skills, attitudes, and values of scientific inquiry.
Teachers of Science... actively participate in the ongoing planning and development of the school science program.	Doing this, teachers ...plan and develop the school science program. ...participate in decisions concerning the allocation of time and other resources to the science program. ...participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.

Figure 4: Overview of the National Science Education Standards-- Teaching Section Only

Though the language of The Standards is simple enough to comprehend, it is not easy to understand how actual teaching practices are to be realized. Ambiguity and generalizations leave the reader without a clear picture of what is intended. There is scant explanation of just how one is to "focus and support inquiries while interacting with students," or how a teacher is to "create a setting for student work that is flexible and supportive

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supportive of science inquiry," (p. 32, p. 43). Each directive that outlines what teachers of science ought to do, and what action they might take to implement that practice (plan, participate, model, structure, enable, display, make, identify, engage, create…) falls short of helping a teacher decide what to do in her classroom Monday morning. The Standards provide occasional descriptors of real situations to illustrate suggested practice ("Earthworms" on pages 34-35, "Science Olympiad" on page 39, "Musical Instruments" on pages 47-49), but these are brief snapshots that do little more than vaguely point in some direction. In fact, these idealized portraits are often experienced as naïve possibilities or incomplete recipes.

Now, several years after the promulgation of The Standards in 1996, it is taken for granted that teachers should be creating a science experience that is "student-centered, active, experiential, democratic, collaborative and yet rigorous and challenging," (Zemelman, Daniels et al. 1998). Subsequent publications have attempted to add specificity to The Standards. Volumes of case studies in science teaching have been compiled to provide instructors with real teaching stories as roadmaps to best practices (Annenberg, Science and/or Mathematics Education at Illinois Institute of Technology, NW Regional Ed Lab, etc.). The assumption is that by reading, or watching videos about actual situations (or even fictitious classrooms) with abundant details about what teacher and student are "supposed" to do, a practicing teacher will be able to alter her practice and meet these new standards.

Zemelman, et. al., provide particular illustrations to demonstrate best practices in six content areas (reading, writing, mathematics, science, social studies and the arts). The example offered for science instruction is an account of fourth graders working with “mystery powders.” Entitled “Teaching Science the New Way—Elementary,” (Zemelman, Daniels et al. 1998) the story is rich with details, but the salient points might be summed up as follows:

- students work on a project for an extended period of time—in this case it is one month
- students work in small groups to collect data and test their own hypothesis
- teachers do not impose answers, but rather guide student questions
- students predict what will happen before experiments are conducted
- students smell, touch and listen and record observations—they are actively engaged in phenomena
- students spend extended quality time on tests, data collection, experiments—in this case they spend a week conducting tests on the mystery powders
- students write a report as a group comparing the results of their own tests
- discussion takes place about the findings yielding more questions about the mystery powders—though some answers are found, it is the process that takes precedence over the factual information

Zemelman’s illustration provides substance and content for one unit of instruction that encapsulates the dominant elements of reformed science teaching practice. It fleshes out The Standards with its portrait of a teacher who does not lecture to students, who is open and flexible about how children solve problems, and who allows students to solve mysteries of science in a variety of ways. The Standards strongly suggest that through hands-on experiences facilitated by teachers who "focus and support" inquiries, students will most effectively learn science concepts.

Inquiry and The Standards

One of the dominant themes of The Standards is an emphasis on the principle of inquiry as the basis of science instruction. "Inquiry into authentic questions generated from student experiences is the central strategy for teaching science," it argues (page 31), and "At all stages of inquiry, teachers guide, focus, challenge and encourage student learning," (page 33). "Inquiry" is valorized in The Standards and an explicit goal of instruction is the encouragement of students to pursue questions of their own while being assisted by teachers who support student inquiry; the teacher who is "guide on the side" not "sage on the stage." Inquiry is the backbone to this reformed way of learning and thinking in science education today.

The science education community has struggled with inquiry as the core mode of science teaching and learning since The Standards were released. Publications have attempted to clarify purposes and provide answers to questions about the pedagogy of inquiry (Tamir 1985; Collins 1986; Shymansky 1990; Alberts 2000; Wheeler 2000). The attempt at clarification and justification of inquiry as the essence of science education is a significant outcome of The Standards document. A volume of thirty essays written by leaders in the science education research community was compiled and published in 2000 (Minstrell and Zee 2000). Aptly titled <u>Inquiring into Inquiry Learning and Teaching in Science</u>, the work includes data and analysis by Sandra Abell, Doris Ash, Rodger Bybee, Audrey Champagne, Fred Finley , Kathleen Fisher, Richard Lehrer, Lillian McDermott, Randy McGinnis, Jim Minstrell, Leona Schauble, Emily van Zee among others.

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The aims of inquiry based science instruction education are many. However, two prominent themes are featured in the literature. First, school science should mirror professional science practices as closely as possible (Alberts 2000; Wheeler 2000) based on a particular understanding of what scientists really do and how they do it (Latour and Woolgar 1979; Traweek 1988; McGrayne 1993). Second, inquiry based learning is superior to other types of learning because it requires higher order thinking skills and complex cognitive development (Zohar 2000).

Just as there are multiple purposes envisioned for inquiry learning, so too are there multifaceted attempts at definition. Formalizing the concept of inquiry learning is a formidable task. For instance, Minstrell asks:

> What does it mean to do inquiry? One definition is that it involves fostering inquisitiveness; inquiry is a habit of mind. Another holds it to be a teaching strategy for motivating learning. But what does that mean? Some say inquiry means "hands-on." Others say that is too simple: that hands-on is not necessarily minds-on, and inquiry includes manipulating materials to become acquainted with phenomena and to stimulate questions, as well as using the materials to answer the questions. Scientific inquiry is a complex process. There is no single, magic bullet. Some instructors, in the interest of a focus on inquiry, address only one aspect of the complex process. That contributes to the impression that inquiry means different things to different people. So we need to identify the various aspects of the process and see them as a whole. (p. 472).

Unfortunately, the varied and occasionally conflicting messages provided by researchers and practitioners in the field have left teachers adrift on a sea of imprecision. Does inquiry mean that students develop their own study? If not, how is inquiry to be directed? Is the teacher expected to possess all answers to every inquiry? Do students learn significant, meaningful content if they learn science through inquiry? Finally, is inquiry a process comprised of disjointed parts that might be implemented independent of the whole?

The Standards present a research- based model for science education (National Research Council 1996; Collins 1998; Zemelman, Daniels et al. 1998). However, the Standards create an impression that a teacher ought not be the source of any fact, should not directly manipulate activities engaged in by students, or require kids to work under close supervision. The Standards frighten many teachers because they are couched in terms that seem in opposition to previous modes of teaching, in particular direct instruction. The examples provided in The Standards and in the plethora of case studies regarding inquiry-based science teaching never tell a tale of teachers teaching anything in the traditional sense where students are guided to discover ideas themselves. Instead, instructors are provided with examples of idealized experiences resulting from effortlessly arranged tasks and activities. The details of case studies offered up as examples within the Standards document are too pat (National Research Council 1996).

Misconceptions about the essence of inquiry hinders reform in schools. Teachers don't need more scenarios of inquiry-based science teaching to improve their pedagogy. What they do need is a realistic hybrid model of practice, in which didactic teaching that stresses fundamentals is blended with inquiry-based science instruction. Whatever inquiry means to the science education community, it needs to be incorporated into a sensible, sound program created and refined by classroom teachers.

Connie and Bob have developed a program that fuses the basic tenets of The Standards to didactic teaching and have created a realistic coherent plan that is ultimately successful. Their model includes exploration of scientific concepts and a pedagogy that utilizes inquiry, but is not solely dependent upon it for student success. Their program is not inquiry learning according to The Standards, but rather is a composite of teaching styles and practices.

Setting a New Standard:

Conni and Bob's Hybrid Pedagogy

In observing practice in Conni and Bob's classroom, I often saw examples of the type of teaching highlighted in The Standards. That is, I witnessed instruction in which teachers guide student learning and provide the resources necessary for students to engage in scientific tasks. I also observed events not in keeping with The Standards—lessons cut short due to the crunch of time, and students who never wrote anything in their science journals all year. Yet students learned rigorous science in this classroom. How can this incongruity be reconciled?

Conni and Bob have developed a blended pedagogical practice incorporating elements consistent with The Standards and some that are not. What appears to be crucial in their approach is not that a pedagogy be based on inquiry for inquiry sake, but rather that a system where students learn both the process and content of science be implemented. In the hybrid model, emphasis is shifted away from inquiry as an ultimate aim of the unit to lessons built from basic, central questions posed by the instructors, followed by a routine intended to answer specific questions and foster the development of a more general understanding of the processes of scientific investigation. Conni and Bob use The Standards to couch their lessons in a question format, but they do their own construction from there. What follows is a discussion of the way a question is used to initiate a task for students in The ""Farside"" and how the rest of the lesson unfolds.

Hybrid Standard #1 for Science Teaching:

Start With a Question From the Teacher

Bob or Conni always begin science time with a question—there are no exceptions to this rule (see Appendix R-U). This voice from above doesn't fit into any of the models of inquiry-based instruction. It is simply a question posed by the teachers. These questions are part of a bigger question or unit of study, again determined by the teacher. For a unit on light some of the opening explicit questions were:

- How does light travel?
- How does distance affect the way light travels?
- What materials will light pass through?
- How does light reflect off a shiny surface?
- How is it you can see a second candle as lit through the glass when it is not?

Sometimes the question is not stated outright but is implied through the teacher's directions. Some implied questions were derived from watching a demonstration conducted by the teacher:

- How does light travel in water?
- How does a laser light travel in water?
- We are going to fool around with reflection and our faces today, after, you will see if you can explain it.

The opening questions serve as an impetus for the lesson at hand and it sets the goal for the lab or experiment which follows. Students are given factual information after the question is posed, which they write in their science journals just as they would in the direct instruction approach. Often the instructor briefly recounts what has occurred in the previous lesson.

Hybrid Standard #2 for Science Teaching:

Engage in an Activity That Can Answer the Question

The exploration phase that follows the opener of each lesson in "The Farside" allows students to work in small groups on some task. Students engage some phenomenon by touching, feeling, seeing, hearing, tasting, or smelling. During the year of this study, students made goo yuk and silly putty to learn about polymers, explored pen chromatography, participated in several air pressure demonstrations that included the use of vacuums and pumps, tested items for opacity during the light unit, just to name a few of the lab activities. This experience is followed by writing, drawing and discussion. In this classroom science is meaningfully "hands-on." Every lesson includes some event where the students experience science in a dynamic and personal way. The vignette highlighted in Chapter One is a good example of how the students became personally engaged with the material, even when it was through the teacher demonstration at the onset.

Hybrid Standard #3 for Science Teaching:

Conduct a Large Group Discussion About the Exploration and Formulate an Answer to the Original Question

In every lesson, the answer to the question posed in the opener is reached during the debriefing phase. "Debriefing," a term typically found in military or political contexts, is used here to denote a time when students share what they have discovered or accomplished during their exploration. The term is explicitly employed in the class. After the students have commented on their observations and had time to ponder questions posed by the instructor to the entire class, the appropriate answer is clearly enunciated by the teacher. This declaration might be a recap of a student's comment or a synthesis of various comments pulled together to make one coherent statement about the phenomena. Generally, this is the end point for the lesson and students document the discovery in their journals. Answers might include "light travels in a straight line," or "laser light bounces, or is reflected off the bottom of the water tank as well as the top of the water." As noted earlier, this could easily be classified as the transmission model or direct instruction (see Appendix R-U).

Staples of Hybrid Pedagogy in "The Farside"

In <u>every</u> science lesson in "The Farside" the following occurs:

- teacher poses an opener question
- students write in their science journals
- teachers incorporate student comments and questions into lesson discourse
- students experience science within small group structures called Coaching Teams
- teachers facilitate questions and connections by students during Coaching Team time
- students predict the outcome of exploration
- teachers add real-life applications to the lesson
- students engage scientific phenomena in a dynamic way (either by doing a task themselves or observing striking and captivating phenomenon created by the teachers)
- teachers ensure that the answer to the original question is provided during the debriefing phase of the lesson

Students write in their science journals. Science journals are used for writing the opening question, drawing pictures of science phenomena, copying data and information from the teacher's demonstratives, making predictions, noting data from the small group work, and summarizing what took place in the lab. These journals are also used for assessment. Thus, students know they must have information in their journals or they will be marked accordingly. All students are expected to write in their journals for every science event.

The teachers spend extensive time at the beginning of the year explaining their expectations for the journal. It is not for art or doodling, notes to friends, scratch paper, or other subjects. Each new event is to be dated at the top of the page. On the first page of one student's notebook the following was written:

Lab book
Procedures
Date all entries
Use every page
Title each page
Best work
Label all diagrams

These notes were obviously from directions provided by the teachers. This list clarifies some of the ways students are expected to proceed with their science journals.

By the end of the year, most had written on almost every page with observations and drawings of their science lessons -- 100 total pages in a composition notebook 9 and 3/4 inch by 7 and 1/2 inch. I had an opportunity to study some thirty of the notebooks. Handwriting skills and quality of drawing varied a great deal. So did the depth and proficiency of predictions and grasp of theories, but there were few scribbles, doodles, or other extraneous writings in the books. However, there were a few journals with almost no entries

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no entries. Interestingly, in terms of the argument I make here about the direct instruction that is part of the hybrid teaching, on average, a third of the data in the notebooks was teacher generated—information directly copied from the overhead or dictated by the teacher.

Student questions and comments are honored, sought after, and referred to by the teacher. Every students' insights were valued. Either within the opener of the lesson or during debriefing, student comments were often included in the language used to illuminate a concept (see Appendix R-U). Some restating occurred if the actual language spoken by a student was not precisely what the teacher had in mind. Restatement was more prevalent in the debriefing phase of the lessons because the findings, observations, and speculations of the students were elicited in student's words in order to explore what had gone on in the Coaching Team phase. The debriefing served to formulate an articulable concept derived from the experiences of the hands on Coaching Team segment. Clear accurate language was crucial at this stage. Through active discussion, with input from both students and teachers, an answer to the original question was voiced and underscored.

The instructors actively observe the environment and pose questions to the Coaching Teams during the lab sessions. These are pointed questions designed to get students to observe more closely and to connect one learning event to another. I rarely saw Conni or Bob telling a student exactly how to do some part of the lab, but their questions were posed to elicit sharpened explanations. For instance, during a lab in which students were trying to shine a flashlight through holes in index cards, Bob walked by one group and asked on several occasions, "Did you have to hold the flashlight in any particul

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particular way to get it to shine on the last card?" This was a transparent bid by the teacher to direct the Coaching Team to think about how light travels and how light behaves.

Whenever possible, the teachers include real life examples to better illustrate the concept being studied. Students learn about the way car headlights seem to shine only so far, how we protect ourselves from UV light with sunscreen lotions and sunglass lenses, how air pressure is used in machinery and toys like Super Soakers, how laser eye surgery is conducted. Conni and Bob connect personal experiences with real world science concepts. The vignette of the four students discussion air pressure in Chapter One is also evidence of such practice.

The Routinized Components of the Science Lesson Serve as a Model for Scientific Exploration

These elements that characterize what I call the "hybrid" pedagogy are common across Conni and Bob's science teaching. One striking common feature is the collection and sequence of activities that seem to be a string of substructures. These substructures within the hybrid pedagogy: opener, exploration and debriefing, make "The Farside" special. The instruction is a blend of telling students what to do and letting students explore in small groups. This system is grounded by a set of routines students learn at an early stage. All year long, students find the structure of science mirrored in the pattern of each lesson and within this structure they develop an understanding of difficult concepts and a sense of success engendered by their lab work.

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In order to better demonstrate this three-segment lesson structure, the following is a synopsis of the first lesson on light constructed around the opening question, "How does light travel?"

Lesson:	Light Through Holes
Total time:	30 minutes
Opener:	12 minutes
Exploration:	12 minutes
Debriefing:	6 minutes

Students arrived at school to find the following on the board announcing the day's agenda: 11:45 Science -- Light. Bob had the students seated in small groups in the classroom. He initiated the lesson with the opener wherein he asked the students to share things they wondered about light. He patiently called on students to explain their queries that ranged from issues of color and speed to black lights and "can light kill". Next Mr. D, as the students call him, put a list of questions on the overhead projector for all to see as he read a similar list of questions from past classes. He was careful to note any overlaps between past and current questions. "See, this is like your , Donnie" or "This one is similar to yours, Susan." Eight minutes had passed by this time. The next part of the opener, Mr. D's explanation of the task for today's lab, was four minutes long. The guiding question for the day was "How does light travel?" This was written on the overhead, as was a detailed drawing on how to do the lab. The instructions were intended to get students to line up 3 X 5 cards using small bits of clay as holders. The task required students to lay out several cards, each with a single hole punched in it, and then to shine a flashlight beam from in front of the first card. Students were to try to get the light to shine through the hole of a fourth, fifth, or eighth card on to a blank last card that had no hole -- the target card. Students were cautioned not to place the cards too close together. They were to work in the darkened classroom at tables where they were seated. The challenge was to get a small circle of light to shine on the last card of a series of at least five cards spread across the table. (One group was actually able to successfully line up twelve cards.) Twelve minutes had passed as the Coaching Teams began the lab at the conclusion of the opener. The Coaching Team exploration time took another twelve minutes and the lesson debriefing took six minutes. The entire lesson took about thirty minutes (plus a few minutes for transitions and a flashlight "light show" authorized by Bob just before the debriefing began). Of the thirty minutes of instructional time, student lab time comprised 40% of the total time, with the teacher opener, teacher instructions and the teacher led debriefing taking the other 60%.

Figure 5: Classroom vignette recorded on 4/19/00, "How does light travel?"

Figure 6 is a schematic of the lesson in which the above vignette occurred.

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Segments	1. Opener (12 minutes, 40% of total lesson time): Teacher provides background for task, elicits comments from students, gives directions, provides a drawing, and helps students prepare to conduct a lab activity. 2. Exploration (12 minutes, 40% of total lesson time) 3. Debriefing (6 minutes, 20% of total lesson time)
Students write in their science journals	[from student journal EM, 5^{th} grade] "4/19/00" "How does light travel?" (diagram of cards lined up with holes just as drawn on overhead by teacher) "Flashlight"
Student questions or comments are honored, sought after, and referred to by the teacher resulting in every students' ideas being valued	During the opener: Mr. D. (00:00-13:00): "What are some questions you might have about light from your homework that you gave to Mrs. C?" Many students provide comments, questions, statements about light and Mr. D. restates these at least 11 times after calling on students. Some of his restatements include "wow" or "that's a toughie." Eventually he begins a description of the intended lab for the day by reiterating the question, "How does light travel?" During the debriefing: Approximately one third of the vocabulary and phrases spoken by the teacher and students is found in the language of the opener segment.
Students engage with some phenomenon	The activity required students to line up index cards that had one hole punched near the center top and to shine a flashlight through the holes hitting a target card at the end. Students were able to line up to 12 cards and successfully see the target "hole of light"
Students engage with the science phenomenon in small group structures called Coaching Teams	The task was undertaken at round tables in Coaching Team structures of 4 students per table group.
During the Coaching Team phase, teachers walk around the lab or classroom asking questions of individual groups	(Comments from Mr. D. to students as he walked around the room speaking to individual Coaching Teams) Mr. D. (21:03): "What's critical about the way you hold the flashlight?" Mr. D. (21:39): "Is there anything you are noticing about the way you are holding the flashlight?" Mr. D. (24:28): "...are you noticing anything in particular about the way you old the flashlight?" Mr. D: (25:24): "What do you notice about the way you are holding the flashlight?"
Teachers include real life examples	References to pickle relish jar and opacity, length of headlight beams, sunscreen and UV ray protection.

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The answer to the question posed in the opener is reached	Mr. D. (29:20) "So, how does light travel?" Student (31:08): "Light travels in unblocked, uh..." Student (31:25): "Light goes in a fixed place." Student (31:57): "Straight." Mr. D. (32:08): "Light travels in a straight line, precisely."

Figure 6: Patterns and Segments of a Science Lesson, "How does light travel?" recorded on 4/19/00

Breaking down the "How Does Light Travel" lesson highlights the intricacies and complexities of Bob's instructional methods. A similar analysis was completed for all the lessons on light. Bob and Conni utilized identical lesson structures regardless of the lesson content. Parsing this lesson indicates that The Standards are missing something of major significance (see Appendix Q).

What The Standards Miss

Because The Standards place such a premium on inquiry as foundation of exemplary science teaching, the balance of the National Science Education Standards is marginalized. Glib bumper-sticker style generalizations are mistaken for statements of good practice. Teachers don't need examples from case studies to visualize how to teach in reformed way—they need a reformed way to teach that is realistic, one they can incorporate into their own practice. The dilemma is that the worthy concept of inquiry is reduced to a snippet of an idea: inquiry is the base of science education; or set in an oppositional mode: didactic teaching is passé. A hybridized model of The Standards would be a useful tool. At the very least, teachers need a generic structure into which they can

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they can envision their own kids, classrooms, content and practice. Contextualized themes and generalized case studies go only so far.

Other aspects of Conni and Bob's teaching might prove useful in extending a hybrid pedagogical model for science teaching. The richness of their practice offers the kind of detail required to effect a blending of The Standards with typical classroom experience. It isn't enough to know that a lesson ought to start with an opening question. It isn't enough to know that kids ought to be grouped together for the exploratory phase of a lesson. Teachers need help in understanding which specific task will best help students learn rigorous science for a particular unit. Is the establishment of a pattern all that is required for students to learn difficult science concepts? Is the infrastructure of an opener, an exploration and a debriefing time sufficient or must certain characteristics exist within the tasks themselves to ensure students engage in science successfully? The answer to these questions is pretty obvious; the infrastructure alone does not yield great results. What follows is a discussion of the nature of the tasks students are asked to engage in during the exploration segment of their science lessons in "The Farside" classroom.

The Nature of the Task in the Hybrid Model

The National Standards directs teachers to "select science content and adapt and design curricula to meet the interests, knowledge, understandabilities, and experiences of students" What would constitute such tasks? In considering the possible identity of these tasks, several other questions arise concerning the nature of science instruction in elementary school. Should every child be able to do every task successfully? Will every student complete the task as well as every other child? Should the tasks follow formulas designed

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designed to mimic the classic scientific method? Despite contemporary calls for collaborative small groups in science classrooms, are certain tasks really more appropriate for individual work rather than shoehorned into group structure?

Answers to these questions help clarify why inquiry for inquiry's sake is less important to good teaching than is the nature of the tasks students are asked to do. If the questions posed by Conni and Bob were mundane and obvious, and if the tasks (labs, experiments, problem solving events, theorizings) were simple, diluted experiences, then all the manipulations of three time segments and other lesson elements would have little effect on learning. Instead, the nature of the task matters greatly in providing the catalyst for quality observation and engagement by students. If a lesson adheres to the time allocations and incorporates the elements discussed above (e.g., the everyday use of science journals, debriefing with the whole class, incorporating students' ideas into class discussion) <u>and</u> the nature of the task is high-quality, engaging, thoughtful, and represents scientific principle connected to other science ideas, then, perhaps, students can learn difficult science concepts. In "The Farside" it matters more that questions are worth pursuing, not how or where they are generated.

Reintegrating Process and Content

The separation of content from process has long been a subject of science and philosophy. John Dewey was a proponent of science education as a way for students to learn about the world, not just in the accumulation of facts, but as a way of thinking and being in the world (Dewey 1900/1902). Though state and district mandates might require otherwise, some researchers believe the science process skills (such as observation, note taking, problem solving) and content (facts and ideas) cannot be separated (Millar and

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Driver 1987). "The Farside" would be a case in which the separation of content and process seems impossible. What students do to learn science is constitutive of the science itself.

The nature of the task as Conni and Bob have constructed it, results in students grasping science ideas. Usually these are just some smaller facets of some (a?) bigger concept, so that eventually these parts add up to a larger whole. In order to accomplish this, the teachers must consider how the task will be approached (with others, alone), what question the task seeks to answer, if an answer is really discoverable by the students, what is the appropriate level of difficulty, and how this task fits with other student experiences.

Four lesson types emerged from the data provided by an analysis of multiple science lessons in "The Farside." These were

- cooperation required (CR)
- discussion only in small groups (DO),
- students work alone (A)
- students work with one partner (P).

Students worked in their assigned four-person Coaching Teams to accomplish tasks over 50% of the time -- this is the cooperation-required (CR) mode. More than a third of the time the students were asked to work in their Coaching Teams to problem solve and theorize about a demonstration that had been conducted by the teacher. In this mode, students were not physically touching any materials, but were engaged in a discussion about what they saw during the teacher demonstration. This is the discussion only (DO) mod

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only (DO) mode. Lastly, about a tenth of the time students either worked alone (A), or with one partner (P) from their Coaching Team.

What follows in Figure 7 is an example of the most common type of lab, a CR (cooperation required) task.

> A lab entitled "Measuring Light on a Grid," opened with a question "How does effect the way light travels?" Students were required to work cooperatively. Mr. D directed students to distribute the various duties required for the lab among the group. Coaching Teams were told to hold a flashlight 1, 3 and 7 cm above a sheet of 1/4 inch graph paper, and to draw the outline of the circle of light shining on the paper at each of the three experimental heights. Additionally, students were to count the number of squares within the circle of light for each height. Holding the flashlight, drawing the circle, and counting the squares was carried out a bit differently for Coaching Teams 1 and 5. Team 1 drew all the lines first and then developed a way to count the squares, whereas Coaching Team 5 decided to draw and count before moving on to the next height to draw and count again. Teams encountered various problems including holding the "light source" stable enough to draw the outline of light, and maintaining the exact 1, 3 and 7 cm height for each trial. Students did the best they could by holding the ruler and flashlight together perpendicular to the paper. Controversies arose over how steady one could hold the tools and how to count the squares. In any event, it did not much matter how the students did the lab because it appears that everyone clearly saw that as the light source was raised the circle of light got larger and the reflection on the page became dimmer.

Figure 7: Classroom vignette recorded on 4/26/00, "How does distance effect the way light travels?"

It would have been impossible to do this lab alone and very difficult to carry out if only two or three people did the task. Four-person Coaching Teams were able to share the burden of holding the flashlight steady, drawing the lines and counting squares. Such is the nature of a CR lab--it takes cooperation from all students in the group to accomplish the goal.

The level of difficulty chosen is a major factor in the success of the science teaching and learning in this particular classroom. It is not a new idea to have students engage in science in hands-on ways. One reason the CR lab is significant is because the tasks are a

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tasks are actually quite difficult to carry out. Many teachers have students do something in science, but the tasks are often very easy, so that everyone can be successful or they are too difficult and nobody can do them well. Neither is the case in "“The Farside”." Just how hard are the labs the teachers arrange for their students to conduct in “The Farside” classroom for science learning? Can most or every student complete each task successfully? In assessing level of difficulty in many science labs through the course of the year several factors emerge.

On an informal scale of 1 to 10, where 1 is very easy, so easy as to be uninteresting, and 10 is very hard, too hard to ever be very successful, the science labs in this class were a consistent 8. Of the twelve Coaching Teams in the classroom there was almost always one or two teams that could not complete a task successfully. However, there was no pattern as to which groups did or did not succeed. That is to say, every group struggled at some point in the year and all groups experienced success some of the time. No group consistently failed. It is as if the tasks were just a bit out of reach for some students some of the time. This finding helps clarify why this classroom is such a nurturing environment for science learning. It is also a potential example that illustrates what The Standards might be aiming for when suggesting school science should model professional science practices. Though most scientists would readily acknowledge “failure” as a major element of their research, The Standards do not offer such a caveat for teachers trying inquiry. In “The Farside” students are challenged. Students experience success and some failure. By keeping the tasks just beyond some students, some of the time, the teachers have created a rigorous science environment without causing

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causing students to feel discouraged or bored. The following lesson in particular might serve as an apt illustration of this factor:

> Cartesian Diver Systems: During the unit on air pressure the teachers opted to have the students create "Cartesian Diver Systems" inside used two liter soda bottles. The principle behind the task is to create a system between a small amount of air inside a glass vial and the surrounding water contained within the soda bottle that will demonstrate the relationship between buoyancy and density. These models are challenging to make. After receiving directions, students went to work on their individual diving systems while seated in Coaching Teams inside the lab. Students happily drew faces on their "bobbing Bob" vials, or "divers," that would be placed upside down inside the soda bottle already filled with water. Coaching Team members commented to one another about previous experiences they had with the phenomenon, through friends, siblings or other teachers. They were definitely excited to make their own divers that would, in theory, rush to the bottom of the bottle when the outside of the soda container was squeezed, and then rise again when the pressure was let off. When the system is operating correctly it's a counter intuitive visual experience to squeeze the bottle and watch something go down instead of the expected up. After several tries at filling the two-liter bottle and then shoving the vial diver inside, only one in four students could claim a successful diver system, in the whole class. The teachers asked the students to make sure they had at least "one working model" per Coaching Team and that was about all the class could provide.

Figure 8: Classroom vignette recorded on 3/29 & 30/00, "One working model of a Cartesian Diver"

A 25% student achievement rate would not be considered a very successful lab by most teachers' standards, especially in elementary classrooms, and particularly when easily frustrated students disengage from science activities. But the students in this classroom did not see this "lack" of success as a problem. Instead, each was involved in every step of the process even though the result may have fallen short of what was hoped. They were not discouraged as they still had "one working model" in someone's Cartesian Diver at their table. Some students commented in interview that they still felt they were successful even though their particular diver didn't work right. (All eight focus students from two coaching teams were asked if they were successful immediately following

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following the lab event. All eight said yes. Only two students, one at each table, has made a proper Cartesian Diver that worked.)

So, the task can be very difficult, but if the individual student can participate and still be able to claim to have done the task with some degree of success, perfection is not required. Teachers can continue to plan labs with a high degree of difficulty. (Group affiliation plays a major role in how students view themselves in these situations and this will be further discussed in the chapter on Coaching Teams.)

For more than a third of the time spent in labs, students were asked to work in their Coaching Teams to problem solve and theorize about a demonstration that had been conducted by the teacher. This mode, where the only task to be completed was to try to explain some phenomenon that was demonstrated earlier, was designed as a cooperative task but in actuality did not require participation by all members of the team in order to be accomplished. This DO mode of Coaching Team-work is about talk. This mode was utilized when Conni and Bob performed various demonstrations during the air pressure unit and students were asked to meet in their Coaching Teams to attempt to formulate explanations of what they had seen. Teachers often have students work in groups to try to explain some phenomena with varied levels of success. They can't insist that students offer opinions or try to come up with a theory if the students refuse to do so. But in "The Farside" the observations were funny, insightful, and motivated, not merely some dry representation of an idea related to air pressure or force and motion. The DO mode is especially interesting in light of The Standards' suggestion that good science learning must be hands-on. In this classroom where a third of the science time is spent by teams conducting some task, and a third of that time is spent only talking, a different kind of practice t

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practice takes place. In interviews, students repeatedly noted how much they valued the time devoted to participating in science. However, much of the science time is actually spent talking in small groups or in whole class.

Thus, students in "The Farside" spend 80% of their time either doing science themselves or being asked to discuss a science event they generally find inspiring. When Mrs. C asked her students to figure out "How to blow up Mr. D," students conferred enthusiastically and tried to use the hints they had been given in a host of ways. When Conni used the school's industrial vacuum cleaner to remove the air from a large plastic bag containing all but the head of a male student (the title for this lab was "Spencer in a bag" or "Shrink-wrapped Spencer"), the students were animated in their attempts at connecting this with all the other air pressure labs. Even though they weren't touching any materials, the students sat in Coaching Teams and with high energy and excitement, spent fifteen minutes trying to talk and write about the scientific ideas implicated in air pressure. These tasks, where students are asked to theorize and not engage in hands on activity, are the antithesis of what seems to be called for by The Standards and in their successful promotion of the ultimate aims of science instruction, indicate one more shortcoming of the reform document.

Comments on Content

Some discussion of content is necessary to more fully assess levels of difficulty of "The Farside" science lessons. Because the class is a combination of fourth and fifth graders, the teachers implement a two-year science program. In this way no student experiences the same unit of study twice. Instead, matter, force and motion, light, insects, air pressure, and the other topics the district and state mandate are rotated and taught every o

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taught every other year. There is no dumbing down of the curriculum so that fourth graders receive some lesser version of matter than the fifth graders. The content is taught the same way to all the students for every unit.

At this school, the units of instruction used to teach science are created by the teachers. There are no textbooks, only units of instruction pieced together based on the model of constructivist science teaching that Conni and Bob learned from Berkheimer in workshops several years ago. These units have developed over the years using a concept map of ideas the teachers developed that serve as the foundation for what activities students should experience. The units appear to be "under construction" all the time. The tasks themselves are chosen because they effectively teach the concepts important to the unit.

State and national requirements obligate more than conceptual teaching of certain material at certain grades. There are also elements to be taught that are considered process rather than content. These process skills include observation, documentation of data in an accurate manner, and the development of theories about phenomenon. Process skills also include questioning, communicating observations, and specific hands-on competency from use of a microscope to accurate measurement techniques and manipulation of chemicals. In analyzing the nature of the work the Coaching Teams accomplish in science labs, a strong case can be made that the process skills needed for the labs is actually content (Millar, 1987 #441).

Conclusion

The National Standards in Science Education have been helpful to many teachers and reformers. Components of The Standards have forced teachers and administrators to consider t

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consider the complex nature of teaching sophisticated concepts to diverse student populations. The Standards are built on a foundation of inquiry and this fact alone has helped elevate the conversation about science teaching to a more student-centered approach. The Standards have also awakened teachers to the idea that the form of school science can mirror the form of professional science. Unfortunately, inquiry has become the mantra of those trying to reform science teaching practices resulting in an array of unintended consequences. Figuring out how to teach using inquiry has proved a daunting task. Inquiry engaged in solely for the sake of developing a grammar of inquiry cannot save students or teachers from failure.

Bob and Conni have developed a hybrid model of science instruction that builds on a science question and develops student learning through a model where process and content cannot be separated out from each other. Theirs is an integrated version of teaching, a direct and specific method of helping students understand rigorous science concepts. And it all takes place in a particular medium or environment. Such a model ought to be the next step in reforming practice in elementary education in our country.

One way to think about the hybrid pedagogy of Conni and Bob is to imagine one of Gary Larsen's cartoons. Perhaps there's a machine filled room—the laboratory--with levers and pulleys, electrical wires and smoking chemicals strewn about. In the middle of the room are two wild-haired, mad scientists stirring cauldrons and building robots. Around the scientist are fifty children exploring, talking, laughing, thinking together. The creative risk-taking scientists add a dash of one pedagogical idea and a hint of another. All this gets mixed together within the air and space of the imaginary lab. In the end a troop

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end a troop of children emerge, smart about science ideas, interested in concepts of science in their daily lives, and all it took was Conni and Bob's hybrid pedagogy.

Chapter Four

Evolving culture: Why we need small group learning structures in science

In biological laboratories where scientists study microscopic organisms, experiments are carried out in shallow glass petri dishes. Inside these small and highly controlled environments some medium is used to foster the growth of a particular organism. Under the right conditions -- the amount of a special nutrient added, perhaps, or the quantity of light allowed into the dish -- the cells flourish. In this lab the culture grows and evolves over time, but only if certain conditions prevail. The medium of the culture is crucial to the organism's survival.

Growing a different kind of culture in a science laboratory is the subject of this chapter. In this case, the laboratory is an elementary classroom of fifty 4th and 5th grader and the organisms are students working in four person "Coaching Teams". Preliminarily, I offer an account of previous studies of educational small cooperative groups, which later serves as a basis for a comparison with the small groups in my study. I then introduce the Coaching Teams in my study through descriptions and vignettes of their interactions. Having provided a picture of what the Coaching Teams are and how they operate, I compare and contrast these small groups with the literature. The differences between the two – what the literature reports about small group learning on the one hand and the example provided by my experience with Coaching Teams in this study on the other -- illuminates new properties of group work worth consideration. What is highlighted in this extended analysis of cooperative learning is a view of students evolving as a culture of science learners. A number of characteristics of Coaching Teams and their role in group success warrant a closer analysis, notably, the duration of the group's existence, cross age membership in the group, and group autonomy in decision making. Most crucial is a special co-factor I have labeled "task rigor" that I believe is an essential component for these small groups to thrive. Understanding the way in which Coaching Teams blend the best of cooperative group learning with multiage group learning will allow us to more accurately assess the role of teachers in the process. This chapter on the Coaching Teams is followed by a look at Conni and Bob, the teachers in this story, and their practice.

Cooperative Group Learning in the Literature

Conni and Bob chose "Coaching Teams" as the label for the small cooperative groups they began utilizing in their classroom science program several years ago. As the words imply, the individuals in these groups are expected to assist each other and to interact so as to create a cohesive unit. Such strategic arrangements within educational settings fall under the heading of cooperative group learning.

Best known of the researchers regarding cooperative group learning are Johnson and Johnson (Johnson and Johnson 1990; Johnson and Johnson 1994). Fundamental to their analysis is the perspective that all group work is essentially a socially interdependent process. The core of their inquiry is an attempt to determine if students achieve at superior levels in cooperative learning settings when compared to competitive or individualistic systems. By looking at alternative teaching strategies including combinations of cooperative, competitive, and individualistic efforts, Johnson and Johnson determined that achievement is consistently highest for students using predominantly, even on occasion, exclusively, cooperative methods of learning.

Attempting to assess this benefit, Johnson and Johnson have outlined what they believe mediates reported achievement gains. Simply putting students together in groups does not, in and of itself, promote greater achievement. They identify five components of cooperative group work that when implemented promote classrooms in which students can enjoy greatest achievement (p. 27):

- Clearly perceived positive interdependence.
- Considerable promotive (face-to-face) interaction.
- Felt personal responsibility (individual accountability) to achieve the group's goals.
- Frequent use of relevant interpersonal and small-group skills.
- Periodic and regular group processing.

Johnson and Johnson have helped define what it is that teachers must actually do in order to maximize student achievement in a cooperative group setting. Their theories are based on social interdependence and are not necessarily linked to any particular curriculum or content (Johnson & Johnson, 1990; Johnson & Johnson, 1994).

Slavin is concerned with curricular issues in tandem with cooperative group structures. This aspect of research in schools has led to program development in mathematics, reading, and writing directly associated with learning in cooperative small group settings (Slavin, 1990). Slavin joins the expected benefits of cooperative group learning with the demands of certain content. Research linking content and cooperative group learning comes primarily from observation in mathematics and reading, over limited durations, for a specific skill based task, where the groups are constantly in flux. For instance, studies in mathematics were designed to determine achievement in computation. Studies in literacy involved reading comprehension or other specific skills like decoding for reading. The data for these studies was collected from multiple groups, over various time periods, from one lesson to a unit of study. Each of these endeavors resulted in positive effects on achievement. These programs (e.g., Team-Assisted Individualization or TIA for mathematics, Cooperative Integrated Reading and Comprehension or CIRC) incorporate teaching strategies that draw on various models from strict cooperative group activities to combinations of group and individual and whole class activities. Materials for these programs blend direct instruction and complex instruction into a set of directives for the teachers, a kind of to-do list where the details of teaching the lesson are provided. Information about what the teacher is to say and do, as well as what is expected from the student, is prescribed in the materials. With few exceptions, these programs are considered successful, on some level or another, and yield achievement superior to those of students in similar programs without a cooperative learning component (Slavin, 1990; Slavin, Madden, Dolan, & Wasik, 1996).

Cohen also looks closely at the social dynamics of students learning in groups, highlighting complex instruction strategy in her research with students engaged in math, social studies and science (Cohen, 1986). Cohen in summarizing her conclusion regarding the benefits of cooperative groupwork argues that:

> Groupwork is an effective technique for achieving certain kinds of intellectual and social learning goals. It is a superior technique for conceptual learning, for creative problem solving, and for increasing oral language proficiency. Socially, it will improve intergroup relations by increasing trust and friendliness. It will teach students skills for working in groups that can be transferred to many student and adult work situations. Groupwork is also a strategy for solving two common classroom problems: keeping students involved with their work, and managing students with a wide range of academic skills (p. 6).

Central to Cohen's research, and that of Cohen and Lotan, is the issue of status among group members learning together (Cohen, Lotan et al. 1990). Though researchers engaged in the examination of cooperative group learning seem to agree that the underlying process in group work is basically a social one, the focal point for Cohen and Lotan is the inequitable power held by group members. Slavin is concerned with large-scale curriculum projects using a blend of many strategies, whereas Cohen and Lotan use CI as the foundation for equalizing the social power or peer status among individuals within a group. Content is peripheral to Cohen and Lotan's concern with student learning. Their work predominantly involves heterogeneous groups where language and ability levels are strikingly diverse. Rather than considering content programs as Slavin does, Cohen is most concerned with equity in classrooms. Focus on power and equity in school group interactions can be instrumental in ensuring the widest access to knowledge promoted in the lessons in which the students are participating. Such a perspective on group dynamics leads many classroom teachers to an awareness of the various ways in which power and knowledge are kept out of reach of many students, particularly minorities, in diverse school environments (Cohen & Chatfield, 1991b; Cohen & Lotan, 1997; Cohen, 1986; Cohen, Lotan, & Catanzarite, 1990).

Others have studied additional aspects of cooperative learning. Knight has examined achievement in an approach similar to Johnson and Johnson. (Knight & Bohlmeyer, 1990). Brufee looked at cooperative learning as practiced in higher education (Bruffee, 1999). And very recently, Aronson has made strong claims about his version of small cooperative group learning as utilized school wide in several California high schools, positing broad benefits for the community, including a reduction, perhaps even prevention, of school violence (Aronson, 2000).

An overview of reports on cooperative learning as an instrument for instruction illuminates several predominant ideas. First, all reports are positive, suggesting that cooperative group learning is a successful practice overall, worth further investigation. It generally produces higher achievement levels when compared to competitive or individualistic approaches. Second, the wealth of verifiable and replicable research adds credibility to the findings. Third, as explained by Cohen, the indirect benefits for students engaged in a cooperative group learning process (e.g., language skill development for those participating in groups learning mathematics) are commendable for any type of teaching strategy. If students learn advanced language, social, and problem solving skills, it must be good practice. Finally, if the use of CI can propel minority and other marginalized students through the school system with greater success, it ought to be a significant consideration for any teacher working in schools today. Every stakeholder in education, every student, parent, administrator, superintendent, or scholar must be encouraged by the benefits engendered by cooperative group learning.

It is no wonder then that every content area national reform document calls for the use of some type of small cooperative group teaching and learning strategies.

National reform documents in all of the four major content areas taught in schools today -- math, social studies, literacy and science -- either suggest or mandate the use of small cooperative groups for teaching (American Association for the Advancement of Science, 1998; National Council of Teachers of Mathematics, 1991; National Research Council, 1996). Though other strategies are also suggested, the small group structure has been adopted and integrated into the elementary curriculum by teachers everywhere. Walking the halls of any elementary school today, it is easy to observe students engaged in the activities of education -- from coloring in maps or calculating math problems -- in small group structures of two, three or four students. Teachers all over the country have readily adopted small group structures into their teaching.

As a former elementary and middle school teacher, and as an instructor of university students in the teacher preparation program at Michigan State University and The University of North Carolina Chapel Hill, I too am very encouraged by cooperative group learning strategies. However, I have a nagging itch about something that seems out of sync between the literature and practice from my own experience. From the personal and anecdotal to the formal findings of this study on Coaching Teams, there is something amiss as to what is reported in the literature and what is played out in schools.

Having been trained in an intense Johnson and Johnson two-week workshop early in my career, and having implemented cooperative learning in my own programs over the course of several years, I have direct experience with the methods and strategies discussed by cooperative learning experts. I have found the practice somewhat wanting. It is considerably harder than it appears to make successful cooperative learning happen. Just gathering together materials for name tags and job assignments was difficult enough, let alone finding tasks requiring appropriate skills from a universe of disparately talented students. I claim no expert status at this practice. Perhaps others have enjoyed greater success. But still, though I was an experienced teacher, “trained” in the particular intricacies of cooperative learning, I experienced daunting problems when I asked my inner city middle school students to work together for science instruction.

I was skeptical, as I began my case study of fourth and fifth graders, about what could really be accomplished in Coaching Teams and what teachers did to make these structures successful, if in fact, they were. What follows is a discussion of the Coaching Teams in Conni Crittenden and Bob DeLind's classroom.

Coaching Teams: An Introduction

I spent hours observing and videotaping science lessons in a classroom that utilized the small group structure of the Coaching Team for all science instruction. The fourth and fifth graders aligned in their teams taught me a great deal about what a Coaching Team is and how it functions.

A Coaching Team consists of four students (sometimes five). Usually two females are paired with two males. Two of the four are fourth graders and two fifth graders. Each of the fifty students in the multi-age classroom called "The Farside" are in one of the 12 Coaching Teams. Teams remain together for an entire school year and meet as a team for every science related lessons.

Conni and Bob carefully create the teams using their own formula for success. The traditional school calendar is in effect and the groups are formed each October. Their decisions are based on multiple criteria -- student gender, age, grade, personality, academic strengths and weaknesses, existing friendships, maturity level, and interests. The goal is to create a balance of personalities using the strengths and weaknesses of the students. The teachers consider a variety of skills from the academic to the athletic, including leadership, humor, and artistic ability. Group members are rarely reassigned after the initial first team-building event that takes place when the small group configurations are announced. The teams remain intact all year long.

Science lessons usually take place across the hall from the regular classroom, in what was the media center. Conni received a grant several years ago to turn the media center into a mathematics and science lab. All the teachers in the school are constantly using the space and it is amply supplied for learning. The lab is prestocked for most science lessons contemplated by Conni and Bob. Cotton balls, batteries, seeds, pop bottles, Petri dishes, crayons, electrodes, refrigerator, sinks, oven, stove, microwave, and a few computers-the list goes on and on. A sunken round theatre space in one area of the room allows students to sit in a circle on the two outside steps and the teachers comfortably conduct demonstrations in-the-round. Here, too, they use the overhead projector and facilitate large group discussions. Behind this section of the room are 12 circular five-foot long tables where students sit and work in their Coaching Teams to carry out lab activities. During observations and tapings of these science lessons there was often a great deal of activity and noise emanating from both teachers and students. Students were asked to leave because they were disruptive and occasionally students were off-task, talking to members of another team. But these instances were exceptions, not the rule. Generally, students moved from the circle to their Coaching Teams easily and had no problem conducting their lab work at their assigned table.

In terms of achievement, it is generally accepted that these students do well on state tests, and that these fourth and fifth graders learn concepts as well as facts in several modules each year. During the year of this case study the students learned about matter, air pressure, rocks, light, and they participated in the classic all-grade murder mystery science experience now popular in many schools.

The Coaching Teams exhibited behaviors consistent with the findings on cooperative learning mentioned earlier. Conni and Bob asked their teams to engage in activities that seemed to promote the same qualities Johnson and Johnson enumerated as fundamental to successful group work. These were clear positive interdependence, direct interaction, encouragement of personal responsibility, promotion of interpersonal and small-group skills, and frequent group processing. (Johnson & Johnson, 1990, p. 27).

My observations of these groups were also congruent with Cohen's perceptions of the benefits and outcomes at the heart of cooperative learning and CI strategies. These Coaching Teams fit well with Cohen's view that "group work is an effective technique for achieving certain kinds of intellectual and social learning goals…it is a superior technique for conceptual learning, for creative problem solving, and for increasing oral language proficiency. Socially, it will improve intergroup relations by increasing trust and friendliness…" (Cohen, 1986, p. 6).

The following vignette, Figure 9, is a good example of "intergroup relations" often displayed by Coaching Teams:

> While Sara (a 4th grader) is off getting some supplies for testing, the other three Coaching Team members are sitting at their table waiting. The lab task for today is to locate a number of different materials and to test each one for its opacity quality, to determine what light will pass through and what it will not pass through. The students have already brainstormed a list of items they wish to test. Sara is off getting aluminum foil. Donovan (a 4th grader) makes a statement to Sam (a 5th grader) and Emmalee (a 5th grader) that is actually a question, "It wouldn't go through a lab book." Matt is referring to light passing through an item on his list, compiled just a bit earlier by the group, which he has mistakenly listed as "lab book" instead of "lab book paper." Sam says "No, lab book <u>paper,</u>" and then demonstrates his point by lifting up his lab book and shining the flashlight through one page in the book. Emmalee and Donovan see that the light goes through the page and begin to write down their observed finding. Sam quickly announces, "But we should wait for Sara". The other two students immediately stop writing and look up to locate Sara somewhere in the room. She

returns shortly thereafter and the group proceeds to test each item on the group list one at a time beginning at the top of the list.

Figure 9: Classroom vignette recorded on 5/02/00, "We should wait for Sarah"

This episode is significant as a demonstration of the concern Sam has for Sara. This Coaching Team functions as a small democratic group or family in which the students care enough about each other to wait a moment, in order to be fair and kind.

Another example of student behaviors that illustrate the point of trust and friendliness, a characteristic mentioned by Cohen and linked with the Johnson and Johnson's list of what teacher's should promote, is the method Coaching Teams employ to choose who does what task in their groups. What follows is an analysis of how the students in my study reported on the process of determining roles and responsibilities for science labs.

From my observations during one lab on light:

> I observed Coaching Team five as they walked from the whole class discussion "in-the-round" area in the science lab toward their designated circular table. They barely looked at each other as they mumbled something I could not hear. They took approximately 25 seconds to walk from the whole class area to the table. Immediately on reaching and sitting at the table, the group commenced on the project they were assigned. But the designation of individual tasks to the group members took place apparently by some magical method. How it was decided that _________ (either Sarah for Team One or Cameron for Team Four) would go get the supplies was not visible on camera.

After the science lab event mentioned above each student in the team was interviewed regarding the way in which jobs had been distributed that day. Other students were also interviewed and asked the same question about how their Coaching Team decided on the assignment of jobs during lab time. What follows is a synopsis of how different teams allocate jobs and deal with personal preferences, and concerns of fairness and efficiency.

1. " I wanna do this. I want to pour the water into the cup."

One way teams decide who should have a job is by individual declaration of preference. Students simply say which job they want to do and determine, for themselves, how important the job is.

> Like when we got to our table and we know what materials we have, somebody goes okay, I wanta do this. I want to pour the water into the cup. They call it and if there's more than four things, cuz we only have four people in our group, then we like try to make it so it's fair so if you have like a little part, you get to do that or if you...let's see. Or, If you really, really think that you'd be the right person and your group agreed, you could do that. And that's kinda how you do it. (Lindsey, 5/18/00).

2. "[We] do rock, paper, scissors."

Sometimes the group finds a way to settle conflicting desires by utilizing some random method equivalent to drawing straws. The students determine (after a period of discussion or controversy) who has the longest pencil that day or they might spin a pencil like a top. The person it ends up pointing to gets to do the job in question.

> Well, sometimes we like, what we usually just kind of, okay, we argue and then the person who like, well, after we argue, somebody like says oh fine, I don't wanta do it because they're like getting sick of the arguing and so that's kinda...and then it's between us, three of us and then somebody else like drops out and then they do a little thing called a, they do rock, paper, scissors. (Joe, 5/17/00).

3. "We kinda say just if they ask, they can do it."

Occasionally, individuals might decide it's just nicer to let someone else do what they want and accede to another's first choice.

> We all work as a group...like we don't fight over who would do what and we just...we kinda say just if they ask, they can do it...we were sitting in a circle, we all just decided before that and just said, cuz after we heard all the items that we were gonna go get, we all wanted one thing and then one person decided on one thing, the other person decided on the other. So like there's one thing that everyone wanted to get so it worked out fine. (Ben, ___00). Well, somebody

> asked if who could do the pens and somebody, he said, Joe said, I'll do it and then she said no, can I do it please and so he just said fine. (Ben, 2/12/00).

4. "First of all, we make sure everybody has a job."

For some interactions within a Coaching Team, the group makes sure that everyone gets to do something.

> Well, sometimes we don't always decide that well. We always, well, first of all, we make sure everybody has a job or we, if there's only three jobs and there's four of us, we split a job in half and we eventually decide who's gonna do what. And what that person wants to do they usually get to do...or sometimes if we have enough time, we run through two trials and we switch parts. Like maybe one person, if there's only three jobs can be an observer and then they can get a job the next time and somebody else is an observer, if they already got a chance to do something. (Kirbay, 5/23/00).

5. "Somebody gets to do the cool thing one time and then the next time, somebody else gets to do it."

One student told me that her group keeps a mental record of who has done what job over the many weeks of the school year. In this way, she says
"Well, it's like somebody gets to do the cool thing one time and then the next time, somebody else gets to do it." (Emily, 5/23/00).

Coaching Team Reports in Comparison With the Literature on Cooperative Group Learning

The first observation I made of the Coaching Teams seemed noteworthy, that is, <u>the method in which roles within teams are assigned is not visibly apparent</u>. I became intrigued with the Teams' individual practices and as I pursued the question it became evident that there is a gap between what I had been taught in my Johnson and Johnson training years ago, how the cooperative learning is described in the relevant literature, and Conni and Bob's actual real life Coaching Teams. As I was trained and as it was described, teachers are expected to assign roles for group work. After all, students cannot be counted on to be fair and thus some students might not get a chance to experience each of the roles -- like recorder, reporter, supplies person – creating an inequitable situation in which some students would be denied equal access to the substance of the lessons.

There is a striking difference when comparing my observations of the way "Farside" participants in Coaching Teams ascribed roles with descriptions of cooperative learning and CI in the literature. Curious about the ways in which cooperative learning proponents were directing teachers on student job assignment, I recently found a text in a west coast university bookstore designed for use in a class on middle school teacher education. Complex Instruction in the Middle School Implementation Manual: A Guide to Teaching and Classroom Management -- The Theory and Practice of Complex Instruction (Cohen & Chatfield, 1991a) is used as a standard text for the Teacher Education Program. As CI is the cornerstone of cooperative learning for proponents such as Cohen and Slavin, this seemed like an appropriate resource to understand one simple aspect of groupwork that intrigued me as a classroom teacher and researcher: How should individual roles within cooperative settings be assigned? The following is from chapter 4, "Rules and Roles," of the manual (p. 16-21).

A. Why is it important to have clear roles and rules?

If students have clear rules and roles to play, they will:

- Perform their tasks in a business-like fashion.
- Take responsibility for their own learning.
- Help one another get the job done.
- Free YOU, the teacher, to extend learning, evaluate learning, and observe and evaluate how well the whole system is functioning.

E. What are the jobs and roles for student in complex instruction?

General roles

- facilitator

- recorder
- resource
- materials manager
- reporter

Specific task roles

- safety officer
- measurement specialist

G. Many of the roles will also need development

- Don't expect people to play roles well unless:
- The role is clearly assigned. USE ROLE BADGES.
- Students get lots of practice playing all the different roles.
- Students have learned behaviors expected of each role.
- You hold students accountable for playing their roles.

H. What are some tips on assigning groups and roles?

- Make up a role chart that can easily be changed so that students can always see what group they are in and what roles they are to play.
- Always rotate roles so that everyone gets a chance to play each role.
- Never let groups choose their own roles because some students will not ever get a chance to play what the group considers the most desirable roles.

According to the third point in section H above, a teacher should never let groups independently choose roles for individual team members. In this model, groups are to function at the earnest direction of a teacher responsible for decisions regarding the identity and characteristics of roles and who then ought to be assigned to them. I was left with the sense after reading Complex Instruction that Cohen and Chatfield doubted students were capable of choosing and assigning roles on their own without teacher intervention. The tone of the manual is prescriptive, limiting, rigid and vaguely oppressive.

What Joe, Ben, Lindsay, Kirbay, and Emily had to say about their Coaching Team's job selection technique suggests openness, flexibility and respect for personal preference. Student explanations of the process linked back to my own discomfort with experiences I have had both as a teacher organizing student cooperatives and as an adult being placed in analogous groups. If teachers determine who performs a role and exactly what the role is, then how are students problem solving, getting to know each other's preferences, respecting individual differences, and being kind to each other? Could this teacher intervention actually inhibit groups connecting to each other on some fundamental personal basis? Is it possible that the teacher's control of this aspect of the groupwork actually hinders the robust growth and development it is intended to foster? In current vernacular, is the CI model a case of micromanagement rather than a program allowing teams to devise solutions to their own problems?

The CI manual asserts similar rules and regulations to those I recall from my Johnson and Johnson workshop. I tried hard to implement the practice as recommended, but it was exhausting for me and my students. It caused a great deal of conflict among the students as the rules were discussed and individuals became sergeants-at-arms ready to pounce on any person who did not follow the rules exactly. Rules, rigid roles and regulations sometimes crowded out content learning and goals I was trying to accomplish. The CI Manual made occasional references to allowing students to work out their own problems. But why not emphasize the benefits of student task assignment from the start and provide practical guides to its facilitation? It would be a powerful way to encourage responsible prosocial behavior.

Discussion of job assignment is critical for understanding Coaching Teams because knowing how groups make decisions about who does what is a way of knowing what the teams value. By looking carefully at how teams decide roles and responsibilities I began to get a sense of a culture of learners, not a group of students performing tasks in rule-bound contexts. I came to understand the Coaching Team as something richer than just any small group performing a task in some sort of cooperative manner; groups not merely smarter or better than the sum of their parts. It became evident that these teams, put together to teach and learn science concepts, evolved over time, through a process of acculturation, into cohesive units knitted together in a remarkable fashion.

I also found that the way students working in Coaching Teams solved their own problems in a more realistic and honest way than what seems likely in other cooperative learning models. Students are not perfectly just and fair with each other all the time, and it still is an open question as to <u>what is</u> equitable practice and learning in science class. But what is it about teaching in Coaching Teams that seems richer and potentially more rewarding than what the literature suggests should be possible?

Coaching Teams Have Culture

As I hope is clear by now, I have been using the term "culture" in a dual manner. In the sense that it is used in the biological sciences, a culture is the cultivation of biological material in a medium containing nutrients. Culture in an anthropological context is generally the behavior and attitudes of a particular group encompassing a shared system of meaning, primarily mediated through the use of a common language. It also includes technique of organization. It has a reflexive quality in that the shape of a culture is determined by evolving conduct and beliefs, and the prevailing culture in turn colors the choices made by individuals and the group as a whole; that is culture acts as a medium for nurture and growth. The issue of individual role assignment within a Coaching Team is a culturally determined factor in both senses of the word.

In addition to role assignment, I have identified three other salient features unique to Conni and Bob's Coaching Teams when compared to cooperative groups recognized in the literature. These components are (1) autonomy, (2) cross-age population, and (3) longevity of membership. Just like the complexity of cells growing in a Petri dish, the Coaching Teams are evolving cultures working together and in which individuals learn from each other and act towards their partners in kind and caring ways. What follows is a brief account of these additional aspects of Coaching Teams in Conni and Bob's classroom that make their case special and illuminate the concept of a "culture of learners."

Unique Coaching Team Component #1: Autonomy

<u>The students in this study were given the freedom (almost all of the time) to determine, on their own, who did what.</u> This is not to imply there are no teacher interventions or guidelines. Students frequently heard that there should be "no hitch hikers" in any group, and that working out problems is part of the job of a Coaching Team. The teachers schedule explicit team building activities early in the year to foster cooperation and problem solving, employing methods from sources such as those found in Tribes (Gibbs, 1995). Conni and Bob might prompt their students with something like, "remember, every Coaching Team member should be participating in this task" but there would be no follow up to this decree by the teachers -- they do not check to see if whether equitable participation took place. Beyond these "bumper sticker" statements suggesting all members should contribute to group work, not much else is done overtly to

ensure that every student is participating or that all students get a chance to experience each role at one time or another. If a leader were needed within a group, the teachers did not move to orchestrate decisions to fill the void. If the task required a reporter, or someone to get supplies, the students in the Coaching Team worked out who should have these roles on their own. The way in which Coaching Teams decide who should do what and when is fascinating and idiosyncratic. The Teams are sovereign in choosing the manner in which they carry out tasks assigned for science labs. The Coaching Team structure fosters results much more in line with the ideals of democratic education, shared power, and development of interpersonal communication skills detailed in the literature as the very purpose for establishing these small groups in the first place. "The Farside" system is far more realistic and organic than the idealized models of cooperative learning suggested by the literature.

Unique Coaching Team Component #2: Longevity of Membership

The students in this study were placed in Coaching Teams by the teachers at the beginning of the school year and remained in these groups for the balance of the academic year. Coaching Teams exist as a unit for eight months. Though other groups may change for reading or math, these science groups remain constant. This is a unique feature in elementary education. Keeping group membership stable for the year runs contrary to conventional thinking about group interactions. It is generally accepted that students get bored working with the same peers for a whole year, and that students need to work with different students as often as possible to increase their experience and acumen in working with others.

The literature on cooperative learning addresses the issue of duration by suggesting that group membership ought to be varied often, for instance after a lesson or unit of instruction. Such is the case in reports such as Bianchini's regarding middle school science where groups are pulled together for the treatment only. (Bianchini, 1997)

When interviewed, Coaching Team students were unequivocal in their opinions on staying together for an entire year -- they thought it was a good idea.

Trisha: It's kind of good to stay with the same people all year so you get to know them more (5/22/00).

Mitchell: ...you get to know [the group] instead of just changing right away and meeting new people every week or two weeks or whatever (5/22/00).

Ben: ...cuz you get to know [the group] better and if you were switching around all the time, you wouldn't get time to know each other and stuff like that (5/22/00).

Kirby: I think that's a good idea because then when you go to share ideas, you're used to sharing ideas with other people that are in your Coaching Team, those same people, and you're used to working together (5/23/00).

Keeping students together for an entire year as a cooperative group is a significant difference between the Coaching Teams and the groups reported in the literature. By staying together for eight months students have an opportunity to really get to know each other, and to develop a sense of affiliation. This practice leads to a shared sense of community, greater individual responsibility, and optimum conditions for learning science.

Unique Coaching Team Component #3: Cross Age Population

"The Farside" classroom mixes fourth and fifth grade students. Every Coaching Team has members from both grades -- which means every Coaching Team has members who are veterans of the process from their experience previous year, and novices who are new to the arrangement. This form of configuration is unique in cooperative learning. Generally groups tend to be comprised of students in the same grade. But the implementation of a setting like "The Farside"'s promotes leadership and cooperation and it fosters the development of confidence and self-esteem. The Coaching Team is an advantageous arrangement with implications for many disciplines, but especially science.

As I considered the importance of these three factors in the creation and durability of Coaching Teams, I tried to find relevant literature and discovered significant findings on multi-age group strategy. It seems that the benefits of mixed age grouping are many and they link up with Coaching Teams in my case study.

Connecting Coaching Teams with Multiage Classroom Literature

The strength of the three unique dimensions of Coaching Teams -- autonomy, duration of membership, and cross-age population – results in good measure from the multiage structure in place in the greater classroom. Because there are students from two grades in the same classroom, the Coaching Team structure is an excellent way to reap the benefits documented in the literature on the subject of mixed-age grouping. Conni and Bob have created a group structure that blends the best of several conditions.

The multiage classroom has been a part of the history of education in the United States since the 19th century. As with many aspects of education, student achievement is considered one of the prime ways to judge this practice. Almost all reports are positive with regard to performance in multiage settings (Kinsey, 2001), (Kasten, 1998), (Veenman, 1995). Beyond achievement, recognizing and honoring individual difference has been the focus of much of the discussion on this grouping structure. (Krockover, Pekarek, & Riggs, 1999). Unfortunately the research has been conducted on literacy and mathematics curriculum -- there do not seem to be any reports of multi-age elementary settings as they pertain to science education (Dever & al., 1994), (Kinsey, 2001), (Young & Boyle, 1994).

But one study in particular appears relevant to the story of Coaching Teams. Katz reports on the overwhelming benefit of having students of varied abilities, ages, and skill levels interact with each other. Students placed in multiage groupings benefit not only from cross-pollination and modeling as one might expect. But an additional impetus to success results from what is often missing in single age classes -- namely competition. According to Katz, when a single age/grade class is the dominant structure, there is a tremendous amount of pressure on both student and teacher for everyone to function at the same level. Difference is expected and therefore tolerated and even encouraged in a multiage classroom, constructing an environment conducive to creativity, community and care. Katz explains that when children of the same age group work together there is an immediate tendency for domineering behavior. In multiage groups, older children are drawn to model and help younger children (Katz, 1968). So goes the Coaching Teams with their combination of fourth and fifth graders. The older students act as mentors and the younger students are the mentees. The younger students develop into leaders, models and helpers by the end of the year and the process continues with the next class of fourth graders. In exit interviews, focus students explained their beliefs about how to be a good mentor (fifth graders) and their role next year (fourth graders).

Like cooperative learning groups, the multi-age classroom is a good place to learn. A Coaching Team is a particular instance of multi-age group structure that weaves together all the very best we know about student learning.

What the Students Have To Say About Their Multi-Age, Yearlong, Autonomous Coaching Teams

Individual interviews of "The Farside" students provided an array of reasons why the Coaching Team structure was something highly valued. They gave me many rationale why Coaching Teams were deeply beneficial to learning science. For instance, in answering a question regarding the benefits of Coaching Teams, Owen said, "In Coaching Teams, you have other people to help explain things out to you and help you kind of understand. If we, if you worked alone, and you didn't get it, you wouldn't get too far in experiments." He went on to explain a rendering he made of a perfect Coaching Team interaction, "I drew a person who wasn't understanding and someone else in the Coaching Team helping the person out." He added, "I think some people might need the Coaching Team more than others because some people might not be as smart as others. I'm not trying to put anyone down."

Carolyn told me "You don't have to do everything by yourself. You don't have to try to understand everything by yourself."

When asked about what specific role he might play in his Coaching Team, Joe replied, "I'm kind of like the assistant of Hannah or something like that. And Carolyn, when Hannah's absent, she takes her place. Like Hannah's the president, Carolyn's the vice president and like secretary and Ben's like the assistant secretary." Later Joe told me about his ideal Coaching Team, his dream team and who would be on it. "Well, Seth because he's smart and he's kind of like if somebody's like not getting it, he'll help you out. Spencer, because he's smart and helps too. And Carolyn, because she's a good worker and she'll help but she doesn't quite give away the answers."

Loren is a fourth grader and she told me that one of the things she has learned is "Well, Kevin, he's taught me how to be nice to the other fourth graders and let them do some things and all be equal and stuff."

Regarding staying together for a year, Trisha said, "It's kind of good to stay with the same people all year so you get to know them more." Mitchell agreed, "You get to know them instead of just changing right away and meeting new people every week or two weeks or whatever."

Students told me Coaching Teams were more fun than doing things alone, that they got to communicate, and that students helped each other remember things. In a word, the Teams felt like families.

Coaching Teams as Evolving Cultures

This chapter began with a metaphor about cells in a petri dish representing the students in my case study as they evolved their own culture. I have tried to demonstrate that Coaching Teams are cooperative groups exhibiting behaviors and engaged in practices that go beyond the literature on best practices for cooperative groups. Literature on multiage group structure is of some value in broadening the context for Conni and Bobs' Teams. But the Coaching Teams posses unique qualities in their longevity, in their composition of two grades, and in the autonomy with which the Teams operate.

Coaching Teams have all the attributes of the best of both groupings reported in cooperative learning and multiage learning literature. The benefits resulting from four-person yearlong groups are many. The manner in which students in these groups learn from each other will be discussed below in the chapter on learning, but it is beyond dispute that comprehension of science content is promoted in this setting and group structure is a significant part of the success students experience. The quality of instruction is also a foundation of the superior quality of learning, and this will be covered in the chapter on teaching.

My study suggests a complex set of "nutrients" is required for a "culture of learning" to thrive, more complex than almost all small group directives would claim. The benefits resulting from utilizing Coaching Teams to teach science seem to be products of something other than mere student preference for a learning style or some logistical efficiency with supplies. Coaching Teams are not just good structures for socialization of young students who happen to be studying science. The students I studied exhibited a host of behaviors and learned many significant skills, from the social to the procedural, and I attribute their growth to the group structure. <u>But first and foremost, the students in "The Farside" Coaching Teams learned science</u>.

Chapter Five

Reciprocal Cross: Sarah and Donovan exchanging science "know how"

History: Girls and Science

During the thirty plus years between the 1960's and the 1990's various controversies developed regarding girls and their performance on math and science tests. Attention was focused on the fact that females were underrepresented in mathematics, science and engineering majors, graduate and professional programs in those disciplines, and hence, women were underrepresented in those respective careers. In an attempt to develop an understanding of the causes of the scarcity of women physicists and chemistry majors, disputes emerged around teacher behaviors, curriculum, pedagogy, and the very nature of the disciplines themselves.

Both feminist and non-feminist scholars embarked on research agendas designed to answer big questions in education: Are tests biased in favor of males? Is the school climate hostile for girls? Do female students lack good mentors? Do girls simply learn differently than boys? Results of the ensuing studies informed practice and added fuel to the ongoing debate about equity in schools and parity of opportunity afforded boys and girls.

As we embark on the 21st century, we know a few things about girls and math/science knowledge and performance that we didn't know in the 1960's. From sex – related differences work we learned that "when girls succeed in science, they credit luck. When boys do well, they credit ability…" (Reyes and Padilla 1985). From Sadker and Sadker, we learned that teachers sometimes unconsciously favor their male students by asking boys high status, probing questions and, alternatively, giving girls only a friendly nod during question and answer sessions in class. (Sadker and Sadker 1994). We learned there might be certain "ways of knowing" that females tend to hold (Belenky, Clinchy et al. 1986). We also learned to pay attention to the gender gap on performance measures such as SAT scores, in which females continue to score below their male counterparts in mathematics by an average of 33 points (1994 study by ETS).

Numbers that helped propel the gender debates have been changing over the past couple of years. Females are now the majority of students enrolled in US medical and law schools. The gap in SAT scores between males and females is closing. There is a sense that girls are doing better, and not just catching up to boys, but roaring past them. The perception among some is that boys are in deep trouble (Sommers 2000).

Now, where there were once "women's studies" departments at universities, "human" or "gender studies" are commonplace. Somehow the message from the Women's movement of the 60's and 70's has mutated -- the alarm now centers on boys' performance. Instead of reading about young girls angst and issues of low self-esteem produced by dysfunctional school practice and societal oppression as we did in Reviving Ophelia and Schoolgirls, we are now confronted by Raising Cain and The Trouble with Boys. Redirecting the analytic lens on boys has replaced a sensitivity regarding gender bias favoring boys, to one suggesting that schools are biased against boys.

Science, as an instance of one content area in the curricula spectrum, has traveled its own path of self-discovery and consciousness-raising during the past few decades. History has recorded a mainly European male set of characters who discovered and launched the big ideas of science. But digging deeper, a host of women have been revealed as responsible for creation of some of the essential structures of science, and the inspiration for innumerable scientific discoveries. Unlike their male counterparts, these women remain unknown to most of the modern world, but they advised, counseled, translated, extended, and interpreted much of the knowledge of their more socially accepted fathers, brothers and husbands. Madame Curie was not the only woman to contribute significantly in science while overcoming incredible obstacles along her way. Other prominent women in science include Irene Joliot-Curie, the daughter of Madame Curie, and Barbara McClintock, Dorothy Crowfood Hodgkin, Lise Meitner, Gerty Radnitz Cori to name just some Nobel Prize winners in chemistry and physics (McGrayne 1993). Active recruitment of females and minorities into math and science related fields is now an integral part of university agendas.

The received notion of science as an objective enterprise is also under reconsideration in education. A growing interest in what should count as science literacy and how to teach that knowledge throughout the life of a student is yet another indicator of the way in which the field continues to question what feminist philosopher Sandra Harding posed as "Whose Science? Whose Knowledge?"

Science Education for Today

What the National science reform agendas explicitly aim for is "science for all Americans" (American Association for the Advancement of Science 1989; American Association for the Advancement of Science 1993; American Association for the Advancement of Science 1998). In addressing the dual problem of underrepresentation of women and minorities in science careers, this call is a step toward democratic notions of education in general, and science specifically. But such a mandate is confronted by the reality of a school system rife with inequities of resources, cultural bias and gender concerns. Do girls and minorities have comparable access to content as their male counterparts do? Might a feminist pedagogy be a vehicle to get more students involved in science education? What would a classroom based on such a paradigm look like?

As fostering "science for all" has become the foundational basis for much of the research on science teaching and learning, the study of "The Farside" classroom is strikingly apropos. Taking just one piece of the whole educational picture — the pedagogical practice of putting children together in small groups called Coaching Teams for an entire year to learn science—puts the rest of the story in perspective. The single most important aspect of "The Farside" classroom, is, in fact, the Coaching Team. As children interact with each other in these intimate groups, touch and play with materials, talk and laugh about ideas and things in their world, they fufill the objective of "science for all." And they do this by carrying out science for themselves and for each other.

Reciprocal Cross—Sarah and Donovan

I am identifying the connections between and among students in a Coaching Team as the "reciprocal cross," a term utilized in genetics which refers to a process at the cellular level that insures that no trait is sex dependent. A reciprocal cross is a kind of egalitarian practice that helps nullify dominance and recessiveness among genes. In plants for instance, the reciprocal cross effectively controls which traits subsequent generations will exhibit. In the case of ""The Farside"," it is not just that students share or work together, but that males and females interact in meaningful ways that affect their own experience as learners and knowers of science. No single person possesses all the knowledge or dominates the group. The structure of the Coaching Teams supports cross-pollination of individual knowledge and process skills to the benefit of all. The analyses that follows is based on two focus students from one coaching team. Within a Coaching Team, many examples were available.

Sarah and Donovan are novice fourth members of their Coaching Team. Their participation in Coaching Team One is illustrated in the vignette highlighted in Chapter One titled "Four Students Grapple with Air Pressure." Though similar in age and grade level, these two students are quite different in their perception of Coaching Teams. Interestingly, as discussed later, that difference does not detract from their individual learning in their Coaching Team.

Listening to Sarah

The profile for Sarah is easy and fun to write. A fourth grader, short and with blonde hair, verbal, creative, clever and humorous, she is the student teachers can't help but favor. Her energetic nature is direct, her personality, generous. Group work is made for Sarah. She thrives on the social interactions and relishes being part of a Coaching Team. Her answers on the following questions administered early in the study, illustrate these characteristics.

On the initial survey given to students in "The Farside", Sarah completed one item thusly: "After my group work in science today, I felt smart." During an interview at the same time, she responded:

Interviewer: Did you learn something in science class today? If so, how did you learn it?

Sarah: Yes, we did because of all the groovy experiments.

Interviewer: Did anyone help you learn something today in your Coaching Team in science? If so, how did they help you?

Sarah: My whole Coaching Team, because it was fair.

Interviewer: Did you help anyone learn something today in your Coaching Team in science? If so, how did you help someone?

Sarah: I don't know if I did, but if I did, it was probably for the same reason.

Interviewer: What went well in your Coaching Team in science class today?

Sarah: We did the experiment, we didn't mess up or anything.

Interviewer: What did not go well in your Coaching Team during science today?

Sarah: I don't think anything, we didn't fight or argue, we had a discussion and we worked it out.

Interviewer: What is the best part of being in a Coaching Team for science class?

Sarah: Working together, like a team thing, it really helps.

Interviewer: What is the worst part of being in a Coaching Team for science class?

Sarah: I think it is when you know something is right, you have to go through it and explain it, even if you know its right, it takes a lot of time, you gotta stick with it and not get too frustrated.

Interviewer: Did you like working in your Coaching Team today?

Sarah: I think I did, we always work together good; it's always fun. You get to do it with someone, science is real fun when you get to do it with someone.

Sarah's comments indicate she thrives on the interaction of the group. She believes she contributes to other people's learning and feels as if she is a significant part of the Coaching Team. Additionally, Sarah acknowledges the contribution others make to her own learning. She sees a connection between the quality of the experiments she is given to engage with and her learning ("because of the groovy experiments"). Sarah seems to have internalized the nature of group argumentation; it takes time to make your point and you must control your emotions ("not get too frustrated") in order to make your point.

Observing Donovan

Donovan is a bright 4th grader who often appears to be in his own world. He is not a big talker and perhaps, a bit immature. Though he would surely be considered a quiet student, he is eager and sharp, with wide dark elfish eyes that sometimes sparkle as he takes in the world. For the most part he is enthusiastic about science.

On the initial survey of students in "The Farside", Donovan, like Sarah, completed one item this way: "After my group work in science today, I felt smarter." During an interview at the same time, he responded to questions:

Interviewer: Did you learn something in science class today? If so, how did you learn it?

Donovan: Yes, oil is heavier than water.

Interviewer: Did anyone help you learn something today in your Coaching Team in science? If so, how did they help you?

Donovan: No.

Interviewer: Did you help anyone learn something today in your Coaching Team in science? If so, how did you help someone?

Donovan: No.

Interviewer: What went well in your Coaching Team in science class today?

Donovan: Well, we didn't fight or argue, we all just got along.

Interviewer: What did not go well in your Coaching Team during science today?

Donovan: Nothing.

Interviewer: What is the best part of being in a Coaching Team for science class?

Donovan: You get to meet new people in the class.

Interviewer: What is the worst part of being in a Coaching Team for science class?

Donovan: You don't get to pick who you work with.

Interviewer: Did you like working in your Coaching Team today?

Donovan: Yes, we got to do test tubes and its just really cool how we layered the liquids.

Donovan's comments indicate he places little stock in what other members of his team contribute to his own learning, or his contributions to theirs. He does not seem very inclined to offer analysis of his Coaching Team except to say they didn't argue on the particular day of the interview. Donovan's reply that the worst part of a Coaching Team is not getting to pick your team mates suggests he would like to pick other people to work with or doesn't much like the one's he is with now. But at the same time, he finds meeting new people a good part of the experience. His response to the last question suggests he is aware of how interesting the science task is he was given to accomplish.

Analyses

A comparison of Sarah and Donovan's interview responses yield stark contrasts in the way in which they view their Coaching Team. In addition, the vignette in Chapter One titled "Four Students Grapple with Air Pressure" reveals the way they differently interact in the Coaching Team. In that vignette, it is easy to listen to Sarah and the other two 5th graders as they facilitate their own discussions to appreciate the dynamics of this Coaching Team. They construct grand theories and extol them to each other (i.e. Sarah:

"He couldn't move because of all the air pressure on top of him."). But Donovan is rarely part of the group discourse. To understand the role that Donavan plays in the group, you have to watch and study closely. He rarely makes comments and when he does they are occasionally odd. But sometimes his proclamations are thoughtful about what has just taken place in the petri dish or over on the demonstration table (i.e. as when he posits in the vignette that the results of the bunny experiment "maybe has something to do with the marshmallows"). Sometimes, as in this case, he is ignored. By reviewing tapes of many hours of this Coaching Team in action, a pattern could be discerned wherein Donovan usually spoke well after the other students had hashed out ideas and only spoke minimally (he only makes twelve comments to Sam's more than 35 in the vignette in Chapter One). Donovan is no leader. But a fourth grader in the group would hardly be expected to be.

Sarah, conversely, was often the first to speak and get the group in order (i.e. Sarah begins the group discussion about air pressure with "I think I'll start like we did before"). She can be heard on tape offering ways to go about carrying out the task at hand, how to proceed with next steps, what to do when the group got stumped, and what the findings might be. She easily offers hypotheses and draws conclusions. She is a leader along with the other two fifth graders, noted in part in the way her comments are incorporated in the comments by other group members. In the vignette, Sarah says regarding the Spencer in a bag experiment, "He couldn't move because of the air pressure on top of him." Emmalee follows right afterwards with, "The air pressure was pushing on him." As a fourth grader Sarah is quite unusual in her capacity to play such an active role in the Coaching Team arrangement.

Formalized, sophisticated edicts concerning national reform agendas are forsaken when observing this small group interact during science class. What remains in the forefront is a vibrant picture of students doing and thinking science for themselves and for each other—no other grandiose scheme prevails. Whatever science for all Americans implies, these kids are engaged in science for themselves, intrinsically motivated or encouraged by something external created for them out of the efforts of Conni and Bob. This is not to discount the importance of the ingredients to "The Farside" classroom science program, be it lesson structure or content. However, at the moment of theory construction by the students, it's just four kids sitting around a table trying to make sense of their world.

The Coaching Team structure allows for the reciprocal cross of ideas and social interaction. Sarah leads, Donovan listens and when he can, he contributes. Sometimes he alters the course of the talk, sometimes he is ignored. What would happen to these blossoming intellects if they never had the opportunity the Coaching Team affords? Sarah would be denied the experience that builds her science knowledge and confidence essential to the growth and development of females in the sciences. And Donovan would be limited to his own thinking and musings. For example, like Sarah, he is able to respond correctly to the ST when asked about the similarity between the air pressure experiments. Through the Coaching Team, Sarah has a reason to reason about the ideas aloud and Donovan has a reason to focus his thoughts and listen to others. John Dewey wrote in The Public and Its Problems (1926) that

> Equality denotes the unhampered share which each individual member of the community has in the consequences of associated action. It is equitable because it is measured only by need and capacity to utilize, not by extraneous factors which deprive one in order that another may take and have. A baby in the family is equal

with others, not because of some antecedent and structural quality which is the same as that of others, but in so far as his needs for care and development are attended to without being sacrificed to the superior strength, possessions, and matured abilities of others. Equality does not signify that kind of mathematical or physical equivalence in virtue of which any one element maybe be substituted for another. It denotes effective regard for whatever is distinctive and unique in each, irrespective of physical and psychological inequalities. It is not a natural possession but is a fruit of the community when its action is directed by its character as a community.

Sarah and Donovan's contributions are different, but they are equal.

Chapter Six

The Science Experience as Whole

I began this dissertation with a story about Gianni, the boy cared for by his female classmates. He is typical, perhaps, of some boys in school today. But if he is, how is Donovan, any different from Gianni? Coaching Teams might just be another species of stereotypical girl and boy roles—domineering or silent males interacting with passive or caretaking girls. Before elaborating further on the Gianni and Donovan comparison, it might be appropriate to harvest concepts from the previous chapters and focus on a more fully formed picture of "The Farside" classroom. The role of science education research in contemporary schooling must also be addressed.

Global politics and modern technologies keep pushing the science education community to teach better, help students test better, and provide the skilled work force required for a modern society in the twenty first century. I believe, as many other educators do, that public education must be at the core of a democratic nation, and science literacy has as great an importance in an individual's life as reading or writing skills.

Getting a good education, especially a strong science education, remains a challenge for students. It is common knowledge that in the United States many elementary teachers don't teach science at all, and if they do venture to try, they resort to practice far from the best as we have come to think of them. Bad science teaching is teacher directed, uninspiring, didactic, limiting, scripted, and based on facts, not concepts. Conversely, Standards based science education relies on an inquiry approach, where "less is more," where projects extend over significant duration, and assessments are as diverse as the student population enrolled in today's schools.

This case study includes analysis of unique teaching practice, student learning, group interactions, gender equity, assessment, discourse, and content. Each chapter is a discussion of a core idea, but each connects to every other chapter. None stands in isolation. I did not find it useful to try to comprehend teaching in "The Farside" without simultaneously looking at content, or to try to understand student learning without looking at how the teachers arranged their students in small groups. A study might justifiably be centered solely on any one of these themes. But from the start, I could not parse out discrete elements from the whole mosaic. Just as the culture of any group cannot be well understood through analyses of a single element of their existence--food, clothing, shelter, religion, childrearing, government--such is the case in the classroom. The very interconnectedness of classroom experience argues against attempts at dismemberment. "The Farside" is a living organic whole.

Each Chapter in this study is only possible because of the links between teaching, learning and student interactions. One cannot be shown or understood without the others. Hence, the Coaching Teams are worth studying because the talk is so rich among individual members, which is due to the lessons structure and rigorous task orchestrated by the teachers.

For instance, Chapter Two is an overview of what makes science teaching so hard, and specifically, why concepts related to light are especially difficult for students to learn. Student misconceptions are documented and demonstrably challenging to alter. But evidence of real student learning in "The Farside" is also reported. A model from microdevelopment is used to support an image of learning as waves rather than the more traditional conception of learning experience akin to a staircase or scaffold. This offers a more holistic view of learning, in context, and properly emphasizing interdependence. Chapter Two highlights students learning of science concepts. This information in isolation isn't very helpful if we don't also probe the role the teachers played in making the learning possible.

Chapter Three attempts to connect student learning with teaching through a review of the National Science Teaching Standards. Conni and Bob developed hybrids of The Standards to teach science to their 4th and 5th graders. Individual lessons are consistent, with deliberate beginnings, middles and ends. Students are led through a question phase, exploration phase, and a debriefing phase in every session. Conni and Bob have devised a science program that is attentive to The Standards, but is not limited to them either. What these two teachers have done is create an amalgam of what National Reformers have tried to articulate. The enacted practice in "The Farside" encouraging students to consistently apply methods of a scientific approach, results in strong process skill development along with conceptual knowledge growth. Multiple iterations of a concept—many activities over several days or weeks to reinforce concepts of light or air pressure—support theories of learning as waves. Students inch forward, fall back, roll along at their own pace, grasping the ideas, losing them, and finding them again in another task. Learning depends on the teaching, but not <u>just</u> the teaching.

Chapter Four focused on the Coaching Team system for science lessons. First and foremost, these cooperative groups depend on teaching strategies and content for their survival. When students are given challenging tasks, in an environment that supports problem solving, creativity, and autonomy, that minimizes inter-student competition, and encourages peer teaching and discovery, strong learning occurs. There are two prominent components of this small cooperative grouping as practiced in "The Farside": Coaching Teams remain intact for an entire year and they are composed of both novice and experienced students. A system that can do all of this at one time is very complex. It can only be grasped as a whole.

Even so, it was always significant to me to try to understand the Coaching Teams from the students' perspectives. Just as I had asked my middle school students years before their opinions on pink and blue paper, ultimately I wanted to know how the students in "The Farside" felt about their Coaching Team experience. Chapter Five is a look at how the system of science education in this case study came together for two students and how dependent the entire enterprise is on the interactions of individual group members. Sarah and Donovan, as participants in a Coaching Team, benefit from all the other parts of the system that have been constructed. The moment of student interaction at the round table, with journal notebooks open and with some experiment underway, that is the most important single moment of all—students talk and listen to each other. The classroom is alive, it flourishes. To comprehend such a moment, the other aspects of the culture have to be understood as well. The culture of the Coaching Team is the medium that fosters growth and ultimately the prize of students engaged in communication and contemplating science concepts. The chemistry of the whole system creates something greater than the sum of its individual parts.

I argue in chapter five that a framework that supports the hybrid teaching practices, the extended Coaching Team arrangement, and several other aspects of the practice observed ""The Farside"," is part of a feminist pedagogy. The literature regarding elementary science education in a feminist frame is scarce. Maher and Tetreault, Rosser, and others have provided educators with precepts about how elements of a feminist pedagogy ought to be implemented in secondary education, and what might evolve from the practice. The teacher is the facilitator and a source of knowledge, but not the <u>only</u> source of knowledge in the classroom. The content to be studied is joined to the lives of the students. "The Farside" classroom did not explicitly include elements of a "liberatory pedagogy" (Barton) that challenges societal norms of gender, race and class. But it did include science that engaged local environmental concerns when the bat population was threatened by the loss of its habitat because of the proposed demolition of the district transportation barn where they resided. Under current circumstances, this might be as connected to their lives and as liberatory as this school could provide. It is also an area of growth for these teachers, should they choose to tackle content linked more directly to inequities in society that science influences.

Future Directions

Several possibilities emerge in contemplating directions for future research. First, and most obvious to me, is that the Coaching Team strategy must be tested in more diverse settings. The particular classroom I chose to study was comprised predominantly by white children. If the ethnic composition of the class were modified, would I find behaviors consistent with those reported by Anderson with regards to small lab groups where inequitable role assignment and traditional power distribution was manifested. [Anderson, 1997 #306] [8]? This proposed study ought to be carried out with a more

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[8] In this cited study it was reported that the white male fourth grader tended to be the leader, the white female student was the secretary of the group, the quiet hispanic male student was allowed only one task --

diverse student population to determine if the Coaching Teams can push on social issues of gender, class, and race. Accepting as indisputable the social nature of group learning, and recognizing the associated challenges of multicultural schooling, still leaves open a fundamental question: Can students from diverse populations benefit from long-term, stable small group learning strategies to master rigorous science concepts in upper elementary classrooms?

A second issue fertile for investigation is whether the Coaching Team strategy as implemented by Conni and Bob might be employed with middle school students. My teaching experiences lead me to believe keeping diverse students together in small groups for a year could be a very powerful strategy to help counter negative peer pressure, and gender, race, class stereotypes—the bane of middle school experience.

More studies need to be conducted that address learning outcomes for students engaged for over a year with particular peers in science inquiries. How rigorous can the science content be and still engage students? How might different content topics, for instance, life science, affect actual Coaching Team practice—does content matter all that much to the process?

Additionally, my experience illuminates discontinuities in The Standards. The teaching described in this study shows a more blended approach. Encouragement of creativity and support for at least a modicum of independence might actually result in drawing in more practitioners which is badly needed in elementary education.

Another marker in the study is the perception of the science classroom as incubator for a particular kind of culture, namely the Coaching Team culture. Karen

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to draw a picture, and the black female student was ignored, even though she had many correct answers and information that would have helped the group succeed in their task?

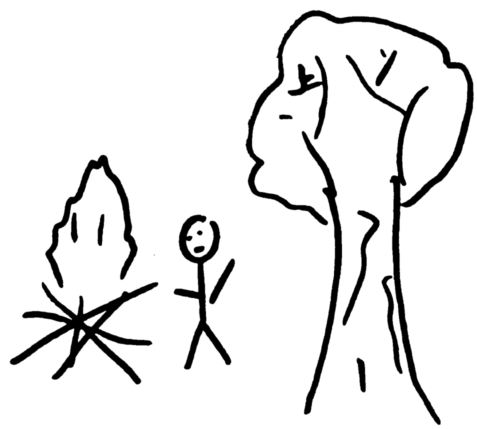
Gallas, Vivian Paley, Phillip Jackson, have all contributed to a view of a classroom as a cultural phenomenon with certain attributes. The lens needs to be turned toward the Coaching Team and its promise as a vehicle to developing trust that students can make decisions for themselves.

Back to Gianni and Donovan. Teachers cannot control all the interactions among their students, even if they thought it a good idea to try. What teachers can do is create environments, creative spaces, where the best possible outcomes are possible. Gianni, and the girls who helped him, got nothing from their teacher to counter societal norms that were replicated in their classroom. These students, left to themselves, devised mechanisms to function and make the best of their situation.

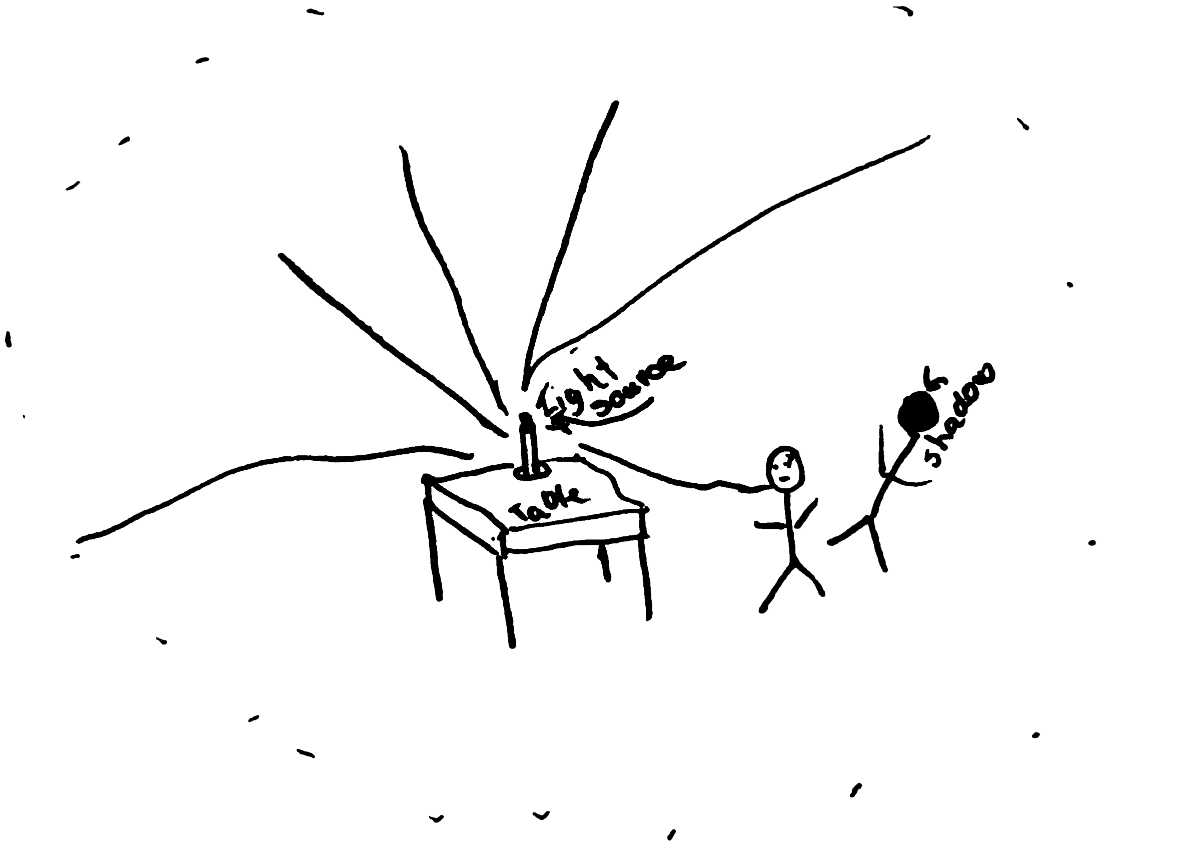
My focus as the teacher years ago was far more directed towards content and reading groups than interactions between and among students. Donovan has a different culture and situation for his interactions during science class than did Gianni. The Coaching Team structure does not dictate how Donovan should behave. But the group channels his behavior and thinking just as his behavior and thinking affects others. At times, Donovan offers a procedural suggestion (instances recorded on video) and is corrected by another member—without this mediation, he would persist in his flawed analysis of the experiment to be conducted. Occasionally, he poses hesitant questions to his group that might never be asked if he had only his teachers to turn to. In return, his fellow group members have the chance to explain details and test and refine their own understanding as they respond to Donovan. Mentors and mentees need each other in these cross-age, cross-experience Coaching Teams. Donovan is cared for and nurtured by the group. This is where he belongs when science starts. He is grounded, linked and an indispensable part of his Coaching Team, and Donovan can rely on the support of his group to succeed, even as he sometimes drifts into silence or day dreams about things far removed from the classroom. Without his Coaching Team, Donovan would need to find his own means of support. Or not. Not every child has Gianni's resourcefulness.

APPENDICES

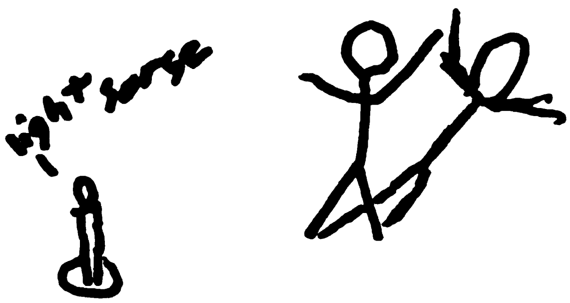
Appendix A
Student Work
Pre Light Unit Drawing (E.A.)



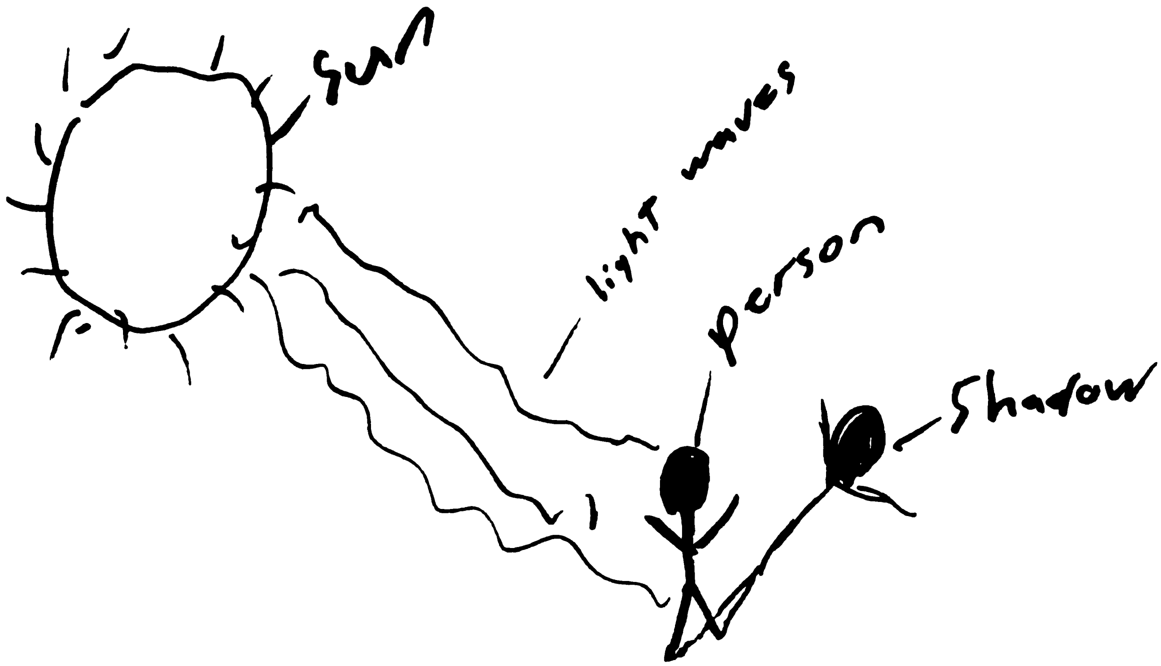
Appendix B
Student Work
Post Light Unit Drawing (E.A.)



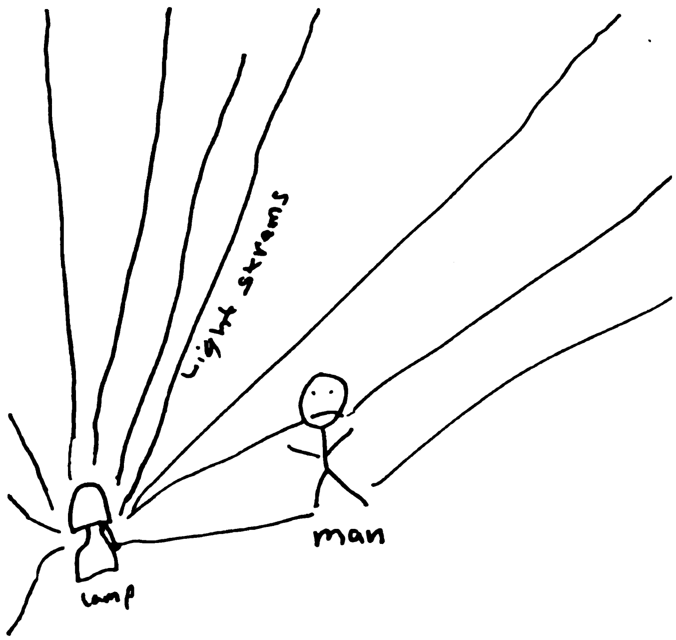
Appendix C
Student Work
Pre Light Unit Drawing (S.D.)



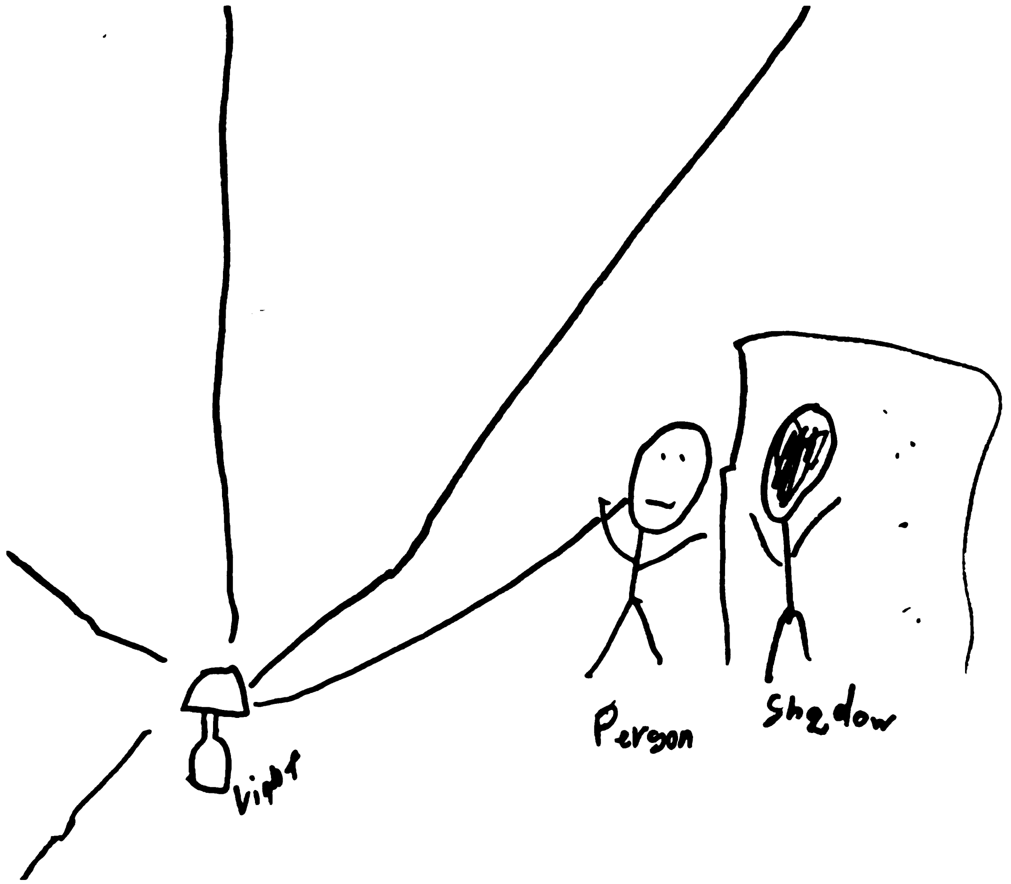
Appendix D
Student Work
Post Light Unit Drawing (S.D.)



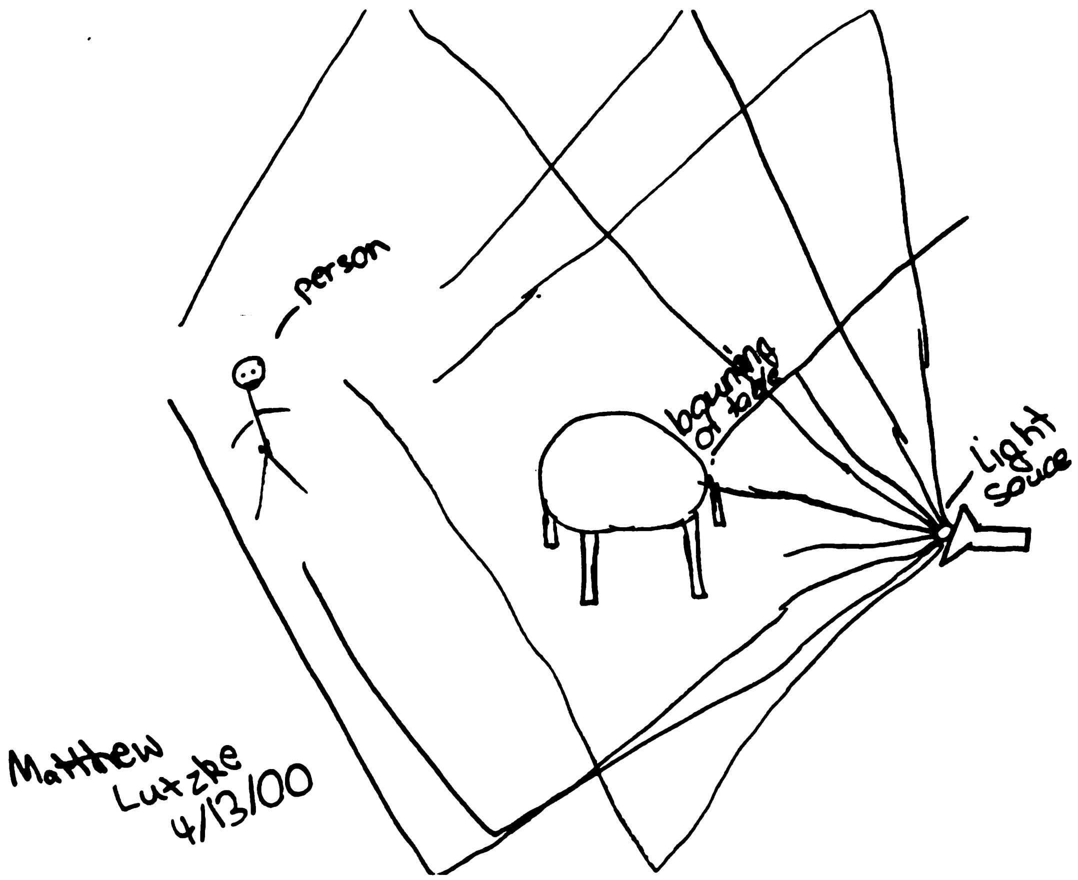
Appendix E
Student Work
Pre Light Unit Drawing (D.H.)



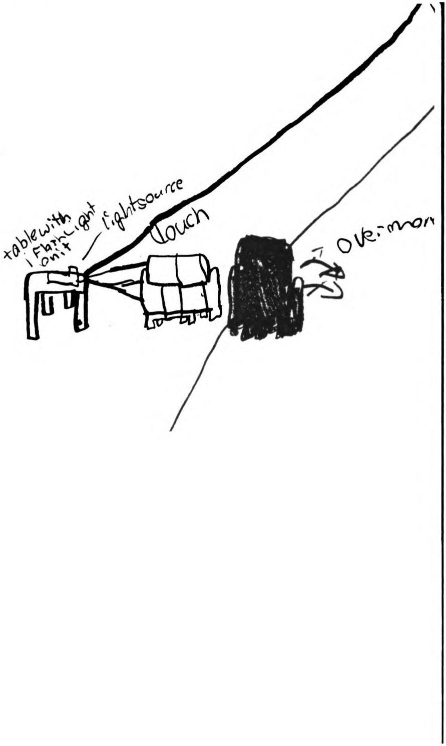
Appendix F
Student Work
Post Light Unit Drawing (D.H.)



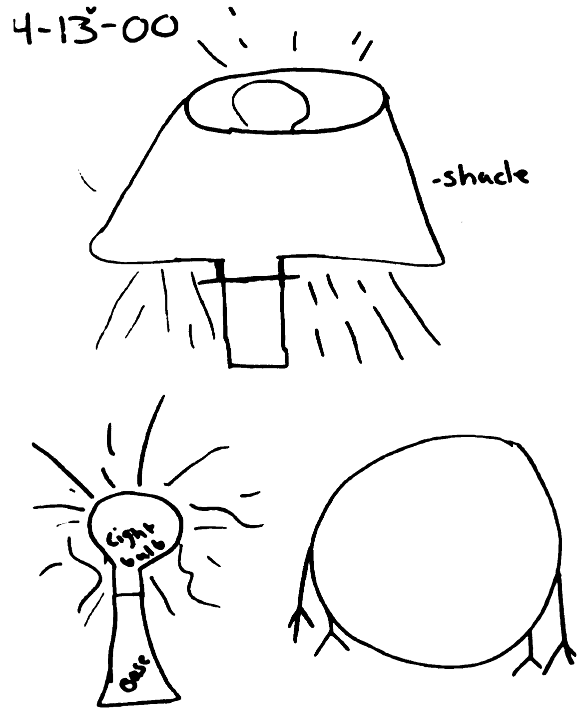
Appendix G
Student Work
Pre Light Unit Drawing (M.L.)



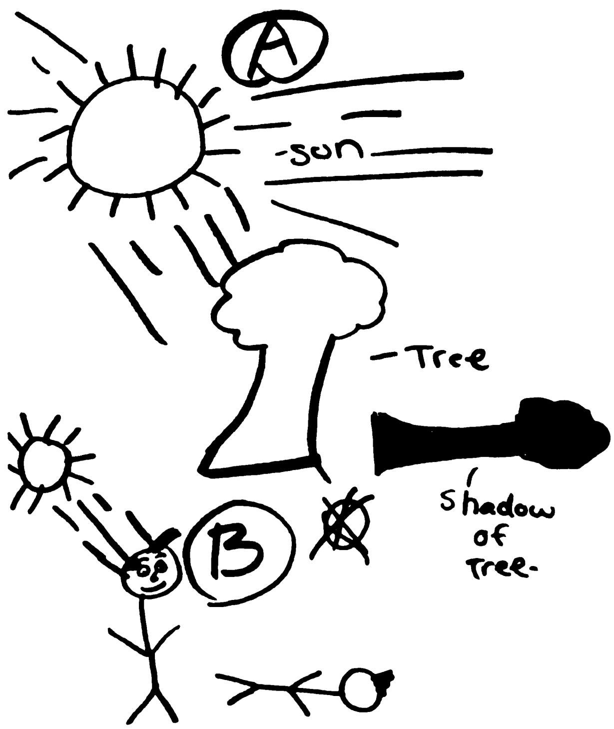
Appendix H
Student Work
Post Light Unit Drawing (M.L.)



Appendix I
Student Work
Pre Light Unit Drawing (E.M.)

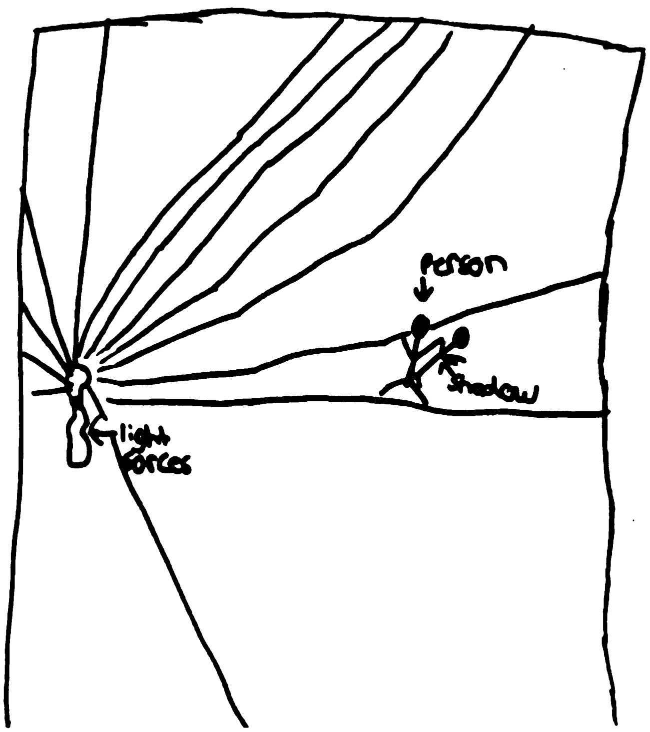


Appendix J
Student Work
Post Light Unit Drawing (E.M.)

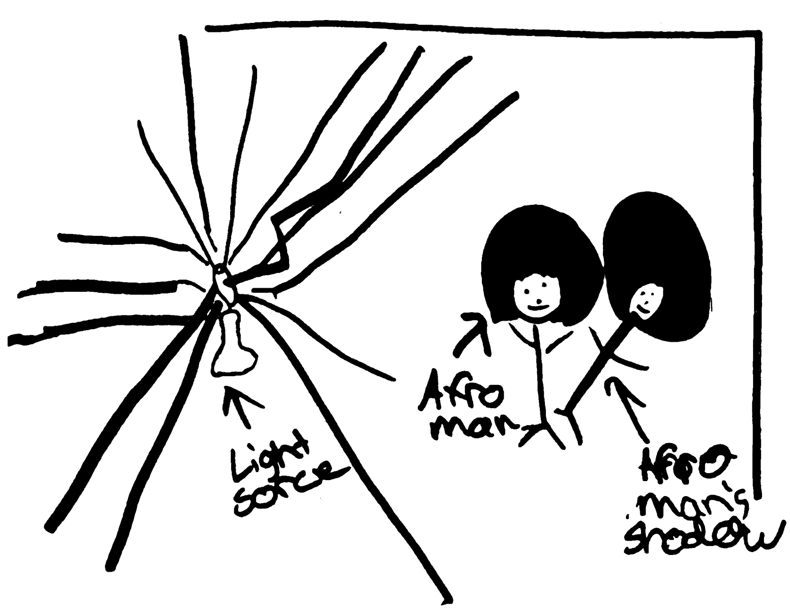


Appendix K
Student Work
Pre Light Unit Drawing (C.P.)

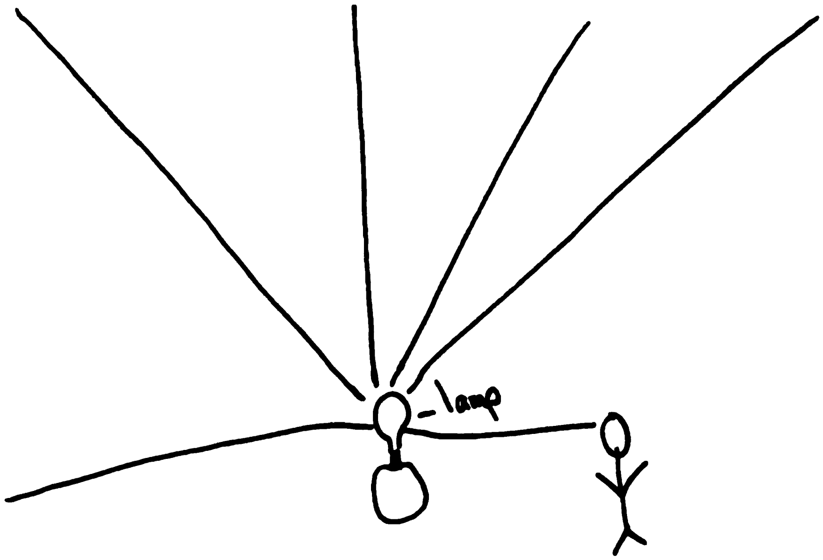
Cameron
4/19/00



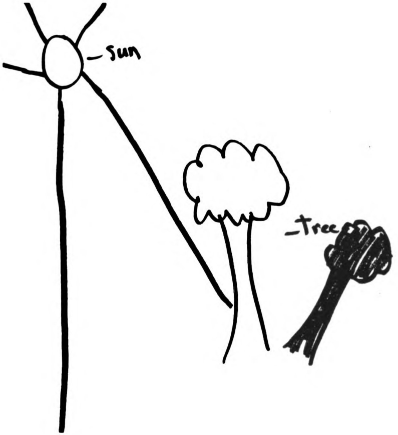
Appendix L
Student Work
Post Light Unit Drawing (C.P.)



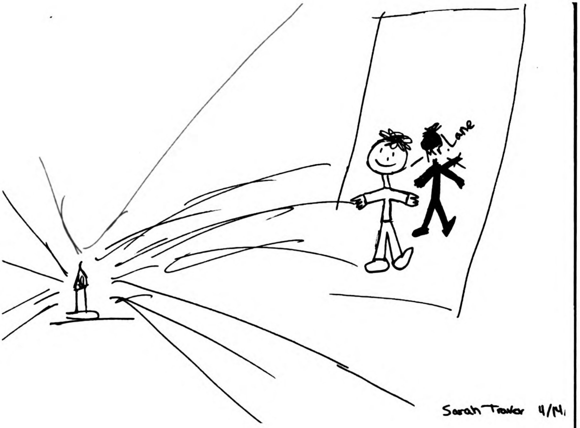
Appendix M
Student Work
Pre Light Unit Drawing (S.S.)



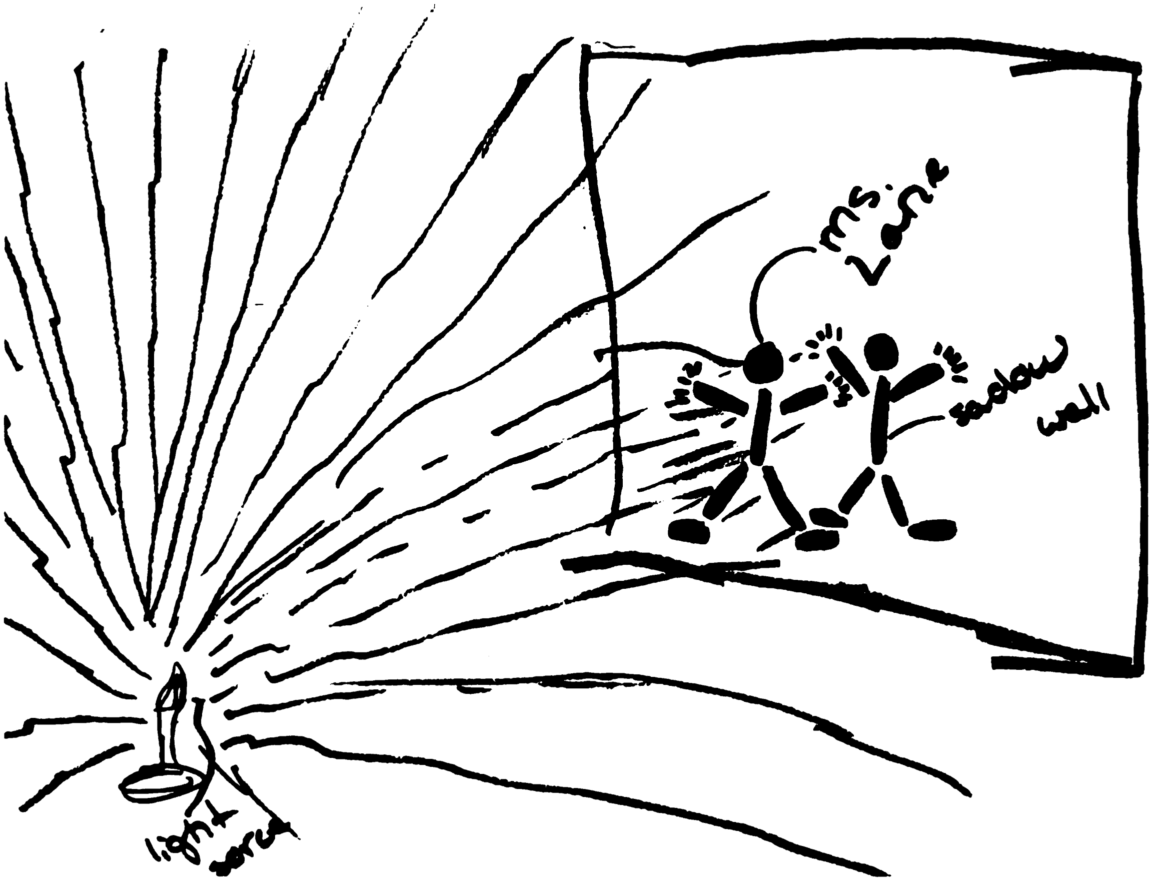
Appendix N
Student Work
Post Light Unit Drawing (S.S.)



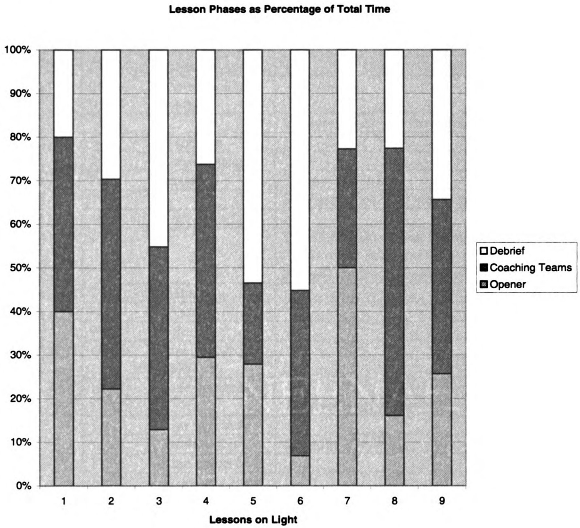
Appendix O
Student Work
Pre Light Unit Drawing (S.T.)



Appendix P
Student Work
Post Light Unit Drawing (S.T.)



Appendix Q
Lesson Segments



Appendix R
Lesson Analysis
Light #1

	Time	Examples of science related word repetition during lesson	Types of T (teacher) and S (student) discourse across lesson phases
Phase One: T poses question and models task	0:00 – 01:20	Clear, matter, L sources	
	1:26		T: (poses question) How does L travel?
	1:44	L sources	
	2:25	L and warmth	
	2:57	matter	S: How fast is L?
	3:34		S: Where does L go when its dark?
	4:16		
	4:52		T: (reading list of past questions from S) Types of L? Prisms? Black L? Lasers? Shines? Bounces? Pass thru?
	7:18	matter	
	8:18	color	
	9:48	hole	
	10:26	Line up cards, hole	
	11:02	Line up cards	
	11:12		T: (gives a definition of L)
	11:19	Line up cards	
	11:24	Straight lines	T: (foreshadowing)
	11:35	Line up cards	
	11:40	Work as a team	
	11:55	Pathway, direction of L	
	12:02	Pathway, direction of L	
Phase Two: Students engage in task	14:21	Shooting	
	14:35	Shine, shooting	
	15:15	Line up cards	
	15:37	Shining, measure	
	16:21	Line up cards	
	18:00	Shining, adjust	
	18:06	Line up cards	
	18:14	Line up cards	
	19:00	Shining	
	19:08		
	19:23		

	20:01	Line up cards	
	21:03		T: (posing question) What's critical about the way you hold the flashlight?
	21:33		
	21:40	Holes, shine	T: (question) Is there anything you are noticing about the way you are holding the flashlight?
	21:59		S: We can only get it if we shine it in the exact spot, hold light steady.
	22:09		S: Hold light steady.
	22:23		S: L can't travel forever, can it?
	23:00		S: You are not holding it right. Too high, too big.
	23:37		S: We have to move them over.
	24:15	Shining, holes	S: I want to try something .
	24:28		T: I am going to ask you once again, are you noticing anything in particular about the way you hold the flashlight?
	25:02		S: Let's try the shadow, it's a moon.
	25:24	Shine, holes	T: What do you notice about the way you are holding the flashlight?
	25:33		S: I am helping you guys. S: We don't need any help, its our thing.
Phase Three: Debriefing	26:49		S: (give strategies)
	27:22		S: (give strategies)
	27:28		S: (give strategies) lots of clay
	28:29	Cards	S: If you moved it you had to move all the cards
	28:45	Cards	S: The more cards the weaker it got. T: No. (foreshadows future lessons).
	29:07		S: (give strategies)
	29:20		S: (give strategies) Hold it steady.
	30:08	L	T: (asking question again) How does L travel?
	30:48	L	T: How does L travel?
	31:08	L	S: L travels unblocked.
	31:25	L	S: L travels in a fixed place.
	31:57		S: Straight.
	32:08	L	T: L travels in a straight line.
	32:10		T: (suggests precision) Precise.

Appendix S
Lesson Analysis
Light #2

	Time	Examples of science related word repetition during lesson	Examples of T (teacher) and S (student) discourse across lesson phases
Phase One: T poses question and models task	0:00 – 01:07	Review, explain, target card, shoot, light, perfectly, exactly in line, L travels in a straight line, L wouldn't bend,	
	1:08	Grid paper, flashlight,	Question is posed by T: Today we are going to test how distance affects how L travels.
	1:26	Distance, shine/bright	
	1:30	Record	
	1:36	1cm, 3cm, 7cm	
	1:50	Ruler	
	1:57	Grid paper, flashlight, distances	
	2:06	Flashlight, cooperation	
	2:15	Height	
	2:19	Flashlight	
	2:24	1cm, draw, circle	
	2:33	1cm, squares	
	2:43	Measure	
	2:50	3cm	
	2:55	Flashlight, 7cm	
	3:08	Circle, perfect	
	3:22	Count, counting	
	3:36	Count, counting, circle	
	3:50	Count, counting	
	4:26	Circle, perfect	
	4:39	Circle, squares	
	4:46	1cm, 3cm, 7cm, circle, square	
	5:09	1 cm, 3cm, 7cm	

	5:28	Flashlight, shine bright, see	
	5:40	Bright, 1cm, 3cm, 7cm	
	5:54	Defined edge	
	5:59	Defined edge	
	6:14	Holding it steady	
	6:24	Any questions	
	6:32	Talk, come to conclusion, distance and travel	
Phase Two: Students engage in task	6:47	Draw, circle, measure	
	6:54	Ruler, squares, count, counting	
	7:16	1cm, ruler	
	7:33	1cm, ruler, inches	
	8:27	Ruler, circle, measure, see, defined edge, low, lower	
	8:50	1cm, ruler, holding it steady	
	9:00	Low, lower, down, down	
	9:05	Circle, measure	
	9:46	Draw/drawer, holding it still, it looks big	
	9:50	Circle, see	S: Are you sure this is it?
	9:51	Circle, holding it steady	
	10:00	1 cm, ruler	
	10:37	Flashlight, draw, drawer	
	10:48	3 cm, ruler	
	10:51	3 cm, count, counting, any questions, up, higher	S: Should I count that one?
	11:28	Count, counting	S: Yes?

	12:11	Drawer/draw	S: 102?
	12:19		(S makes another claim for another strategy for counting) … times two?
	12:35	Count, counting	S: Yeah but the next one might be bigger or smaller.
	12:44	Count, counting	S: 103 or 2?
	13:02	3 cm, circle	
	14:26	circle	
	14:32		S: But this size is different.
	14:40	Ruler, inches, count, counting, holding it steady	
	14:58	3 cm, count, counting	
	15:08	Count, counting, perfect	
	15:38		S: We are supposed to do a different spot.
	15:47		S: Start from 103.
	16:53		
	17:05	7 cm	
	17:10	Count, counting	
	17:23		
	17:38	Down	
	17:53	see	
	18:15	see	
	18:24	L	T: Do you think you would have felt any difference if you had put your hand underneath the flashlight?
	18:38	Draw, down	
	19:03	Count, counting	
	19:11	Count, counting	
	19:15		Vignette: "You are a cranky baby" S: You are a cranky baby. S: Yes, when I don't get enough sleep.
	19:30	counting	
	20:24	counting	S: Is this right?
	21:09		S: There's over 300 (speculation)
	22:17		S: Probably 400.
	23:17		
	23:49	Grid paper	
	24:08		S: (S answers to other S)

Phase three: Debriefing	24:27	Trend, count, counting	
	24:32	L, bigger, farther	T: What are you finding about how L travels? S: The farther away the bigger it is.
	24;40	Distance, light, bigger	
	25:04	Bigger, farther away, dimmer	
	25:11	Bigger, dimmer	
	25:18	Spreads, dimmer	S: Ok, dimmer.
	25:39	dimmer	S: It gets bigger the farther and higher it goes, it expands, gets dimmer.
	25:43	L, energy	
	25:50	Flashlight, transferring, target card, L energy	
	26:09	Flashlight, grid paper	T: (refers to past lab)
	26:30		S: It's the same amount. Its just further away
	26:37	L, grid paper, energy	
	26:51	L, transferring	
	26:55	L, dimmer	
	27:11		S: (checks hand in flashlight beam)
	27:30	L, angle	T: (demo with piece of paper)
	28:17	Direct, energy	
	28:24	direct	
	28:38	Sun, covers more area, energy, L, shining	T: What if L was shining…? What do you think?
	29:03		T: (demo with globe)
	29:39	Flashlight, sun	
	30:22	L, flashlight, circle, sun, angle	
	31:14	Circle, ellipse, angle	
	31:27	Covers more area	
	31:45	Ellipse, energy, angle	
	32:08		T: 246 dots in this area.

Appendix T
Lesson Analysis
Light #3

	Time	Examples of science related word repetition during lesson	Examples of T (teacher) and S (student) discourse across lesson phases
Phase One: T poses question and models task	32:26-32:43	Predict, prediction, L	T: (Poses question) What material will L pass through?
	32:47	test	
	32:54	Predict, prediction	
	33:04	Transparent, pass through	
	33:10	Predict, prediction, test	
	33:27	Predict, prediction, pass through, observations	
	33:33	Predict, prediction, transparent, pass through	
	33:52	Transparent, pass through, blocked, material	
	34:12	Pass through, material	
	35:29	Paper, water, glue, waxed paper, cup	
	36:23	Cup, flow motion tube	
	36:42	Flag, overhead screen, agenda, empty water bottles, cylinder	
	37:26	Tissue paper, table	
	37:49	Duct tape	S: Do you have anything you want to try Donovan? S: No.
	37:54	Duct tape, wrap	

	38:13	Table, mirror, duct tape, wrap	S: It has holes in it.
	38:39	Table, mirror	Vignette: "We should wait for Sarah."
	38:48	Pencil sharpener, folder	
	38:53	Lab book paper	S: That has holes in it.
	39:02	Predict, us, hand, tin foil	S: It's not gonna pass through our body.
	39:15	Waxed paper, glasses, tin foil, I MAC computer	
	39:48	book	S: (Student clarifies for another.)
	40:11		S: We should wait for Sarah.
	41:08	Pass through	
	41:12	Transparent, tin foil, rubber chicken, calculator	
	41:20	Waxed paper, L	S: If you shine the L on this long enough, wouldn't it start to melt? S: If it got hot enough it would. T: Any group who doesn't have enough of a list to start testing?
	41:26	Tin foil	
	41:34	I MAC	T: Let's try it again
	41:50	Overhead screen, wrap, I MAC, shine	
	41:55	Pencil	T: This is not a solo activity.
	42:39	Water, flow motion tube, agenda	
	43:00	Flow motion tube, cylinder	S: I would have thought it would go through water.
	44:00	Flow motion tube, empty water bottle	
	44:10	Empty water bottle	
	44:45	flag	
	46:08	Clear tape, duct tape	
	46:29	Paper, duct tape, clear tape	

	46:52	paper	
	47:01	Table, Kleenex	
	47:14	Paper, lab book paper, duct tape	
	47:55	wrap	
	48:22	I MAC	
	48:56	Mirror, glasses	
Phase Three: Debriefing	49:22	L	
	49:55	Tin foil, observations	
	50:40		T: Think about what you were surprised about.
	51:48		T: Who found something surprising?
	52:04		T: Who found something surprising or unusual?
	52:07	Pencil holder, shine	
	52:40	obstruct	
	54:04		T: Who else found something surprising or unusual?
	54:28	Flow motion tube, L	S: Flow motion tube; we thought it wouldn't but it did. T: So it changed the color of the L?
	55:07	Water, L	S: We tried water;, it didn't go through. T: Really, no L?
	55:13		S: We had a shadow. T: Interesting
	56:09	headlight	
	57:28	Colorless or clear	
	58:04	L	T: Did anyone figure out categories of things that did or didn't let L through?
	58:40	Hand, L	T: Did anyone try their hand? S: It turns the L red.
	58:49		T: Why do you suppose that is? S: Because of blood.
	59:00		S: It just goes through fingers.
	00:24	observations	T: Any other observations?
	00:45	transparent	
	02:32	translucent	T: (gives definition)
	02:45	opaque	T: (gives definition)
	03:10	reflection	

Appendix U
Language Thread Analysis
Light Lesson #4: Measuring Angles of Reflection

Segment	Time	Term 1: **"reflection"** (11 total references)	Term 2: **"angle"** (49 total references)	Term 3: **"measure, measuring"** (25 total references)
Phase One	3:50	X T: Today we will talk about **reflection.**		
	4:40	X		
	5:00		XXX	
	5:20	X		X
	5:35	X T: How does Light **reflect** off a shiny surface?		
	7:33			X
	7:59		XX	
	8:30		X	
	10:30		XXX	X
	12:30	X		
	13:44		X	
	19:42		XX	XX
	20:04		X T: Think about what you learned about **angles**…	X
	20:46		XX	XX
Phase Two	27:20	X	XX	XX
	32:19		X	
	34:35		XXX	
	38:21		X	X
	39:30		XX	XXXXXX
	42:37		XX	XXXX
	43:41	XX S: …its not **reflecting** off.		

	47:10		XXX S: Next **angle** is basically the same, seventy-four degrees.	XX
	48:29	X S: Let's see if it **reflects** off of my glasses?		
Phase Three	53:40	X		
	54:19		X	
	54:54		XXX	X
	56:22		XXX	
	57:21		XX	
	57:46		XX	
	59:23	X	X	
	00:52-09:30		XXXXXXXX	X

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