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ABSTRACT

This case study explores the ways in which a beginning elementary classroom teacher gains a foothold in teaching science. The analysis includes episodes from the teacher's first three years of teaching while participating in an educational research project that investigated an inquiry-based approach to teacher professional development. The particulars of the teacher's experiences learning scientific content and practices are examined as well as the initial struggles to bring students' ideas into contact with standard scientific knowledge and ways of knowing. (Contains 61 references.) (DDR)

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Teacher Professional Development as Situated Inquiry:

A Case Study in Science Education

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Teacher Professional Development as Situated Inquiry:

A Case Study in Science Education

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In the last decade, a literature of cases has been developed that provides various perspectives on the nature of expertise in teaching, highlighting, among other things, the importance of teachers' knowledge of both subject matter and pedagogy. Recently, these studies have begun to stress the challenges, dilemmas and uncertainties that teachers face daily, and to portray these moments, as well as moments of certainty, as opportunities for examining the nature of accomplished teaching. This case study explores the ways in which a beginning elementary classroom teacher gained a foothold in this complex terrain in the domain of science. The analysis includes episodes from the teacher's first three years of teaching while she was a participant in an educational research project that, among other things, investigated an inquiry-based approach to teacher professional development. We examine the particulars of her experiences learning scientific content and practices, as well as the particulars of her initial struggles to bring her students' ideas into contact with standard scientific knowledge and ways of knowing.

In a 1987 article in the *Harvard Educational Review,* Lee Shulman called for the development of richly detailed portraits of expertise in teaching as a foundation for improving education. In the last decade, a literature of cases has been developed, which provides various perspectives on the nature of expertise in teaching. These cases have highlighted, among other things, the importance of teachers' knowledge of both subject matter and pedagogy (Ball, 1990; Chazan & Ball, in preparation; Lampert, 1986; Schifter, 1993; Schifter & Fosnot, 1993; Schoenfeld, 1992; Shulman, 1986, 1987).

Shulman (1987) for example, drawing on the research of Gudmundsdottir (1990), offered the case of Nancy, a high-school English teacher with 25 years of experience. Having watched her teach various texts under various conditions, Gudmundsdottir described Nancy's teaching as "not uniform or predictable in some simple sense. She flexibly responds to the difficulty and character of the subject matter, the capacities of the students..., and her educational purposes." Noting Nancy's ability to alternate between more centralized and more distributed learning activities, Gudmundsdottir compared Nancy's teaching to the work of a symphony conductor: "She can not only conduct her orchestra from the podium, she can sit back and watch it play with virtuosity by itself" (Shulman, p.3). This case and others have called attention to the roles that subject matter knowledge and an extensive repertoire of teaching strategies play in skilled teaching (Lampert, 1985; Schoenfeld, 1992; Shulman, 1986, 1987; Wilson et al., 1987).

While these studies have contributed significantly to the literature on what constitutes expertise in teaching, educational researchers, including teachers themselves, have recently begun to write about skilled teaching from a somewhat different perspective (Ball, 1990, in press; Ballenger, 1996; Gallas, 1994, 1995; Phillips, 1990; Schifter & Fosnot, 1993; Warren & Ogonowski, in preparation). These studies have begun to stress the challenges, dilemmas, and uncertainties that teachers face daily, and to portray these moments—as well as moments of certainty—as opportunities for examining the nature of accomplished teaching (Ball 1990, in press; Gallas, 1994, 1995; Lampert, 1990; Warren & Ogonowski, in preparation).

Ball (1990, in press), for example, in portraying her own experience teaching third-grade mathematics, stressed the problems, dilemmas, and questions she faced as she tried to teach in "intellectually honest" ways. Rather than describing what she did when she knew what to do, she chose to probe those cases of "not knowing" (Duckworth, 1987), applying an insight of Duckworth's about children's learning to her own teaching: "What you do about what you don't know is, in the final analysis, what determines what you ultimately know" (Duckworth, 1987, p. 68).

In these papers, Ball examined the dilemmas that arose for her in the context of teaching particular mathematics to particular students. For example, she described the tension she felt when one third-grader, Sean, identified a "new category" of numbers (i.e., numbers that are both even and odd) that was nonstandard. She worried: "Would children be confused? Would Sean numbers interfere with the required 'conventional' understandings of even and odd numbers? Or would the experience of inventing a category of number, a category that overlaps with others, prepare the children for their subsequent encounters with primes, multiples, and squares? How would their ideas about the role of definition be affected?" (Ball, in press, p. 18). In her reflections, Ball has contributed to an emerging portrait of accomplished teaching in which uncertainty plays as important a role as the certainty that derives from accumulated experience and practice.

Together, the portraits by Shulman, Ball, and others suggest that the terrain of teaching is complex, multidimensional, and, importantly, situated in particular instructional moments. They observe that, while skilled teaching is deeply rooted in knowledge of a number of areas, it is also embedded in the particulars of concrete instructional circumstances. On a daily basis, teachers grapple with the challenge of understanding individual students' thinking and of putting that thinking into productive contact with the ideas and practices of the discipline being studied. In this view, while teaching may be guided in some overall sense by a curriculum and/or a teaching plan, "teaching in the moment" has more the feel of informed, spontaneous action as the teacher takes immediate stock of particular circumstances, including her understanding of the discipline under study, students' utterances and actions, and her own emerging questions, confusions, and understandings (Suchman, 1987).

This paper is an exploration of the ways in which a beginning elementary-classroom teacher gained a foothold in this complex terrain, in the domain of science. We will examine the particulars of her experiences learning scientific content and practices, as well as the particulars of her initial struggles to bring her students' ideas into contact with standard scientific knowledge and ways of knowing. The analysis includes episodes from the teacher's first three years of teaching during which she participated in an educational research project that, among other things, investigated an inquiry-based approach to teacher professional development. It is important to stress that this is an account of the beginning of a journey—not its completion—and that, in any case, from our point of view, no journey learning or teaching science is ever truly completed. Through this analysis, we will address the following questions: What is the significance to this teacher of her own experiences doing science in a program of teacher professional development? What intellectual resources does she acquire from these experiences that she then draws on in coping with the challenges of her everyday classroom practice in science? Finally, what implications, if any, does this study carry for the professional development of teachers in science?

To address these questions, we present a case study of Elizabeth (Liz) Cook Dennis, which comprises three episodes from her first three years of teaching. Two of the episodes examine Liz's experience as a learner of science: the first represents a short, three-hour encounter; the second represents approximately twelve hours of work. The third episode examines Liz's successive revisions of a unit on "what causes tides," intended to meet her evolving goals for her students' learning.

We describe and illustrate the ways in which Liz's learning in science shaped her general vision for and particular decisions about curriculum and instruction. Our intention throughout the analysis is to describe the meaning that Liz makes of the situation at hand and why she does what she does, looking for the connections she draws between her experiences as a learner of science and the decisions she makes as a teacher of science. Because much of what Liz does takes place within the context of the research project in which she participated, we describe the project in the next section.

Context of the Case Study

This case study is taken from a four-year educational research effort, the Video Case Studies in Scientific Sense-Making project, which investigated an inquiry-based approach to teacher professional development (Rosebery & Warren, in press; Rosebery & Warren, 1996). The case-study teacher was one of 14 elementary classroom and middle-school science teachers who collaborated with education researchers and scientists to explore how teachers and children make sense of science and what it means to "do science" in classrooms of grades 4–8. The project was viewed by all participants—teachers, education researchers, and scientists—as an opportunity to explore the natures of science, learning, classroom practice, and teacher professional development.

The project assumed a view of science as a human, meaning-making activity, a particular way of conceptualizing, evaluating, and representing the world (Bazerman, 1988; Lynch, 1985; Latour & Woolgar, 1986; Knorr-Cetina & Mulkay, 1983). We viewed the discourse of science, as a set of socially and historically constituted bodies of knowledge and practices, within a particular scientific discipline, for constructing facts and explanations, for arguing theories, for making sense out of contradictory observations, for defending and challenging claims, for interpreting evidence, for using and developing models, etc. (Bakhtin, 1981; Gee, 1990; Lemke, 1990; Resnick, 1989; Rosebery & Warren, in press; Warren & Ogonowski, in preparation; Warren & Rosebery, 1995, 1996). From this perspective learning science means developing command of the discourse of science.

Similarly, science teaching was viewed as a process of inquiry in which teachers draw upon multiple resources—including their experience with and knowledge of the phenomenon under study, their experience of science as a way of knowing, their own histories as learners, their knowledge of individual children, and their pedagogical expertise—to build bridges between children's ideas and ways of knowing and science's ideas and practices. One of the goals of the project was to investigate an approach to professional development in which teachers (1) engaged directly and reflectively with the ideas and practices (i.e., the discourse) of science and (2) inquired into their students' sense-making and their own pedagogical practices in science.

To put these goals into action, project meeting-time over four years[1] was divided approximately equally between inquiry in science and inquiry in teaching and learning. As learners of science, participants conducted investigations in areas such as aquatic ecology, motion and acceleration, and buoyancy and density. Their science investigations were typically driven by their own questions about a phenomenon and were conducted in small groups that were stable across time. For example, participants spent many months exploring the health of a local pond, grappling with phenomena such as eutrophication, biotic and abiotic factors, and dissolved oxygen, and learning to use a variety of tools and methods, including those associated with sampling, measurement, and representation in aquatic ecology (see Rosebery & Ogonowski, 1996; Warren & Ogonowski, in preparation). In addition to their scientific investigations and the associated readings, participants read texts in the history and sociology of science. In this way, they engaged with the ideas and practices of science from their own perspectives as learners and from those of different disciplines.

To explore students' learning, participants examined videotapes and transcripts of science lessons from their own classrooms (DiSchino, in press; Hanlon, in press; Peterson, in press). They explored questions and confusions they had about their students' learning, their own teaching, and curricula. These included questions about how students talked and what could be learned about students' thinking from listening to what they said about a given scientific phenomenon, what questions they had in mind, and what sense they were making of the activity, evidence, or information that was before them. For example, the participants explored what a sixth-grade student might have meant when he talked about "weighing" the upward pull of a helium-filled balloon (Rosebery, in press) or what a fourth-grader might be thinking about air, weight, volume, and density when she said that air was "important in keeping a boat afloat" (Warren & Bodwell, 1996; Warren, in press). In these conversations, the teachers were looking for ways to bring their students' understandings into meaningful contact with standard ideas and practices of science.

During both the teachers' inquiry in science and their inquiry in teaching and learning, discussion of scientific ideas on the one hand and talk about students' learning and pedagogical practice on the other occurred spontaneously and seamlessly. As participants engaged in their own scientific activity, they found themselves wondering how they might teach a phenomenon like acceleration to students. How could Galileo's theory be brought into useful contact with students' own ideas about acceleration? Could it be used as an object of comparison, analysis, and critique as students conducted their own experiments? In what ways might this expand or reduce the students' field of activity, imagination, and subsequent learning? Similarly, thinking about students' sense-making about the concept of buoyancy led participants to analyze and elaborate their own scientific understandings. As they considered a student's explanation that "air" was what allowed a big, heavy boat to float, they probed and pushed on their own understandings of density and the role it plays in buoyancy. How different, for example, was the student's explanation from their own notion of how the hollow interior of a boat increased its volume, thereby decreasing its average density and enabling it to float? In this way, participants regularly probed their own understandings of scientific ideas and their views of teaching and learning. As a result, tensions between "knowing" and "not knowing" were ever-present in their work.

Project staff made explicit efforts to create a professional development environment that supported inquiry. Various activities were designed to foster a culture in which questions, confusions, and errors—instances of "not knowing" (Duckworth, 1987) and what one did about them subsequently— were given equal status to "knowing." To emphasize the importance of developing familiarity with the tools, materials, activities, and phenomena of a domain, significant amounts of time were devoted to "messing about" (Hawkins, 1970; Hein, 1970). Toward a similar end, talk, like activity, was viewed as a form of sense-making, and participants were strongly encouraged to articulate their ideas to one another as a means of knowledge-building (Barnes, 1975; Cazden, 1988; Duckworth, 1987; Edwards, 1993; Rosebery & Warren, in press). Also, the environment in which the project participants worked was resource-rich: measurement devices, physical equipment, texts of various kinds, scientists, science educators, and the teachers themselves were all resources upon which the participants drew.

Project staff spent significant time planning activities. However, because participants' learning was embedded in their own sociocultural histories (Lave & Wenger, 1991; McDermott, 1993; Rosebery & Warren, in press) as well as in the particulars of their project work, the staff often found that they could not anticipate how a given activity would be taken up or what particular aspect of it would be meaningful to participants. For example, significant time was spent designing and creating materials for exploring motion and acceleration.[2] A ramp with special tracks was built to reduce the effects of friction. Timers were developed that could be placed at multiple locations on the ramp, enabling participants to measure the amount of time it took an object to travel successive distances down the ramp. Also, special containers that fit into the ramp tracks were created. A variety of substances (e.g., sand, water, marbles) could be put into these, enabling participants to explore the effects of weight and density on motion. As it turned out, most of the participants dispensed with the timers and containers early on in their activity. For instance, one group used the ramp and a car they built from Legologos™ (brought from home by a teacher) to explore acceleration. (See "Doing Science II: Motion," below, for a fuller description of this group's activity.) Interestingly, as the teachers conducted inquiries into their students' thinking and activity in science, they, too, found that they were sometimes surprised at which particular resources their students used and regarded as meaningful, and which they did not.

Dilemmas, to use Ball's (1990) word, arose for participants as their inquiries and reflections on the natures of science, learning, and teaching deepened. For some, questions arose about the nature of knowledge and what it means to "know" something. Their experiences as learners suggested that understandings in science are not simple, that the more one learns about a phenomenon like buoyancy, for example, the more one realizes how much more there is to know. However, this perspective, existed in some tension with a culture of school science that expects teachers to impart specific, bounded information to students. For example, one teacher wondered what she should have done when her students "talked themselves past the right explanation" of plant respiration while they were engaged in a data-driven, evidence-based argument. She had felt obliged to point out to them that an idea they had discarded was considered the standard explanation in science; at the same time, however, she wanted to encourage what she regarded as a deeply thoughtful scientific discussion. How could she do both? Her dilemma was not unlike the issues that arose for Ball (1990) with regard to "Sean numbers."

Data and Methods

In all, we examine three episodes from Liz's professional life from July 1992 to December 1993. Two episodes focus on her experience as a learner of science ("balloons" and "motion"). These episodes were chosen because Liz herself identified them as hallmark experiences. The third episode ("tides") shows how Liz revised a unit over the course of two academic years to accomplish her evolving goals for teaching science. This episode was chosen because it was the major focus of Liz's classroom-based work in the Video Case Studies project during the period covered in this account.

The data are drawn primarily from a videotape corpus of project seminars, interviews, and classroom lessons collected regularly by staff during the project. Approximately 20 hours of videotape, spanning 18 months, were transcribed and analyzed for this study. Videotape transcriptions are, in some cases, augmented with excerpts from Liz's own written records, including a notebook she kept of her science activity in the project and a paper she wrote describing the balloon activity (Dennis, in press).

In general, we used an iterative process that combined several cycles of analysis and interpretation of the videotapes and transcripts (cf. Erickson & Shultz, 1977). We identified episodes that pertained directly to Liz's learning about either balloons or motion or to her classroom-based work on tides.[3] Using videotape and transcripts, we then analyzed Liz's talk and activity in these episodes. We presented our interpretations to the larger Video Case Studies research group, subjecting the analysis to rounds of comment, critique, and elaboration. Liz's own views of the analysis were also solicited at regular intervals and incorporated into the study.

Working within a situative framework (Bakhtin, 1981; Greeno, 1997; Vygotsky, 1978), our aim was to analyze Liz's talk and activity in order to describe what she was doing, the challenges she encountered, and the ways she took up and transformed particular ideas, experiences, and tools as she went along (Goodwin & Goodwin, 1992; Lave & Wenger, 1991; McDermott, 1993; Ochs, et al., 1993). Additionally, we looked at the ways she used the varied resources in these situations to construct meaning. By "varied resources," we refer to her own personal history, knowledge and experiences of science, learning, and teaching; the material and symbolic artifacts present (e.g., tools, texts, materials, data); and her concerted activity with others (Goodwin & Goodwin, 1992; Lave & Wenger, 1991; Lynch, 1985; Ochs et al., 1993). We thus consider Liz's talk, her actions, and her interactions with others in our exploration of how she assigns meaning to her own learning of science and that of her students.

Case-Study Background

At the time this study started, in July 1992, Elizabeth Cook Dennis was in her mid-20s and had just completed her first year of teaching. Her background in science was limited. She had been a music major in college, where she took one course in animal behavior to fulfill distribution requirements for graduation. At the urging of a teacher in her school, Liz agreed to join the Video Case Studies project. As a first-year teacher, Liz had taught all subjects except science to fourth graders in a middle-class suburb of Boston. At the end of her first year, she was reassigned to sixth grade for the following year, where she was expected to teach science in addition to other subjects.

This study begins by looking at an activity that took place at the end of the project's first year, during a summer session in July, 1992. Liz and other participants spent approximately three hours exploring the behavior of helium-filled balloons under the direction of Eleanor Duckworth, professor of education at Harvard University.

Doing Science I: Balloons

Eleanor Duckworth was invited to join the project seminar for a morning to introduce participants to her perspective on learning and teaching. She engaged participants in an exploration of the behavior of helium-filled balloons. Duckworth (1987) typically presents learners—whether teachers or students—with a challenge that probes the learner's understanding of an aspect of physical science—in this case, equilibrium of forces. A hallmark of her approach is to engage learners in problems that pique their curiosity. Duckworth supports learners' inquiry by urging them to articulate what they are thinking, to listen to one another's ideas and explanations, and to check what they are thinking against what they are seeing happen in front of them. One of her goals is to help learners see the sense in their own ideas and to feel that their ideas are worth pursuing. Video Cases project teachers and staff engaged with this view of science learning—considered radical by some—as part of their ongoing study of what it means to learn and teach science.

While the balloon activity was not intended to—nor did it—provide participants with a complete understanding of the mechanisms underlying equilibrium, many of the teachers, including Liz, felt that this experience gave them insight into the phenomenon and into learning and teaching in science. In this section, we describe those aspects of the balloon activity that Liz identified as significant to her professional development.

"Maybe if you had the right weight..."

To begin, Eleanor challenged pairs of participants to float a balloon at the same height as an orange balloon that was in a state of equilibrium (i.e., the forces acting on the balloon offset one another so it floated at a steady height above the ground). She had put the balloon in equilibrium by tying yarn "tails" to it and adjusting them until the balloon floated in place with several inches of one of its tails resting on the floor.

An explanation of the behavior of a helium-filled balloon in equilibrium might go something like this:[4] Helium is less dense than air, which is mostly nitrogen and denser than helium. A helium-filled balloon will float to the ceiling of a room because the upward, buoyant force on the balloon (which is due to the difference in densities between the helium and the air) is greater than the downward force of gravity (due to its weight, together with the weight of whatever string is attached to it). A balloon is said to be in equilibrium when the upward buoyant force on the balloon–yarn system is equal to the downward gravitational force.

To put her balloon into equilibrium, Eleanor had to increase the downward force on her balloon by adding more weight to it—in this case, by adding yarn. As she added yarn and thus increased the overall weight of the balloon–yarn system, the balloon began to sink because of the increased pull of gravity. Once she had added enough yarn so that the system's weight was equal to the upward force, the balloon floated at a steady height off the ground in equilibrium. That is, the balloon floated at the height at which it was able to hold up itself and just enough string to offset the upward buoyant force. Any "extra" weight (yarn) rested on the floor.

As Liz and her partner for this activity, Barbara, attempted Eleanor's challenge, they found themselves trying to develop explanations for the behavior of their balloon. At first, they thought it would be easy to float their balloon at the same height as Eleanor's. They taped yarn to their balloon and tried to adjust its height by snipping away pieces of the yarn. They found that they could cut off quite a bit of yarn without making a difference in the balloon's height until, with one last cut, their balloon would suddenly rise to the ceiling. They found this frustrating. They experimented further by changing the length and number of yarn tails, paying attention to whether the tails touched the ground, and to how much of the tail was on the ground. They quickly found themselves speculating about the possible effects of several variables, including the weight of the yarn, friction, static electricity, and an unnamed force that Liz felt might be "attracting" the balloon to the ceiling.

After 20 minutes of experimentation, Eleanor reconvened the group, asking what they were thinking now about their balloons. Participants had questions about the function of the yarn tails, the role of yarn balls that some participants had attached as "anchors" to their balloons, and the possible role of friction between the carpet and the yarn tails, among other things. Gilly, a project staff member, trying to get her balloon to float like Eleanor's, began snipping away tiny bits of her balloon's yarn tail as the others watched. With one final snip her balloon began to float around the room. It slowly rose toward the ceiling and then slowly sank toward the floor but it never actually touched either the ceiling or the floor. This prompted much excited talk.

Eleanor asked the group what they thought about Gilly's balloon. She started the conversation by turning to Liz:[5]

Eleanor:	Liz, what are you thinking?
Liz:	... because of what just happened with what Gilly did, where it was going both to the ceiling and to the ground where it- it- Is there a length, a point, a weight, that if you were closer to the ground it would be attracted to the ground or if you were closer to the ceiling it would be attracted to the ceiling? Where it was kind of-
Eleanor:	Does it matter where you let go of it?
Liz:	Yeah, where it was less the weight and more the attraction of the ceiling or the ground that was pulling it?
	...
Eleanor:	Just let me summarize what I think Liz's point was just now. Gilly just kept cutting a little bit off and no

matter how little she cut or something, it would either go to the ceiling or go back to the ground, right? Liz is wondering whether it matters where you let go of it. Whether the same amount of string on it, if you let go of it up, would it go in a different direction than if you let go of it down?

Liz: At a certain point. I mean if it's [pointing to the balloon's tail] longer, it's going to go to the ground, maybe because it's heavier. But she [Gilly] had it at kind of a- a weight that seemed to be attracted either to the ground or the ceiling. Maybe that would depend if you had the right weight which it was attracted to. (July 1, 1992)

With these words, Liz haltingly described her emerging idea of an "attractive force" that she thought might account for the rising and sinking movement of Gilly's balloon. She wondered whether, once a balloon got to a certain "length, point, weight," there was a force (or forces) in operation that "attracted" the balloon either to the ceiling or to the floor. "Length," "point," and "weight" seem to refer to a point or position in space where the length and weight of the yarn were such that the weight became unimportant ("where it was less the weight and more the attraction") and instead her "attractive force" would come into play and act on the balloon. Implicit in what Liz was saying is the idea of balance ("she had it at kind of a- a weight that seemed to be attracted to either to the ground or the ceiling. Maybe that would depend if you had the right weight which it was attracted to.")

While Liz clearly considered weight to be an important factor in determining where the balloon would float, she was also working with the idea she had of "attraction," which at first may seem a bit "outrageous" (as she later dubbed it) to those who understand equilibrium as an offsetting of forces. From our view, her emergent idea provided Liz with an important entry point for thinking about equilibrium, one that played a crucial role as she continued to engage in the balloon activity.

Liz's notion of attraction seemed to be rooted in her past experiences and in the emerging talk and activity in which she participated. Her speculation was driven by a childhood image of how a balloon should act:

> Once a balloon had found an equilibrium, why couldn't it simply stay at that height, floating in the air if the string was adjusted to be clustered in a more condensed way... I was certain that in my childhood I had seen a balloon hanging midair. (Dennis, in press)

The following images and ideas seemed to stand out as significant for Liz at this point: (1) her childhood memory of a balloon hanging in midair; (2) the notion from her work with Barbara that getting their balloon to float like Eleanor's was difficult; (3) the idea, also from her work with Barbara, that the length/weight of the yarn was important; and (4) the idea, from discussions with Barbara and the rest of the group and from observing the "up and down" behavior of Gilly's balloon, that an additional "attractive" force might possibly be in operation.

"A balloon can hold itself in midair."

As this experience unfolded, the behavior of some of the other balloons caught Liz's attention. She saw three balloons acting quite differently from one another: (1) Gilly's red balloon, which was floating up and down around the room; (2) Valerie's green balloon, which was "anchored" at the same height as Eleanor's balloon by a plum-sized ball of yarn attached to its neck and suspended between the balloon and the floor; and (3) Eleanor's orange balloon, which was gently bobbing up and down in one place and had several inches of yarn resting on the floor (see Figure 1).

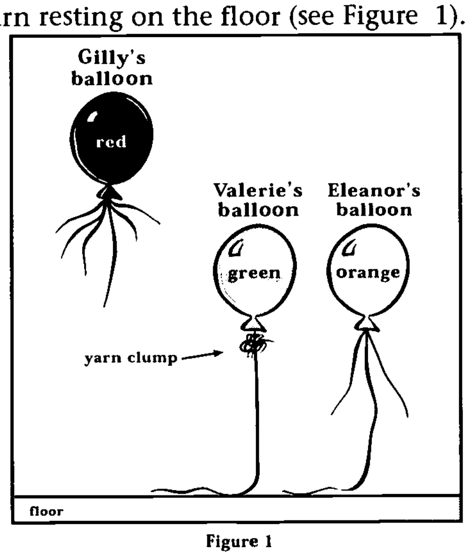

Figure 1
Behaviors of the three balloons

How might a physicist explain the different behaviors of these balloons? As we noted earlier, Eleanor's balloon was in equilibrium because she had equalized the downward pull of gravity and the upward pull of the buoyant force on the balloon–yarn system. She was able to do this because of the nature of yarn. Because it is soft and pliable, any "extra" yarn attached to the system (i.e., yarn that made the mass of the balloon system greater than the upward force) rested on and was supported by the floor, enabling the balloon to hold up exactly as much as it could but no more. Valerie's green balloon was also in equilibrium. However, her balloon apparently had a lot more helium in it than Eleanor's had and therefore required a lot more yarn (a plum-sized ball) to be added to the balloon-yarn system in order to offset the upward, buoyant force. Gilly's balloon was a slightly different case. The mass of her balloon–yarn system was very close to being equal to the upward, buoyant force so it did not have any "extra" yarn that trailed on the floor.[6] Because of this, her balloon floated freely in the air and was subject to air currents present in the room.

What sense did Liz make of the behaviors of these three balloons? When Liz, at Eleanor's request explained her thinking about them to the group, her colleagues, and one teacher in particular, Glen, did not agree with her and questioned her pointedly:

Glen: So Liz are you saying that this green one [Valerie's]...(is) in your words not "trying to go up?"

Liz: This [pointing to Valerie's balloon] *is* trying to go up. These ones [pointing to Eleanor's and Gilly's balloons] are not.

Glen: Why is this orange one [Eleanor's] any different from that one [Valerie's]? Just because it [Valerie's] has a bigger clump [of yarn] at the bottom?

Liz: This [pointing to the yarn clump] is pure weight. What you were saying before about the strings is that it was *only* weight attracting it down but this is pure weight attracting it down because it is still trying to go up.

...

Barbara: Can I say something? What she is trying to say is that in her estimation that [pointing to yarn clump] is far more weight than is necessary to keep that [Valerie's balloon] down.

Liz: Not only is it far more but it is *only* weight keeping it down.

Cheryl: That's what I'm thinking.

Valerie: If we take this off [pointing to the yarn clump], it doesn't work [stay at the height of Eleanor's balloon].

[Valerie gets up and begins to untie the yarn clump; cross-talk erupts.]

Eleanor: Wait a minute, wait a minute. Watch, watch, watch. This is a dramatic moment.

[Valerie's balloon pops to the ceiling; cross talk erupts]

Eleanor: Shhhhhhh, I'll get to you in a minute, Meg, but I want to know what Liz makes of that.

[Valerie reties the yarn clump to her balloon to "re-anchor" it.]

Liz: Yeah. But-but-OK, but it's the two *together*. It [Valerie's balloon] still wanted to go up, I mean like right now, it still wants to go up. [Sighs] Oh. I don't know how to explain this.

Glen: Liz, you're confusing me with the ideas of "trying to" and "wanting to" because I don't think it has any intentionality. It's either going up or it's not.

Liz: OK, when Gilly did her red balloon it wanted to go up but it also wanted to go down so it was moving [up and down around the room]. It would go up to the ceiling and then it would move down and then it would go back up and then it would move back down. So it was attracted both to the ceiling, by whatever energy the ceiling has, and to the floor, by whatever energy that has, *besides* the weight. And that's why she found a good weight where [she pauses and laughs] it was attracted to both the ceiling and the floor.

[Cross-talk erupts.]

...

Liz: The equilibrium level would be like [Eleanor's] orange balloon. That's an equilibrium level. But if it's going up- if it's actually moving up, actually moving up to the ceiling and down, no, but it [Gilly's balloon] is doing both—it's [Eleanor's balloon] not doing one or the other. (July 1, 1992)

In this exchange, Liz was trying to develop a single theory that would explain the behavior of all three balloons. She was accounting for the behavior of Valerie's green balloon and Gilly's red balloon, partly by contrasting them with Eleanor's orange balloon, which she identified as being "in equilibrium." Weight played a primary role in Liz's emerging theory; the phenomenon termed "attractive force" played a secondary, contingent role. In the case of Valerie's green balloon, Liz was trying to explain why "it wanted to go up" at the same time that it was weighted down by a yarn anchor (lines 4–7 and 44–49). She was differentiating between "pure weight" (lines 13–19 and lines 26–27), which she thought was in operation for Valerie's balloon, and the "attractive force," which she thought might be in operation once someone had "found a good weight" (lines 66–70), as in the case of Gilly's red balloon. While hers was clearly a nonstandard explanation, expressions such as "found a good weight" suggest that Liz was beginning to elaborate her ideas about weight (gravitational pull) and the notion of balance, ideas that are central to a force-based explanation of equilibrium.

This exchange highlights the crucial role that other participants, like Glen and Barbara, played in helping Liz construct and elaborate her meaning. In the exchange, Glen directly challenged Liz's suggestion that the green and red balloons were behaving differently (lines 8–12). He also objected to her way of talking about the balloons (e.g., "trying to go up," "wanting to," lines 50–54). It is interesting to note that, despite the force of Glen's critique, Liz, who was often quiet in project meetings, was not deterred from pursuing her line of thinking. Barbara offered her comments in support of Liz's idea, attempting to elaborate on a point she thought Liz had not made entirely clear (lines 20–25).

By listening to their comments and questions, Liz realized that her listeners—and she herself—did not fully understand her idea (lines 48–49, "I don't know how to explain this."). She responded to their comments by thinking through and trying to elaborate her own meaning further. She wrote about this experience later:

> I discovered how difficult it was for me to express myself.... I needed time and some gentle prodding of a few challengers. I started listening to my thinking. I found myself asking, "What am I trying to say? What am I trying to get at? What is my question? What is my theory?" (Dennis, in press)

For the remaining time, participants continued to experiment with their balloons. Liz spent most of her time watching and thinking about what others were doing. At one point, she observed another teacher, Brad, as he experimented with bunching and unbunching his balloon's yarn. She noted that his balloon adjusted itself to different heights as he knotted and unknotted the yarn, but that some of the tail always rested on the table. Liz later wrote that watching Brad helped her see that "the object was not only the balloon but the balloon *and* the string." She began to focus on them as a system in operation and on the system's weight, and to de-emphasize the notion of outside forces such as "attraction."

Later, she watched Gilly and another staff member, Mark, hang a cup from their balloon to create a "gondola," to which they added drops of rubbing alcohol. Evaporation of individual molecules of the liquid enabled them to control the weight of their balloon with greater precision than had snipping away bits of yarn. Liz got involved in their experiment in order to investigate how "weight affected the equilibrium of the balloon." Later she wrote that,

> I saw this experiment as proof that a balloon does not need a string touching a surface, or even a string at all, to keep its equilibrium. When we were not trying to match the balloon's height with that of another [as in Eleanor's original challenge], the balloon stabilized somewhat at its own equilibrium. A balloon can hold itself in midair. (Dennis, in press)

"There is much to be learned from the challenges of other people."

How did the balloon activity end for Liz? What had she understood about equilibrium and about Duckworth's approach to inquiry? As we said earlier, the balloon activity by itself was not viewed as a context for gaining a thorough understanding of equilibrium. Instead, it was considered as an introduction to Duckworth's approach to learning science and as a way to interest participants in the physics of equilibrium. From this point of view, the experience proved fruitful for Liz. While she had much left to learn, her activity with balloons led her toward new perspectives on equilibrium.[7] She abandoned her notion of "attraction" and focussed on "the weight of the system," which was more productive. Moreover, she had been struck by how her own and others' efforts to express their thinking, however incomplete or confused in the moment had supported her learning, and by the perspectives she had gained by observing the activity of colleagues like Brad and Mark and Gilly. She also valued the challenges and disagreements that had arisen for how they had helped her clarify and explore ideas. In her paper (Dennis, in press), she wrote about the role that these opportunities played in her learning:

> There were discussions, conflicts, agreements, and disagreements which helped us to explore more ideas. We presented theories, we rejected theories, we questioned others, and we questioned ourselves....There is much to be learned from the challenges of other people. (Dennis, in press)

In fact, Liz so valued the chance to put her ideas out for inspection, challenge, and discussion by colleagues that when she started to teach science herself (as we will see in the section entitled "In the Classroom: What Causes Tides?"), she deliberately built in a significant amount of time for students to "poke holes in one another's thinking."

In the next section, we analyze Liz's experiences exploring acceleration in an extended scientific investigation.

Doing Science II: Motion

At the end of the second year of the project, during the summer workshop of 1993, participants chose to investigate one of two popular topics in elementary- and middle-school science: Why there are seasons?—or motion and acceleration. The staff's goal in setting up these investigations was to engage participants in in-depth scientific explorations of these phenomena (i.e., pursuing their own questions, discussing theories and explanations, collecting and making sense of data, etc.). Liz and four other teachers formed a group to investigate motion.

To begin their investigation, Liz's group had a number of tools, including a wooden ramp with specially designed tracks, a number of rollable objects (e.g., coffee cans, jars) that fit the ramp tracks, timers, stop watches, and other materials provided by project staff (see project background). Inspired by a reading on motion, they became intrigued with understanding acceleration and designed an apparatus to explore Galileo's work on accelerating bodies.

"The ideas and theories of the great Galileo"

On the first day of their motion study, Liz's group conducted preliminary experiments to explore acceleration by rolling a variety of objects down an inclined plane and timing how long it took each one to travel down the ramp. They timed a coffee can as it rolled down the ramp, noticing that it went faster as it approached the bottom. They wondered if, as Liz wrote in her notebook, "the speed sped up according to some kind of mathematical relationship." They did several runs of the can and measured time to traverse the top and bottom halves of the plane separately to compare speeds. Liz marked their findings as "very exciting" because they found a "direct correlation between the speed of the first half of the ramp with the second half." Specifically, they found a consistent 2:1 ratio when averaging speeds over five trials (i.e., it took the can approximately twice as much time to travel the first half of the ramp as it did the second half). Liz wrote in her notebook that night, "I felt this had proved our theory" that some fixed relationship must exist between the can's speeds over the top and bottom halves of the ramp. The group also wondered whether lowering the height of the ramp by half would double the speed of the rolling can and change the ratio between the speeds for the top and bottom halves, but found that it did neither.

That night, Liz and her partner read a chapter by Gamow (1961) that described Galileo's work on acceleration. The reading helped Liz put the group's initial experimentation into contact with Galileo's work. She wrote in her notebook (Dennis, unpubl.):

> Galileo discovered a mathematical formula to the rate of velocity on an inclined plane. This corresponds directly with the kind of experiment we were attempting to do today. However, we attempted to find a ratio of velocity by marking how much time elapsed for a given distance. Galileo on the other hand found a ratio of speed by marking how much distance was covered for a certain amount of time (a consistent series of water drops). He found that the objects on an inclined plane covered distances at a ratio of 1:3:5:7, etc. Another way of expressing this formula is that the total distance covered at the end of the consistent time intervals are 1 squared, 2 squared, 3 squared, 4 squared, etc. or 1, 4, 9, 16, etc. We should try that experiment tomorrow. There should be a certain connection between our distance results and the water drop time results, shouldn't there? (July 7, 1993)

Liz's explanation echoes the Gamow reading, which explains Galileo's observations about the acceleration of balls down inclined planes: "...if we take as the unit length the distance covered by the ball during the first interval of time, the total distance covered at the end of consecutive intervals, according to the square law, will be 1^2, 2^2, 3^2, 4^2, etc., or 1, 4, 9, 16, etc. Thus the distance covered during each of the consecutive time intervals will be: 1;4–1=3; 9–4=5; 16–9=7; etc. Gamow (1961)." In other words, as the ball accelerates it covers more distance during each successive unit of time, and each successive distance stands in a fixed relationship to the one before.

Liz also wrote the following in her notebook (Dennis, unpubl.) that first evening:

> If I read this article last night, before I had had a chance to "mess about" with motion myself, I don't think that the article would have made much sense to me. After expressing our thoughts from today's experiments and discussions, I felt like I understood a good portion of the ideas and theories of the great Galileo. (July 7, 1993)

In this case, "messing about" referred to the group's specific and varied scientific activity: asking questions, testing ideas, collecting and examining data, discussing results, and manipulating tools. All of these experiences provided her with a framework for making sense of Galileo's classic work. As she looked back on their initial explorations, her "chance to mess about with motion," Liz realized that these activities put her in a better position to understand Gamow's description of Galileo's work on acceleration.

One of the things that seemed particularly meaningful to Liz was her insight that the group had focused on the same factors as Galileo; they had just put them in an inverse relationship. As she described it in her notebook, they had attempted to measure "how much time elapsed for a given distance" (that is, as it accelerated down the ramp the can took less time to travel over each successive fixed unit of distance), whereas Galileo had measured "how much distance was covered for a certain amount of time" (that is, as it accelerated down the ramp the can covered more distance in each successive unit of time). This insight led Liz to suggest that the group try "(Galileo's) experiment tomorrow," anticipating that, "There should be a certain connection between our distance results and the water drop time results [that is, Galileo's measurements], shouldn't there?"

"Doing more method than motion"

The next day, the group continued their investigation. One of the teachers, Meg, brought in a LegoLogo™ kit on the off chance that it might be helpful. Inspired by Liz's report of the Garrow reading, the group determined to collect data on "how much distance it goes in a certain amount of time" rather than continue their previous work.

Because their ten-foot ramp was traversed in less than three seconds, they decided they needed a method for measuring small time intervals, e.g., 1/10 second. They discussed various methods for doing this. Inspired by the Gamow reading, Liz suggested using water drops at regular intervals as a timer, much as Galileo had. This, in combination with Meg's LegoLogos™, reminded Barbara of an activity she had read about in a publication for science teachers. Together, these ideas and material resources led the group to design a car made of Legos™, with a water dripper (a plastic cap from a dish detergent bottle) mounted on its back. As the car ran down the tracks of the ramp, the dripper left a trail of drops at regular time intervals on the bed of the plane.

It took several hours of revising and testing for the group to refine their car so that it performed reliably and consistently enough to satisfy them. They started by using a cap from a dish detergent bottle as the dropper, laying paper towels on the ramp bed to record the drop tracks. The paper towels proved unsatisfactory—they absorbed and dispersed each drop in concentric circles, making it hard to identify with any precision the original point of contact. They replaced the paper towels with adding machine tape, which clearly showed where each drop landed. They also switched from water to coffee to make the drops more visible.

After a few trials, they realized that their dropper dripped at irregular intervals so they brought in and tested a variety of plastic dropper caps. As they continued to refine their apparatus, the group grappled with a number of thorny problems, including friction (between the wheels and the axle of the car and between the wheels and the ramp tracks) and the fact that the coffee dripped more slowly as the cap reservoir emptied toward the end of the run. They finally settled on a cap from a mustard container, which dripped at consistent intervals, could be calibrated with some precision, and held enough coffee so that drops fell at regular intervals for the entire run.

By the time they were satisfied with their instruments, the group had spent several hours on iterative cycles of revision and testing: tinkering with their design, collecting data, altering the incline of the plane, and repeating runs. As Liz wrote,

> We have come to realize that we are working on method rather than an experiment. We have spent a lot of time trying to perfect our instruments. This is an important and valuable part of doing science, so I don't feel anxious about doing more method than motion. (July 12, 1993)

Liz elaborated on this point further during a presentation at the end of the summer seminar, explaining that the group valued each trial of their successively refined apparatus as a "new experiment," and that they viewed their efforts as attempts to make their work "more scientific and more accurate." Liz acknowledged the importance of the time they spent "trying to perfect our instrument." Her words suggest that she regarded their activity as much a part of science as experimentation itself. However, her words also suggest that she felt they had not investigated acceleration as fully as she would have liked. Because of the time spent refining their car, they had done "more method than motion." Given the hours she and her colleagues spent refining their apparatus, it is not surprising that "method" was more salient than "motion" to her at the time.

Working from a situative perspective (Goodwin, 1995; Greeno, 1997; Lave, 1991), the group's activity can also be seen in another light. We believe that their efforts to revise their apparatus also enlarged and enriched their understanding of motion by making them think deeply—through the physical and conceptual manipulation of their materials and methods—about fundamental ideas involved in acceleration, such as the pattern of drops their car should make and the role of friction. Just as their work and understanding of Galileo's ideas had shaped their methods, so too did their work in refining their methods shape their sense of the underlying idea of acceleration. Each provided a way of seeing the phenomenon, of constituting its meaningfulness (Brown et al., 1989; Goodwin, 1995; Goodwin & Goodwin, 1992; Lave, 1991). As we will see in the rest of this account, these experiences with the apparatus undergird Liz's efforts to make sense of and interpret her group's data.

That evening, Liz reflected on their efforts to refine their car and on the learning environment in which she was operating, comparing it to her classroom. She wrote the following in her notebook (Dennis, unpubl.):

> I think of how much time we have spent on this, and how many questions we have that we

> want to explore, and then I think of how much time I normally give students to work on a "lab" test. I don't think I've ever given them more than three days. Here we are in our fourth day, as adults, and we are nowhere near having come close to answering one of our questions yet. It is another lesson to me to give kids more time to conduct experiments. They need at least one or two weeks to pursue something of this nature. It's the quality of the investigation not the quantity that is important. I will need to continually remind myself of that throughout next year. (July 12, 1993)

In this passage, Liz drew direct connections between the time her group had been given to pursue acceleration and the time she had given her students in the past for similar investigations. Given what we know about her activity in the motion investigation, we believe that her reference to time is better seen as a place holder for her unfolding recognition that sense-making in science—at least in her own experience—is a rich and complex business than as a statement about time itself. In her own case, the "how much time we were given" refers to the wealth of experiences she had had reading Gamow's description of Galileo's work, for example, designing and revising their car, calibrating the dropper, collecting data, making representations, and thinking through the connections between Galileo's work and their own. It includes the varied character of her learning as well as its duration. Thus, while her reference to time could be interpreted literally (i.e., "I need to give my kids more time to do science"), we believe that it also indexes her emerging recognition that learning is emergent, iterative, and sometimes unpredictable ("It's the quality of the investigation not the quantity that is important"). As we will see later, she continues to construct her view of learning as she struggles with the particulars of giving "kids more time to conduct experiments."

"The ratio was still the same"

Once they perfected the design of their car, the group conducted many runs. Liz spent considerable time making sense of the data from these trials. At home in the evening she worked with the data, calculating the increase in distance from drop to drop, graphing the points, and looking for patterns based on her understanding of Galileo's explanation of the acceleration of falling bodies. She became so familiar with the data and their graphical representation that she was quite surprised when the data from one run did not fit the pattern she expected. Based on her understanding of Galileo, she had anticipated that, while the data from each run might vary slightly, the slope of the increase in speed should be similar. Not only was the odd run made up of fewer data points, but the slope of the points was markedly different from those of other runs.

As she compared graphs, Liz noticed that

> [e]very fourth drop of [the other] trials matched up with each drop of [the odd] trial. [This] trial was [dripping] at a rate that was four times slower, but the distances covered in those time periods were parallel. That means that there must be a ratio relationship to the increase of the speed! I hope that this is all clear to me tomorrow, because I'll have to try to explain it to the rest of my group. (July 13, 1993)

By carefully examining and comparing the graphs of their multiple runs, Liz realized that the seemingly aberrant trial did, in fact, fit the pattern she had expected; it was just that the dropper was dripping four times slower than usual so the time unit—drop rate—had, in effect, changed. She speculated that they must have forgotten to recalibrate the dropper after the car had "crashed" on the previous trial.

Liz's understanding of the patterns of her data was deeply grounded in her practical activity with the predictive power of Galileo's mathematics, in her intimate knowledge of their apparatus (a consequence of their efforts to refine it), in the measurements they took, and in the graphic representations she constructed for their data. These varied resources figured in her thinking as she grappled with and made sense of the seemingly aberrant data. In a sense, she counted on the generality of Galileo's formula to make sense of her data and at the same time used her data to confirm the generality of the underlying mathematics ("That means that there must be a ratio relationship to the increase of the speed!").

The next day, motivated by her work with the seemingly aberrant data, Liz transcribed the data sets from *all* of their runs in her notebook and calculated the ratio relationship of the increases in distance between successive drops for each run. She found that their data accorded with Galileo's prediction that the "distance covered at the end of consistent time intervals are 1^2, 2^2, 3^2, etc.

As we look back over the work of Liz and her group on acceleration, we are struck by the central role that Galileo's work, and especially his formula, played throughout their work. They modified their original activity to collect the same kind of data as Galileo had (i.e., using distance per time-unit instead of time per distance-unit as the dependent variable). They spent hours devising an instrument to collect those data. Liz in particular found Galileo's formula useful in making sense of their data and, interestingly, she also used the group's data to probe the meaning of Galileo's formula. In a very real sense, Galileo's work became for Liz both a tool for making sense of her group's activity and an object of inquiry itself.

"Those new-fangled math problems"

During a presentation to other participants at th end of the summer workshop, Liz thought aloud about her experience exploring acceleration. She likened it to learning mathematics (Dennis, unpubl.):

> I think about some of those new-fangled math problems that you really have to use your brain to figure them out, and sometimes if you know the answer then it helps you to figure out the process of how to find it. And I feel like that's where I am at right now. If I know what someone's answer was then maybe I can figure out the process of how it worked...if I'd read the article [about Galileo] beforehand it would not have made sense to me. (July 14, 1993)

In this statement, Liz compared her activity in the motion investigation to a process she had apparently used with some success to understand "new-fangled math problems," that is, working backwards from a known or expected outcome as a way to make sense of a solution path of a problem. This is the path that emerged in her motion investigation. In her description, Liz seemed to suggest that "the answer" in a mathematics problem is analogous to a scientific explanation (or Galileo's theory) and that the "process of how to find [the answer]" is analogous to the process of experimentation, data generation, and interpretation in which she and her group engaged, although she is careful to situate the value of the "answer" in the context of her experiences with the phenomenon. In a sense, the group had deepened their knowledge of acceleration in a number of ways—building and refining their car, experimenting with it, representing and interpreting their data, constructing and recognizing patterns in the data—all in an attempt to prove Galileo right. This proved to be a seminal experience in science for Liz.

As we shall see in the next section, many aspects of Liz's rich and varied experiences doing science in the project seminar were present as she designed and structured a unit for her students on what causes tides.

In the Classroom: What Causes Tides?

In the Fall of 1992, shortly after the balloons activity and several months before the motion investigation, Liz taught science for the first time. Like other first-time science teachers, she was concerned about the depth of her own understanding of the topic (what causes tides), and consequently relied heavily on the materials and resources at hand to guide her.

Rather than endorsing a formal science curriculum, Liz's school district identifies themes at various elementary grade levels around which teachers are expected to build cross-disciplinary units, thereby combining science, geography, and language arts, for example. Liz chose water as a theme, in part because her predecessor had done it the year before and had left her a rich supply of materials. What causes tides was among the topics she was expected to teach in such a unit (other topics included, for example, properties of water, water conservation, biology of tidal pools). Among the resources available to Liz were tide charts, suggested activities for graphing tide times and sunrise and moonrise, a sheet of paper with an explanation of what causes tides, and a number of texts explaining the tides (e.g., encyclopedias, trade books).

The given explanation of what causes tides focused primarily on the role of the moon's gravitational pull on large bodies of water on earth: "When water is pulled toward the moon, it creates high tide. At the same time, the water another high tide. The locations of high and low tides change as the earth rotates and different places get nearer to the moon. Because the earth rotates, there are two high and two low tides each 24-hour period." It also explained the role of the sun in Spring and neap tides in particular. Liz wanted her sixth-graders to understand the role of the moon's gravitational pull in causing tides on earth.

In addition to these resources, Liz's view of the tides unit was influenced by her emerging perspective on learning in science, based in her experiences in the Video Case Studies project in general and in the balloons and motion investigations in particular. Like any teacher working with particular students in a particular domain, she faced dilemmas (cf. Ball, 1990) as she began to enact her ideas in the classroom. Among them were conflicts that resulted from her attempts to teach her students the standard explanation for tides while at the same time providing them with multiple and varied opportunities to bring their own ideas into contact with that explanation. In this section, we examine Liz's efforts to bring these goals into harmony as she revised the tides unit over a two-year period.

Tides I, Fall, 1992

When she began to teach tides, Liz modified the previous teacher's plan in accordance with her unfolding view of science learning. Based loosely in her own experience with balloons, she designed an activity to give her students opportunities to think in some depth about their own ideas about what causes tides. As we will see, this activity presented her with anticipated as well as unanticipated outcomes.

As the previous teacher had done, Liz had her students start the unit by graphing the times of high and low tide and moon rise and set. The intention behind this activity was to give students a sense of the relationship between the two phenomena. However, the graphing turned out to be difficult.[8] Liz's students were confused by the transition between a tide time at midnight one day and 1:00 AM the following day and, as a result, they could not figure out a way to graph the data. After trying to explain the transition between the times as best she could, she moved the class on to the activity she had designed.

In small groups the students worked to develop ideas—or "theories," as Liz called them (and as we will refer to them throughout this section)—about how they thought tides work. Her intention was that they use their beliefs, prior knowledge, and what, if anything, they had learned from graphing tides and moon times as the basis for their theories. Liz viewed the process of developing a single theory as an important part of their experience. To arrive at a shared theory, each group would need to explain their individual theories to each other and persuade one another that their theory made sense. Her students' theories ranged over a wide field: one group thought tides were caused by wind while another group believed they were caused by rain and subsequent evaporation. Only one of the groups' theories included a role for the moon or the sun.

After agreeing on a single theory, each group prepared a poster to illustrate it. They then presented and defended it to the class. Liz viewed her students' presentations as an important part of their experience, having challenged them to "poke holes in" each others' theories in the hope that they would think deeply about their beliefs, what they knew about tides, and the logic of their reasoning.

Allowing the students to develop and defend their theories took longer than expected.[9] To avoid falling further behind, Liz felt she had to bring the unit to a close. To do this, she explained the roles of the moon's and the sun's gravitational pull on large bodies of water on earth, and discussed the meaning of this explanation with her students.

Liz's intention to provide her students with opportunities to think through their own ideas—to articulate, explain, and defend them—is embodied both in her effort to adapt her predecessor's unit and in the amount of time she afforded the students' theory development. In an interview a month later, Liz reflected on the tides unit and the extent to which she felt she had met her goals for teaching. She reported that she was pleased with the effort her students had put into developing their own theories, but was frustrated that they had run out of time and was dissatisfied with how she had ended the unit. She had wanted her students both to think deeply about their own ideas about what causes tides *and* to have a chance to think through other explanations, including the standard one. She felt she had accomplished, in part, the first of these but not the second. In an interview, she characterized the dilemma as she saw it then as a tension between letting her students think reflectively about their own ideas and her desire, as a learner herself and as a teacher for her students, for them to learn the standard explanation:

> "I'm struggling with *how* I can set it up so they can think more on their own about things.... but I- I guess I always feel like there has to be some kind of completion that the kids reach.... I personally as a learner like to know. I like to investigate things but in the end I like to know- I like to know there is an answer." (December 29, 1992)

Toward the end of the interview, she proposed a revised design for her tides unit for the following year:

> "Maybe the kids could start out with their theories and then chart the tides and then discuss the data in terms of their theories, and then talk about the big theory, the real theory." (December 29, 1992)

By re-ordering the activities in the unit, Liz's intention was to provide her students with opportunities to think about their own ideas and then to build a basis for inspecting and critiquing them. She hoped that the students' analysis and discussion of the data would push them to think further about their own ideas and provide a context for understanding the standard explanation. In this way, she was attempting to "set it up" so that her dual goals for their learning would be mutually supportive.

Tides II, Fall, 1993

A year later, and approximately four months after the motion study, Liz was scheduled to teach tides for the second time. She still held two goals for this unit: to engage her students in thinking deeply about their own theories and to teach them the standard explanation. Rather than think about her teaching plan on her own this time around, she explored it with a small group of teachers and researchers in the Video Case Studies project that had been meeting regularly to discuss their students' learning and their own teaching (Ballenger, in press; Rosebery, in press; Warren, in press). She told them that she was unsure about what to do after her students had developed, presented, and defended their theories. Should she use the tides charts? Should she just tell her students the standard explanation as she had last year?

Two teachers in the group suggested that Liz use her students' theories as the basis for additional activity. They recounted how their own students' explanations and questions had been the basis for classroom investigations into rust (Hanlon, in press) and earwax (DiSchino, in press), and that the data their students had collected had been useful—although not without difficulties, too—in thinking through their ideas. Liz saw in this suggestion support for her own tentative proposal the preceding year ("Maybe the kids could start out with their theories and then chart the tides and then discuss the data in terms of their theories, and then talk about the big theory, the real theory"). It helped her imagine a way to use the tide charts to engage her students in further exploration of their own theories about what causes tides and to lay a foundation for understanding the standard explanation later on.

Liz started teaching tides a week later, organizing the unit along the lines she had discussed in her December, 1992, interview and with her project colleagues. She first asked small groups of students to develop a theory for "what causes tides." As the groups talked, she handed out tide charts, saying, "This might tell you something to help you with your theory, it might not. It might help you in a week and it might not help you at all. But they're there if you need them."

As she circulated around the room, Liz noticed that, while all the groups were busy discussing what they thought caused tides, only some of the groups used the tide charts. Those students whose ideas included a role for the moon and the sun were more likely to use them. Liz explicitly urged these students to use the tables:

Liz:	What's your theory here?
Brian:	We said gravitational pull of the sun and the moon.
Liz:	How does that work?
Dylan:	Well, we're going to write that. The

sun will rise and it will pull, it will like pull back the water or sometimes, it depends on where it is.

Liz: Where the sun is?

Dylan: Or the moon, it'll pull the water towards it, if it might set- high tide or low tide.

Liz: Okay, can you find anything in your tide charts, since you have something about sunrise here and moonrise and tides, can you find anything here to prove that? (November 11, 1993)

In her exchange with these students, Liz wanted to hear what they were thinking about tides. Because it was the beginning of the unit, she was more interested in having them put their ideas forward than she was in probing any particular aspect of those ideas. Thus she asked Dylan and Brian to articulate their theory ("What's your theory here?") and elaborate on the mechanisms involved ("How does that work?"). Although she stopped short of probing their sense of what it meant for the sun and the moon to "pull" on the water, she directed them to use the charts to develop evidence for their ideas ("Okay, can you find anything in your tide charts, since you have something about sunrise here and moon rise and tides, can you find anything here to prove that?").

After each group had had a chance to work out its theory, they prepared posters for their class presentations. Their theories covered a wide range of ideas, as had those of the previous year's class. Unlike the previous year, however, the sun and the moon featured in the theories of several groups. During their presentations, Liz questioned the students vigorously. She asked them why they thought what they thought and how they could explain, for example, two high tides or the regularity of the tides. Liz occasionally asked a group to clarify their meaning, but for the most part she viewed this as a time for the students to interact with one another around their ideas.

Then the class brainstormed a list of questions they had about tides and tides-related phenomena (e.g., Does the wind affect the tides? What pens during lunar and solar eclipses? If it is high tide in Boston, is it high tide in San Francisco or Europe?) that had emerged during their presentations. They spent the next day in the school library researching these questions. Back in class, they reported what they had found. Many students had located information related to the standard explanation, which Liz capitalized on and used as the basis for a concluding discussion of the standard explanation.

Toward Tides III, December 1993

A month later, Liz reviewed how the unit had succeeded with her colleagues in the Video Case Studies project. She showed them a videotaped episode of Brian's and Dylan's group using the tides charts to explore their nascent theory that the "gravitational pull of the sun and the moon" caused the tides:

Dylan: I think that it's the sun's and the moon's gravitational pull.

Brian: Let's see, I'm going to check [the tides charts], okay the full moon is November 29th.

Dylan: Let's check the tide.

Brian: November 13th, November 1st. What November do you want?

Kristen: How about November 29th?

[Classroom noise]

Brian: Sunrise, moon rise is 12:02 a.m., that's about midnight. When high tide-low tide is 11:35 AM. Wait wait-

...

Brian: [Looking at tide charts.] The tides are different sometimes. You know, the tides-

...

Brian: No see, high- there's a difference between the time of high and low tide between each day because the moon rises and sets at different times each day.

...

Dasha: The tides are different each day [] rises and sets at different times.

Kristen: It's high tide when the moon rises and low tide when the moon sets, or is it-?

...

Brian: Also the earth goes around the sun and that also affects the tides.

Dasha: I think the sun doesn't have to do anything with it because [translating for Sveta] Sveta says she also knows the moon does it- it affects the water.

Dylan: See when the moon and the sun pull on the water at the same time, then it's-Yeah but it's-

Brian: [looking at tides charts] 8:29 PM is low tide and moon rise is 8:49 PM

Kristen: [also looking at tides charts] I have height of low tide- low tide is from 5:53 to 6:18.

Dylan: [to Brian] And what's your point?

Brian: My point is that they're really close together on what- November 4th. And also-

Dylan: Right now can we just write down what happens? [Dylan was the group's scribe and responsible for recording their explanation.]

Brian: Yeah but we also need something to prove it. (November 11, 1993)

Liz told her colleagues that she had chosen this episode because she valued the effort her students were making to understand the data and to use them to try to support their "theory." She pointed out how they struggled to figure out if there is a relationship among the moon's rise and set times, high and low tides, and the sun's rise and set times, and what this might have to say about their theory.

Liz also spoke about the value she saw for individual students. This, for example, is what she said about Brian:

> Brian, I mean his whole expression was, "wait a minute, I need to figure this out, I need to think about this." And- and later on in the tape they-they start to talk about, when Brian was talking about "around midnight the moon rises," what he says shortly after that is, "and then it's low tide right around that same time" and Dylan will say, "What do you mean? What are you trying to say?" And so he tries to explain by using that and then they try to look at the other tides, the AM tides and see if that coincides with anything that they found. But I- I guess what I see is kids who know they have the right answer starting to question themselves. Or you know, where, in the group's needing to, to make that more-to make sense to the other kids in the groups....So I think it made them think a little more about how exactly it would work. (December 13, 1993)

Liz described how she saw Brian engage with the tides data and how he "need(ed) to figure this out." She pointed out how he used the data to probe his thinking and that of the group. She was pleased that Brian, a student who usually thinks he has the right answer, was forced to think hard about his own ideas and she highlighted the role she believed the group played in challenging him to explain himself.

During their discussion of the video segment, Liz's colleagues asked her whether she thought her students had difficulty understanding the standard theory. She said that, while they had talked about it for a long time and their work in the library had prepared many of them to understand it, she worried that, while some students like Brian and Dylan had understood it pretty well, others had not. She went on to tell her colleagues how she was still struggling with "how to set up" her science classes to enable all her students to learn.

In an interview a month later, Liz refers to the ongoing tension she feels between teaching standard explanations and engaging students in thinking about their own ideas in science:

> I wasn't sure where to go with that and how to let- let that play itself out more where some kids were obviously at the point where they felt like they really understood and some kids were not and I didn't know how to make that mesh. [...] A big part of my problem is that I- I try to combine what I want them to know and what I want them to think about. (December 13, 1993)

During this interview, Liz thought about how to respond to this tension. Toward the end of the conversation, she thought aloud about how she might revise the tides unit to teach it a third time:

> I think it might be interesting even another year to start kind of backwards where we start with this is the [standard] theory and then talk about how can this make sense, is there information you can research that can support that theory, can these charts tell you anything? Because charts are hard enough to read when

> you do know something and to interpret how, how that might work. (December 13, 1993)

In this third iteration of her tides unit, we see traces of many of Liz's own experiences doing science in the professional development seminar. She draws on them directly and indirectly in several ways to develop an innovative teaching plan. First, the notion of articulating and working with one's own ideas, based on her experience with balloons, is present. Secondly, she has adapted the use of tide charts to her own ends. They will be used to engage students in inspecting, elaborating, and critiquing each other's ideas about what causes tides, as she did when she explored acceleration in the motion investigation. Thirdly, the idea to "start kind of backwards," which harks back to her interaction with Galileo's theory, will set up and structure the entire activity.

Her plan is a potentially powerful response to the very real instructional dilemma she has articulated: wanting her students to know the standard explanation as well as to think hard about their own ideas. By making the standard explanation explicit to all students at the beginning, she is putting it out as a tool for them to think with, to use as a lens through which to consider the tide-charts data in relation to their own ideas. Moreover, she is attempting to "level the playing field," that is, to circumvent the problem that some but not all students come to class with pieces of the standard explanation. By talking "about how can this make sense," her plan may provide all her students with an opportunity to bring their own ideas about tides into contact with the standard explanation. By finding out if there is "information you can research that can support your theory" and if "these charts (can) tell you anything," students may have opportunities to inspect, critique, and analyze their own theories as well as the standard explanation. In short, these varied resources (e.g., standard explanation, their own theories, tide charts) will likely provide her students with multiple entry points for understanding the standard explanation for tides and for thinking about their own ideas. With this plan, Liz rethinks how to realize her dual goals of "combining what I want them to know and what I want them to think about."

As she develops this third plan for teaching tides, it is clear that an emerging point of view about what science is and what learning in science should be are motivating Liz's thinking. Her revised plan operates on the assumption that children bring their own ideas about tides into the classroom and that these ideas should play a central role in teaching. Furthermore, her plan assumes that the standard explanation—that is, the explanation to be learned—should be put out as a *tool* for children to work and think with, much like scientific theories operate for practicing scientists. Finally, Liz's plan assumes that learning takes place when the children's ideas and the standard explanation are brought into productive contact. These assumptions, which are rooted in Liz's own experiences in the teacher professional development seminar and have developed slowly over time, provide her with a robust foundation for making informed, deliberate decisions about her teaching.

Conclusion

At the beginning of this paper, we posed three questions: What was the significance to Liz of her experiences doing science in the professional development seminar? What intellectual resources did she gain from these experiences that she then used to cope with the challenges of everyday teaching in science? And, what implications, if any, does this study carry for the professional development of teachers in science? We address these questions below.

First, what was the significance to Liz of her many experiences doing science in the professional development seminar? As a result of participating in many and varied investigations through the life of the project, Liz took important first steps in acquiring the discourse of science. In balloons, Liz began to work with some basic ideas underlying equilibrium (i.e., the role of weight as a downward force, the notion of a system in balance); in motion, she acquired a grounded understanding of acceleration and of Galileo's theory of accelerating bodies in particular. In both, she engaged in debate with colleagues about her ideas; asked and sought answers to her own questions;

learned from studying the work of others; made sense of scientific descriptions and explanations; "messed about" with problems and materials; successively refined experimental apparatus; collected, analyzed, and interpreted data; constructed and interpreted graphical representations; compared her methods and results to those of others; and used the theories of others, including the standard explanations of science, as tools in her own work.

It is important to note that Liz's engagement with scientific practices did not take place outside of her work with scientific ideas such as weight, equilibrium, gravity, and acceleration. She did not experience "scientific process" as separate from "scientific content," as one form of a popular debate in science education would suggest. To the contrary, these practices gained importance for her *because* they were integral to her evolving understanding of complex scientific phenomena; her sense of the phenomena themselves was constituted through these practices (Brown, et al., 1989; Lave & Wenger, 1991). For example, she came to see the value of using data to think about theory and theory to think about data as a consequence of the mutually constitutive ways in which she used Galileo's work and her group's car data each to understand the other. In no instance did scientific practice exist apart from concentrated effort to understand the ideas of the discipline. In this way, Liz began to learn how knowledge is constructed in science.

Secondly, what intellectual resources did Liz gain from these experiences that she then drew on to cope with the challenges of everyday teaching in science? Liz's experiences as a learner of science gave her an informed, albeit still developing, perspective from which to think about teaching science. As a result of her activity, first in balloons and later in motion, she set out to create a science program in which she could "combine what I want [students] to know and what I want them to think about." That is, she wanted students to bring their own ideas about a phenomenon like tides into contact with the standard explanation so that they could think broadly and deeply about both. As we saw, however, trying to enact this goal created a number of dilemmas for Liz regarding what her students learned, how they learned it, and, later, whether some students were in a better position to learn the standard explanation than others.

Liz grappled with these dilemmas as she did because her experiences as a learner gave her insight into the rich and varied activity that constituted her own learning in science. Her experience in the balloon activity led her to value both her students' theories about tides and their challenges to each others' theories for the roles they could play in learning the standard explanation. Similarly, her experiences in motion underscored for her the importance of using theory to make sense of data and vice versa, thereby pointing her to a possible alternative use for the tide-chart data. In a similar way, Galileo's theory led her to envision a unit in which she might explain the standard tides theory to students early on, thus enabling them to bring it into contact with their own ideas as well as with the tide-charts data. In short, Liz's knowledge from her own experiences learning science was an important resource for her as a teacher of science. Through these experiences she developed a point of view about science and about science teaching and learning that served as a foundation for her instructional decisionmaking.

Finally, what implications, if any, does this study carry for the professional development of teachers in science? As discussed in the introduction to this paper, Ball (1990, in press) and others (Ballenger, 1996; Duckworth, 1987; Gallas, 1994, 1995; Phillips, 1990) have begun to sketch a landscape in which uncertainty—and how one grapples with it—is as much a part of teaching as is the certainty born of content knowledge and pedagogical expertise. As part of their regular teaching practice, these teacher-researchers take on the confusions and dilemmas that arise out of the inevitably situated circumstances of their classrooms (cf. Greeno, 1997; Suchman, 1987). They keep records of what they and their students say so they can revisit and make sense of these moments and develop constructive responses to them. They do not expect to resolve all the dilemmas that come up, but they do expect to learn from their study of them (Ball, 1990; Ballenger, 1996; Gallas, 1994, 1995). From this perspective, teaching in science, like learning, can be viewed as a form of inquiry.

The case of Liz details the actions and responses of a beginning teacher of science who participated in a program of professional development that deliberately adopted a view of teaching as inquiry. The Video Case Studies project fostered a view of science and a view of learning in science that questions what it means to "know" and to "teach" science, and kept those questions at the forefront of participants' work. Dilemmas of understanding—whether in science or in the classroom—were sought out and discussed openly among colleagues.

This perspective was evident throughout Liz's many experiences in the project. She was regularly asked to give voice to what she understood and did not understand, and to question herself and others in order to further her learning. She was also questioned, as we have seen, by other teachers and staff members. At other times, her activity in and her understanding of the situation at hand prompted her to pose questions to herself.

As a teacher, Liz met regularly with other project colleagues to look at videotapes and transcripts of classroom episodes to study their students' learning and their own classroom teaching. In the same way that we described "content" and "process" earlier as mutually constitutive aspects of Liz's science learning experience, pedagogical "content" and "process" became mutually constitutive aspects of her teaching. As she began to teach science, Liz started to ask herself questions about what her students were learning and how they were learning it. She asked herself questions about her own teaching. She discussed next steps with her colleagues. In this way, she learned how to inquire into her students' learning and her own classroom practice.

What implications for improving programs of teacher professional development does Liz's case suggest? First, it is important for teachers to have varied opportunities to engage deeply with scientific ideas and practices. These experiences should be structured to allow teachers to grapple with complex ideas, to understand the nature of science and scientific knowing, to examine their own and others' assumptions about science and about learning, and to reflect on the character of their own and their students' learning experiences.

Second, teachers need varied opportunities to think through the uncertainties of teaching, ideally with colleagues. It is important that they come to see that dilemmas and confusions will inevitably arise in their classrooms, regardless of how skilled they are, and that these moments are rich learning opportunities. And they need opportunities to explore the kinds of questions, tools, and methods that provide entry points to continually building understanding of their students, learning, the disciplines they teach, and their own teaching practices. In short, in addition to engaging teachers in learning disciplinary content and pedagogical knowledge, programs of professional development in science also need to encourage teachers to envision and experience both learning and teaching as practices of inquiry.

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Notes

[1]The professional development seminar met twice a month for two hours during the school year and for two weeks during the summer.

[2]These materials were designed and developed by Arthur Gansen in consultation with Ricardo Nemirovsky and project staff.

[3]We wish to acknowledge the contributions of Amy Taber in helping to identify relevant episodes.

[4]We offer this brief explanation to give the reader a feeling for the conceptual issues in-

volved in the balloon activity, while realizing that it is necessarily incomplete.

[5]We have used the following conventions to present transcripts, based on Dyson, A. (1989):

[ ] contain explanatory information inserted by the authors;

... represent omitted material;

dashes (but- but-) indicate self interruptions;

commas refer to pauses within sentence units;

conventional punctuation marks (periods, question marks) indicate ends of utterances.

[6]It is important to note that this was a relatively difficult thing to achieve given the limited degree of precision afforded by yarn, scissors, and tape.

[7] When Liz and the other participants investigated buoyancy in water during the third year of the project, they drew on the foundations that were laid in this balloon activity.

[8]For a discussion of the nontransparency of graphs and graphing see Monk & Nemirovsky (in press) and Nemirovsky (in press).

[9] It is likely that Liz's memory of this event played some part in the reflections she wrote about time and her own learning about motion a few months later.

References

Bakhtin, M. (1981). *The dialogic imagination: Four essays*. C. Emerson & M. Holquist (Trans.) Austin: University of Texas Press.

Ball, D. (in press). What do students know? Facing challenges of distance, context, and desire in trying to hear children. In B. J. Biddle, T. L. Good, & I. F. Goodson (Eds.), *International Handbook of Teachers and Teaching*. Dordrecht, Netherlands: Kluwer.

Ball, D. (1991). Research on teaching mathematics: Making subject-matter knowledge part of the equation. In J. Brophy (Ed.), *Advances in Research on Teaching*, Vol. II. (pp.1–48). Greenwich, CT: JAI Press.

Ball, D. (1990). *With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics*. East Lansing, MI: National Center for Research on Teacher Learning. Craft Paper 90-3.

Ballenger, C. (in press). What does it mean to know science?: Three teachers' perspectives. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

Ballenger, C. (1996). Argumentation in a Haitian bilingual classroom. TERC Working Paper 2-96.

Barnes, D. (1975). *From Curriculum to Communication*. New York: Penguin Books.

Bazerman, C. (1988). *Shaping Written Knowledge*. Madison: University of Wisconsin Press.

Brown, J., Collins, A. & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher 18*(1), 32–42.

Cazden, C. (1988). *Classroom Discourse*. Portsmouth, NH: Heinemann.

Chazan, D., & Ball, D. (in preparation). *Beyond exhortations not to tell: The teacher's role in discussion-intensive mathematics classes.*

Dennis, E. (in press). A lesson on balloons with Eleanor Duckworth. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

DiSchino, M. (in press). Teaching science from the inside out: Creating curriculum with third- and fourth-graders. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

Duckworth, E. (1987). *The Having of Wonderful Ideas*. New York: Teachers College Press.

Dyson, A. (1989). *Multiple Worlds of Child Writers*. New York: Teachers College Press.

Edwards, D. (1993). But what do children really think?: Discourse analysis and conceptual content in children's talk. *Cognition and Instruction*, 11(3&4), 207–225.

Erickson, F., & Shultz, J. (1977). When is a context? Some issues and methods in the analysis of social competence. In J. Green and C. Wallat (Eds.), *Ethnography and Language in Edu-*

cational Settings, (pp. 147–160). Norwood, NJ: Ablex.

Gallas, K. (1994). *The Languages of Learning: How Children Talk, Write, Dance, Draw, and Sing Their Understanding of the World.* New York: Teachers College Press.

Gallas, K. (1995). *Talking Their Way into Science.* New York: Teachers College Press.

Gamow, G. (1961). *The Great Physicists from Galileo to Einstein.* (pp. 25–50). New York: Dover.

Gee, J. P. (1990). *Social Linguistics and Literacies: Ideology in Discourses.* London: The Falmer Press.

Goodwin, C. (1995). Seeing in depth. *Social Studies of Science*, 25, 237–274.

Goodwin, C., & Goodwin, M. (1992). Context, activity, and participation. In P. Auer & A. di Luzio (Eds.), *The Contextualization of Language.* (pp. 77–99). Amsterdam: John Benjamins.

Gudmundsdottir, S. (1990). *Nancy: Pedagogical content knowledge of an expert teacher.* Paper presented at the Annual Meeting of the American Educational Research Association, Boston.

Greeno, J. (1997). On claims that answer the wrong questions. *Educational Researcher* 26(1), 5–17.

Hanlon, J. (in press). "I don't know. What do you think?" Talking science in an elementary classroom. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry.* Portsmouth, NH: Heinemann.

Hawkins, D. (1970). Messing about in science. *The ESS Reader.* Newton, MA: Education Development Center, Inc.

Hein, G. (1970). Children's science is another culture. *The ESS Reader.* Newton, MA: Educational Development Center, Inc.

Knorr-Cetina, K.D., & Mulkay, M. (Eds.) (1983). *Science Observed: Perspectives on the Social Study of Science.* London: Sage.

Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Educational Research Journal, 27*(2), 29–63.

Lampert, M. (1986). Knowing, doing, and teaching multiplication. *Cognition and Instruction* 3, 305–342.

Lampert, M. (1985). How do teachers manage to teach? Perspectives on problems in practice. *Harvard Educational Review* 55, 178–194.

Latour, B., and Woolgar, S. (1986). *Laboratory Life: The Social Construction of Scientific Facts.* Princeton: Princeton University Press.

Lave, J. (1991). Situating learning in communities of practice. In L.B. Resnick, J. Levine, and S. Teasley (Eds.), *Perspectives on Socially Shared Cognition* (pp. 63–82). Washington, DC: American Psychological Association.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation.* New York: Cambridge University Press.

Lemke, J. (1990). *Talking Science: Language, Learning, and Values.* New York: Ablex.

Lynch, M. (1985). *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory.* London: Routledge and Kegan Paul.

McDermott, R. (1993). The acquisition of a child by a learning disability. In S. Chaiklin & J. Lave (Eds.), *Understanding Practice: Perspectives on Activity and Context* (pp. 269–305). New York: Cambridge University Press.

Monk, G. S., & Nemirovsky, R. (in press). The case of Dan: Student construction of a functional situation through visual attributes. *Research in Collegiate Mathematics Education.*

Nemirovsky, R. (in press). On ways of symbolizing: The case of Laura and the velocity sign. *Journal of Mathematical Behavior.*

Ochs, E., Gonzales, P., & Jacoby, S. (1996). *"When I come down I'm in the domain state": Grammar and graphic representation in the interpretive activity of physicists.* In E. Ochs, E.A. Schegloff & S.A. Thompson (Eds.), Interaction and Grammer. Cambridge: Cambridge University Press.

Peterson, G. (in press). "The water is like shrinking it." Scientific sense-making in the elementary classroom. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Sci-*

ence Teaching as Inquiry. Portsmouth, NH: Heinemann.

Phillips, A. (1990). *What teachers need to know*. Technical Report No. 3. Newton, MA: The Literacies Institute.

Resnick, L. (1989). Treating mathematics as an ill-structured discipline. In R. Charles and E. Silver (Eds.), *The Teaching and Assessing of Mathematical Problem-Solving*. Reston, VA: NCTM.

Rosebery, A. (in press). Grounded conversation as a professional tool: A study-group snapshot. In A. Rosebery & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

Rosebery, A., & Warren, B. (Eds.) (in press). *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

Rosebery, A., & Warren, B. (Eds.) (1996). *Sense-Making in Science: A Video Series*. Portsmouth, NH: Heinemann.

Rosebery, A. & Ogonowski, M. (1996). Valerie: The relationship between doing science and teaching science. In A. Rosebery & B. Warren (Eds.), *Sense-Making in Science: A Video Series*. Portsmouth, NH: Heinemann.

Schifter, D. (1993). Mathematics process as mathematics content: A course for teachers. *Journal of Mathematical Behavior* 12(3), 271–283.

Schifter, D., & Fosnot, C. (1993). *Reconstructing Mathematics Education*. New York: Teachers College Press.

Schoenfeld, A. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws, (Ed.), *Handbook for Research on Mathematics Teaching and Learning*. New York: Macmillan.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher* 15(1), 4-14.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review* 57(1), 1–22.

Suchman, L. (1987). *Plans and Situated Actions*. New York: Cambridge University Press.

Vygotsky, L. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Warren, B. (in press). "That's another meaning of volume then, for me": Teachers' talk about buoyancy. In A. Rosebery. & B. Warren (Eds.), *Boats, Balloons, and Classroom Video: Science Teaching as Inquiry*. Portsmouth, NH: Heinemann.

Warren, B., & Ogonowski, M. (in preparation). "I have a specific question that probably won't take too long to resolve": An inquiry into teacher learning in science.

Warren, B., & Bodwell, M. (1996). "Why do big, heavy boats float?" Teacher inquiry into student learning. In A. Rosebery & B. Warren (Eds.), *Sense-Making in Science: A Video Series*. Portsmouth, NH: Heinemann.

Warren, B., & Rosebery, A. (1996).2 "This question is just too, too easy!" Students' perspectives on accountability in science. In L. Schauble & R. Glaser (Eds.), *Innovations in Learning: New Environments for Education*. (pp. 97–126) Mahwah, NJ: Erlbaum.

Warren, B., & Rosebery, A. (1995). Equity in the future tense: Redefining relationships among teachers, students, and science in linguistic minority classrooms. In W. Secada, E. Fennema, & L. Adajian, (Eds.), *New Directions for Equity in Mathematics Education* (pp. 289–328). New York: Cambridge University Press.

Wilson, S., Shulman, L., & Richert, A. (1987). "150 different ways of knowing": Representations of knowledge in teaching. In J. Calderhead (Ed.), *Exploring Teachers' Thinking*. (pp.104–124). Eastbourne, England: Cassell.

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