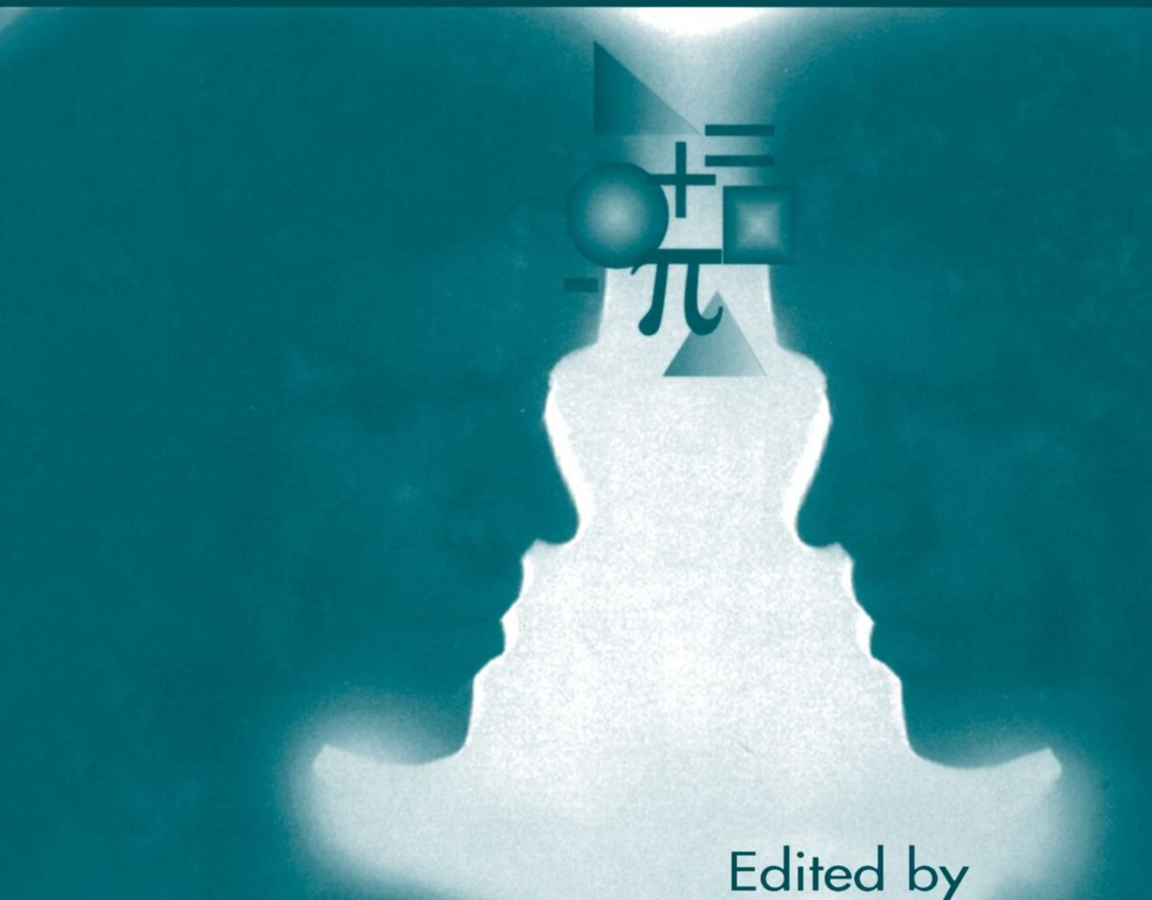
THINKING PRACTICES IN MATHEMATICS AND SCIENCE LEARNING



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Preface

The study of thinking has traditionally focused on individual activity. Recently, however, studies of scientific practice and school activity are beginning to provide concepts and methods for studying thinking as an aspect of social practice.

The chapters in this collection address two crucial challenges. One challenge is the integration of theories and practices of thinking—that is, theoretical accounts of how thinking occurs and practices of fostering students' learning to think more effectively. A second challenge is the integration of concepts and practices that focus on social interaction with concepts and practices that focus on the informational and conceptual contents that students need to learn in their study of subject-matter domains.

The chapters contribute significant progress toward meeting both of these challenges. The authors bring the perspectives of diverse disciplines of research and practice—the cognitive and social sciences, as well as efforts to develop new forms of educational practice. By focusing these multiple perspectives on processes of mathematical, scientific, and technological thinking and learning, the chapters provide insights into ways that subject-matter content is learned, understood, and used in social interaction. And by choosing to analyze activities in learning environments of school and other subject-matter inquiry, the chapters both contribute to the advancement of fundamental theoretical concepts and methods in the science of thinking and provide information that can guide efforts to strengthen the practices of mathematics and science and education.

The chapters were prepared initially for a symposium that was conducted as an activity of the Carnegie Consortium for Mathematics and Science Education at the Institute for Research on Learning. Many people helped us bring the Thinking Practice meetings, the Symposium, and this volume together. Mary Kiley, then program officer at Carnegie, was a strong supporter and participant at several of the events. At IRL, Maria Escamilla was the point person for the conferences and handled all of the details. Noreen Greeno designed the conference brochures. Karen Powell, Kathy Hernandez, Doris Perkins, and Christie Stenstadvold helped us keep in communication with the participating researchers so we could keep versions of the articles, commentaries, and revisions flowing back and forth between the authors. Tina Syer helped with the editing of several chapters. IRL provided an environment that made collaborative work practices possible and sustainable.

James G. Greeno
Shelley Goldman

Thinking Practices: Images of Thinking and Learning in Education

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Institute for Research on Learning

You might not have heard of thinking practices, but we believe this topic will become a coherent body of scientific and educational research and practice. At this time, the title evokes questions that the chapters in this book begin to answer: What are thinking practices? What would schools and other learning settings look like if they were organized for the learning of thinking practices? Are thinking practices general or do they differ by disciplines? If there are differences, what implications do those differences have for how we organize teaching and learning? How do perspectives on learning, cognition, and culture affect the kinds of learning experiences children and adults have?

This book presents progress toward answers to these questions involving several agendas. These include increased interdisciplinary communication and collaboration; reconciling research on cognition with research on teaching, learning, and school culture; and increasing the connections between research and school practice.

The title, *Thinking Practices*, is symbolic of a combination of theoretical perspectives that has made contributions to our understanding of how people learn, how they organize their thinking inside and across disciplines, and how school learning might be better organized. We believe that much foundational work in several research disciplines has had impact on the ways in which school policies, perspectives, and learning practices have emerged. We are sure that research can provide more beneficial contributions to the school learning enterprise. By touring through some of the perspectives on thinking and learning that have evolved into school learning designs, we can begin to establish a frame for what we call *thinking practices*.

WAYS OF THINKING ABOUT THINKING

Theories of thinking developed in academic scholarship and research are aligned with popular, cultural views of thinking. These views of thinking are epitomized by Rodin's statue, *The Thinker*. The view is characterized in the artist's words:

> . . . a naked man, seated upon a rock, his feet drawn under him, his fist against his teeth, he dreams. The fertile thought slowly elaborates itself within his brain. He is no longer dreamer, he is creator. (cited in Elson, 1985, p. 43)

Rodin provided us with an icon that represents our most stereotyped view of thinking. In this view, thinking is solitary—to be done inside the heads of men who sit on pedestals—and without context (no clothes, no subject, no surroundings[1]). Thinking is powerful, transforming dreamers into creators.

We prefer a different image of thinking from the one conveyed by Rodin's statue. *The Thinker* may be a widely known work of art, but an impoverished image of thinking. We prefer an image that represents a group of people in an animated conversation interacting with materials that they are reasoning about and with which they are developing representations of their ideas. It is difficult to capture this iconically or in a static form because its representation might need to be extended in time. Although it is difficult to identify an artistic piece that represents our image of learning, we see many instantiations of what we mean in classrooms where we do research on the Middle-school Mathematics through Applications Project (MMAP). These include images of students working together and with tools to develop their ideas and solve problems, or of teachers coaching groups of students toward better understandings and use of mathematics. We try to capture the image on videotapes and in field notes, and we regularly exhibit versions of thinking practices in action when we communicate with others in our research and school communities. We do not study or represent thinking or learning, but thinking in learning practices—thinking and learning in action in the rough-and-tumble world of school and other places.

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[1]The most familiar version of *The Thinker* sits in splendid isolation. A smaller version is situated atop *The Gates of Hell*, where he is surrounded by damned souls in eternal torment. In this setting, *The Thinker*'s pose seems to us an appropriate response to his surroundings, but Rodin apparently intended us to understand a successful effort to escape from contact with human suffering to abstract intellectual creativity.

The absence of a static representation of our image of thinking practices helps define our agenda. When we ask people to draw a picture of learning, they invariably offer a picture of knowledge working its way from an environment into a head. This is not the learning we study and report in this volume. Knowledge and minds are not separate entities, but different dimensions of practice.

The academic disciplines in which thinking has been studied most systematically—psychology, philosophy, artificial intelligence, linguistics, and neuroscience—have stayed close to *The Thinker* image in conducting studies of thinking as activities of individuals explained by hypothetical processes in each individual's mind. The discipline that has developed theory and research on thinking and learning most extensively is psychology. Behaviorist experimental psychology conceptualizes thinking as a process of stimulus–response association and emphasizes conditions in which novel responses could be encouraged. Cognitive psychology and artificial intelligence conceptualize thinking as a process of representing and transforming symbolic representations organized by schematic knowledge structures including strategies for reasoning in subject matter domains. Developmental psychology includes studies of the growth of children's understanding in conceptual domains. Educational psychology, which has made the educational enterprise its arena for impact on educational policy and classroom practices, emphasizes studies about how students come to think according to the conceptual structures and procedures of subject matter domains in the curriculum.

In perspectives focused on individual thinking, practice is considered part of the contexts in which thinking is applied. In such a paradigm, there might be a volume entitled *Thinking in Practices*, but not one called *Thinking Practices*. Studies that focus on practices have been concerned with social action, interaction, culture, and community. Generally, they have been the domains of anthropology, sociology, and sociolinguistics, and they have only rarely been addressed systematically to thinking.

Sociolinguists portray language as a collective phenomenon with a life of its own in which people participate and contribute small changes (Goodwin, 1990; Goodwin & Durante, 1992; Hymes, 1974; Silverstein, 1996). In this perspective, language is viewed as an institution. The same can be said of thinking. Anthropologists and sociohistorical psychologists study thinking as a collective activity in different cultures. What is thought about and the tools for thinking comprise cultural institutions, just like language (Cole, 1996; Lave & Wenger, 1991; Vygotsky, 1934/1987). The ways people think, what they think with, and what they think about may vary from culture to culture. In each culture and discipline, thinking has its own systematics, defines the activities appropriate to the moment and helps people accomplish them (Frake, 1980, 1985; Hutchins, 1995).

The various research communities concerned with learning and education have begun to concentrate on the nexus of cognition, social interaction, disciplinary practices, and culture. We are encouraged by the catalyzing and productive effects that several recent studies of cognition viewed as a social practice have had on the concerned research communities (e.g., Chaiklin & Lave, 1993; Goodwin & Durante, 1992; Hutchins, 1995; Lave, 1988; Newman, Griffin, & Cole, 1989; Nunes, Schliemann, & Carraher, 1989; Saxe, 1990; Suchman, 1987). At the Institute for Research on Learning (IRL), we participate in many cross-disciplinary conversations that bring the various insights and perspectives of separate disciplines to our studies of learning in schools, communities, and workplaces. IRL is composed of anthropologists, cognitive scientists, science and math educators, linguists, sociologists, and computer scientists. It is committed to ongoing intellectual relationships and collaborations across disciplines. By organizing the Thinking Practices symposium that led to this book, we hope to extend the rich and challenging research interactions and reform activities we have inside IRL to the wider research communities.

Are researchers from different disciplines able to agree or promote specific principles for and features of both in- and out-of-school learning environments? We find that classrooms reflect the results of research and theory even though a direct line never seems obvious, and traces of disciplinary images of thinking and learning are found in folk notions, professional theories, and everyday educational practices.

Philosophy has generated several views of thinking and learning that can be found in classrooms. Images of the Socratic methods, the young child as a tabula rasa and the older student as a rational thinker, and the need for experience in education are each behind some aspects of the organization and delivery of most every curriculum. Cognitive scientists have provided detailed analyses of information structures and procedures that are involved in school tasks and schools have responded. Research, theory, and applied work from psychology have helped confirm and operationalize ideas about thinking and learning as being activities of individuals. Post-World War II schools became consumers of the idea of individual differences in intelligence (Gould, 1981) and IQ scores determined access to content. Psychology has contributed to developing tests and assessments that enable schools to sort students by ability and achievement in different content tracks.

Studies in developmental and cognitive psychology have laid the foundation for an understanding of learning as developmental and sequential. This had an impact on notions of when and how much students could learn. It proliferated spiral approaches to curriculum, the need for prerequisites in curriculum subjects, the teaching of individual skills and concepts, and the need to develop lower order skills before attempting to allow learners to develop higher order skills (Bloom, 1976; Gagné, 1965). These ideas found their way into curriculum development and resulted in a continuing emphasis on basic skills and the importance of memorization as stage setters for more complicated thinking and problem solving.

Psychology's emphasis on the individual as the unit of analysis complemented schools as they developed policies and practices that focused on remediation and specialized services to individual students. Psychological research spawned the learning disabilities field, as well as the field of gifted education, promoting notions of remediation and acceleration. It legitimized differences between vocational education and precollege education and had an impact on the development of certification programs for teachers, administrators, and special service professionals.

The impact of psychology on the schools has been so widespread and enduring that it has become just plain common sense. Sociologists, linguists, and anthropologists—even those who argue with the results of psychological research in education—all define *learning* as the acquisition of skills and intelligence as a stable skill base inside each child's head and *school failure* as an accurate record of what a child can do (McDermott & Hood, 1982).

Some of what the schools have adopted from the research disciplines has impeded deep learning and widespread achievement. The belief system in schools is consistent with beliefs held in the larger culture. For example, only recently have people come to believe that there might be alternative ways to think about the conditions of learning apart from individual capabilities and differences. Research concerned with individual differences has been held captive by its own ideas and the ideas of the larger culture. Breaking out of the box to imagine new possibilities for thinking and learning is both difficult and necessary.

Since the early 1990s, encouraged by a variety of incentives—including support by foundations such as the Carnegie Corporation of New York (which sponsored the Thinking Practices activities), the McDonnell Foundation Program in Cognitive Science and Education, the Mellon Foundation Program in Literacy, the Ford Foundation sponsorship of the QUASAR Project, the New American Schools Development Corporation grants process, and others—many researchers from education have been firmly planted in the middle of school redesign efforts. Several initiatives that reorganize classroom activities, including the Middle-school Mathematics through Applications Project (MMAP) at IRL and Stanford, as well as projects led by Brown and Campione (1994), Cole (1996) at the Laboratory of Comparative Human Cognition at UCSD, Bransford (1994) and the Cognition and Technology Group at Vanderbilt, Scardamalia, Bereiter, & Lamon (1994), Silver (1993), and others, are combining concerns with participation structures of classroom learning with concerns for the subject matter contents of curriculum. There is a growing consensus across the researcher networks that it is time to concentrate on applying research-generated knowledge to the design and implementation of educational environments and to study the learning that occurs in the environments that we help design. At a minimum, researchers need to share what they are learning with each other. Together they must reach an occasional consensus of how research might be applicable. More complexly, researchers must grapple with the problem of how to manage the responsibility of reform work while keeping intact the discipline and clarity required of researchers. Perhaps most radically, they must struggle to redefine *knowledge* as practice, informed and enhanced by engagement with actual life conditions, and not just a rarefied theoretical entity with no ties to application (Greeno et al., in press).

ORIGINS OF THIS BOOK

To move forward on these agendas, with support from the Carnegie Corporation of New York, we organized a series of three small roundtable meetings and a public symposium. Each of the meetings had a topic: science learning, mathematics learning, and learning environments rich in technology and innovative practices. The participants represented different approaches to research and a range of disciplinary backgrounds. The meetings were working sessions where the participants identified common concerns and presented information of mutual interest. We hoped to see how small groups of researchers who were loosely connected could discover mutual ground studying learning from multiple perspectives of content, cognitive processes, and the social practices of teaching and learning. We hoped that, through the roundtable format, researchers would become familiar with each other's work and seek ways to collaborate in the future. At the conclusion of each roundtable session, researchers discussed their plans for papers they would prepare for the Thinking Practices symposium that followed. In keeping with the symposium goals, several researchers decided to develop collaborative papers and presentations. In November 1992, IRL held an open conference on thinking practices that was attended by over 120 people. Researchers who participated in the roundtable sessions presented papers and commentaries on the papers that defined aspects of thinking practices. Many aspects of the symposium were *firsts* for the research and researchers. In a few cases, researchers from different backgrounds shared data and brought their different perspectives to an analysis. Several of the researchers considered the educational implications of their work for the first time. Such collaboration continued as we worked toward the creation of this book.

OVERVIEW: INTERACTION, COLLABORATION, AND CASES OF THINKING PRACTICES

From the start, it was our intention to continue the conversations and collaborations about thinking practices in the pages of this book. Although the conversational task became more difficult to support in print, the book attempts to continue in the spirit of conversation and is organized accordingly. It is a collection of cases concerned with teaching, learning, and thinking on the part of teachers, students, and researchers. It is also a set of interactions about the topic of thinking practices. Each commentary was written by a researcher who was present at the authors' thinking practices roundtable and provides reflection on two or more articles, contributing to syntheses around common issues or themes in the work. Some of the commentaries raise issues or suggest future actions that are extensions or interpretations of the research reported. The interactions between authors and commenters led to new iterations of the chapters, and these offer entry points for readers to join in the discourse about thinking practices.

We use two general identifying criteria to organize the chapters into sections. One focuses on identity and participation in communities of practice. The other focuses on the characteristics of activities designed specifically for learning and the display of specific thinking practices. Both criteria enter into the contents of all of the chapters, but those located in Part I focus more on issues of community and identity and those located in Part II focus more on ways in which learning activities are organized.

These two criteria contrast with the organizing criteria central to behaviorist and cognitive psychological perspectives, in which learning is conceptualized mainly as the acquisition of skills and the understanding of procedures, facts, concepts, and representations of subject matter content. In the practice-based perspective, learning by an individual or group is a trajectory of participation and identity. Successful trajectories often move from relatively peripheral participation to more central participation in the activities of communities (Lave & Wenger, 1991) and toward more coherent identities as competent and responsible individuals (Wenger, in press). Taking this view does not deny the importance of individuals becoming more skillful and knowledgeable as they achieve greater understanding of the contents of a discipline. However, it does consider the growth of skill, knowledge, and understanding as instrumental to both the achievement of a more successful participation in the activities of communities and to a more responsible development of an individual's identity as a capable learner.

Each of the chapters takes up these issues. Many provide examples of how researchers are able to understand thinking practices as embedded in classroom life and report how teachers or students constructed intellectual and conceptual work. The researchers describe how students interact with, understand, and use mathematical and scientific concepts. In each case they make claims for how the classroom teaching and learning is organized. Many of the studies analyze video and observational data from classrooms.

Together the chapters map a movement toward new ways, founded on a respect for the social complexity of teaching and learning, to research the relationships among thinking, learning, and education. We hope the book offers a foundation for a community of researchers to develop a better understanding of the organization and enhancement of thinking practices.

In Part I, Stein, Silver, and Smith (chap. 1) and Lampert (chap. 2) consider issues of participation and identity in the practice of teaching, processes of transforming teaching practice, and the practice of inquiry by teachers regarding their goals and methods. Stein et al. report an analysis of activities by a group of teachers in their QUASAR project. Their interpretation uses Lave and Wenger's (1991) concept of legitimate peripheral participation and emphasizes that successful change in teaching occurs through participation in a community of teaching practitioners organized to support its newer members taking on greater responsibility in the community as they become more experienced. Lampert's chapter is autobiographical. She is a teacher and researcher who develops new methods of teaching and whose research is a study of the processes in her teaching activity. She discusses challenges she faced as she participated in the discourse communities of her colleagues in teaching and her colleagues in educational research. Her discussion spells out ways in which teaching and research are both social activities that occur in communities with differing constraints and patterns of achievement. Greeno's (chap. 3) commentary notes parallels in these two analyses, involving trajectories of participation and identity within and across professional communities of teachers involved in the development and understanding of changes in their own practices.

The chapters by O'Connor, Godfrey, and Moses (chap. 4) and Star (chap. 5) also are concerned with tensions and conflicts that arise between the development and maintenance of individual identity and participation in the practices of a community. O'Connor et al. discuss a case from Godfrey's teaching in the Algebra Project, in which every student had to contribute data to a set that the whole class had to analyze. This chapter emphasizes an aspect of student engagement in activity that is not captured by analyses of their learning to carry out the predefined procedures of traditional problem solving. Star discusses the disconnection in standard scientific practice between the third-person discourse of observation and analysis and the first-person experiences that scientists have, sometimes in the domains in which they do their research. In her chapter, Eckert (chap. 6) sees both chapters exploring the relationships among legitimacy, science, and identity. To Eckert, the challenge for all involved in schools is to make all subjects in school materials for kids' external and internal lives. Eckert goes on to provide an example from her field work in a sixth-grade classroom to explain how identity, the social activity of the classroom, and expertise in fields such as science are never mutually exclusive and, in fact, are essentially related.

The chapters in Part II provide research analyses of teachers and students accomplishing thinking practices in educational environments. These chapters provide glimpses into the growing body of knowledge about characteristics of activities in which students participate in practices of thinking and learning. Many issues are raised, and several perspectives on learning are supported by the combination of reports.

In the first three chapters by diSessa and Minstrell (chap. 7), Hall and Rubin (chap. 8), and Saxe and Guberman (chap. 9), accomplishments involving subject matter concepts and methods in science and mathematics classrooms are viewed as practices that become socially organized across persons, activities, artifacts, and structures for participation. The chapters also point out that teachers have much to do and organize to facilitate environments that are rich in disciplinary ideas, practices, and inclinations. diSessa and Minstrell discuss a classroom activity—a benchmark lesson—in which a teacher introduces topics in physics in a way that engages students' intuitions and experience. Hall and Rubin present an analysis of an episode from Lampert's teaching that illustrates her practice of having students participate in the collaborative construction of their understanding, which in the case they consider included development of a novel representational form in mathematics. Saxe and Guberman discuss a mathematics activity organized as a game that engages students' understandings of quantities that are analogous to those that have been documented in studies of everyday mathematics. The commentary by Goldman (chap. 10) revisits the idea of the thinking-centered classroom and points out that much work needs to be done to reorganize the knowledge, material, and institutional resources in schools for establishing thinking and learning as the core of education.

The next pair of chapters, by Lynch and Macbeth (chap. 11) and Schoenfeld (chap. 12), raise fundamental issues about the conceptual contents of routine activities. Lynch and Macbeth describe participation by children and their teachers in instructional routines that display a basic feature of scientific practice with a particular genre of talk. Schoenfeld shows that there is a similarity in the steps, procedures, and logic of knowing and working with mathematics and having the know-how, feel, and technique to make excellent pasta in the kitchen. McDermott and Webber (chap. 13) show how, in both chapters, the authors are asking these questions: When is math or science and how are they produced? By what arrangement of persons and activities do math and science happen, get noticed as happening, and arranged institutionally to the point of appearing cumulative?

Part II concludes with the chapter by Brown, Ellery, and Campione (chap. 14) and another by Riel (chap. 15). These chapters examine an aspect of infrastructure—telecommunication networks—as a vantage point for reflecting on the roles of community, practice, and knowledge in education. Brown, Ellery, and Campione believe that schools should become communities where students learn about learning and learn how to learn in a community of discourse and scholarly practices. They look at extending the learning community throughout a school and beyond through the use of an electronic mail system. Similarly, Riel describes how a program of cross-classroom, cross-school, and cross-cultural collaborations with telecommunications embeds learning in social and educational experiences that extend beyond what is available in the classroom. Riel's students are encouraged to take an active role in the construction of knowledge. In his commentary, Collins (chap. 16) suggests that both chapters make a contribution to school reform and the teaching and learning of knowledge, and introduces the idea of collective knowledge and private knowledge and their place in the school reform arena.

HOW THE THINKING PRACTICES SYMPOSIUM IMPACTED OUR WORK

Our most recent work has been influenced by the interactions we have had with the research community. Although we did not contribute a chapter about our most recent work in middle-school mathematics, we feel it represents the kind of collaborative research we were promoting with the Thinking Practices symposia.

MMAP was newly funded when we began the Thinking Practices activities. During the year in which the Thinking Practices meetings were held, we were defining the scope and intensity of our work in developing materials, working with teachers on issues of their practice and beginning classroom research. With Ray McDermott and Rogers Hall, we came to the Thinking Practices roundtable discussions feeling that the conditions in math classrooms were ripe for change. We were hoping to learn from the larger research community how to prioritize our efforts as we tried to take our vision of a thinking curriculum into middle-school classrooms. In fact, we represented one of the collaborations we were trying to foster. We came from different disciplines (psychology, anthropology, computer science, and education). We wanted to change teaching and learning processes and approaches and we were embarking on a mission of research and reform.

The main goal of our work in MMAP has been to break down the gates in the school mathematics arena and open up access for more students to learn and achieve. We wanted to experiment with a version of school math that was built on a base of emerging educational research and wisdom. To that end, we developed our vision of a thinking curriculum in middle-school math classrooms. We wanted to develop an approach to math learning that quite purposely capitalized on the social nature of learning. We had the idea that if teachers and students could imagine and begin to act out the ways people in the world use math to solve problems, they would find more reasons to engage mathematically and learn. We also wanted teachers and students to understand mathematics as practical activity and not just bits of knowledge and skills to be captured inside their heads. Finally, we wanted to reify this new approach to math learning in materials and engagement structures that were available to both teachers and students. To date, we have taken steps to address each of these issues.

MMAP has created an applications approach to mathematics. The materials include simulation software, classroom materials, and assessments designed to jump-start students into being mathematical and to support their successful math learning. MMAP consists of group-based projects for students to take on the role of workers trying to design solutions for real-world problems. They might be cryptologists creating and evaluating codes for privacy or population biologists studying two-species population interactions and making policy recommendations to a state government. In each case, a series of memos guide the students through the problem, design, research, and analysis processes, and students are required to discover the need for and use of mathematics to successfully fulfill the requirements of their problem. Computer simulation and modeling environments are provided to help the students with their designs and analyses. The units are followed by shorter extension and investigation units that give the teachers and students opportunities to connect the math they explored and used in the units with more standard mathematical representations, forms, and expressions. Much of the materials' structure requires students to work together and discuss emergent problems, generate analyses, and recommend solutions.

We realized that the kind of mathematics classrooms we enabled were a departure from traditional approaches. We redefined what an applied mathematics problem was and were asking teachers to introduce new math concepts and skills as students needed them to solve real-world problems. We departed from developmental, sequential, and spiral approaches to math content. We required students to complete design work together, introducing a process that is by definition driven by social interactions and collaborations (Perkins, 1986). We introduced computers as an integrated part of core classroom activity, bringing front and center the need for exploration, manipulation, and experimentation on the way to problem solving. We created the necessity for embedded, performance-based assessments. Most important, we created engaging and compelling activities that lured students into mathematical work that also increased tenfold the demands on the teachers.

With all of these demands, we knew we would need to provide teachers with resources, supports, and opportunities to learn as they adapted their classrooms and practices. We were aware that we expected students and teachers to practice math as they designed solutions to real-world problems. The teachers participated in practicum experiences with professionals who used math in their work—visiting, observing, and shadowing architects, emergency workers, engineers, scientists, and business executives. Math-using professionals also consulted with groups working on units, giving more practice-oriented approaches and perspectives to the written unit materials.[2]

From the start, we were involved in building a community of middle-school teachers, education researchers, and math-using professionals to conceptualize and field-test the MMAP materials. This community also directed research and initiatives to identify and implement supports for teachers as they established new kinds of math classrooms with new kinds of teaching practices. The teachers come together with MMAP staff monthly, during summer institutes, and by telecommunications to create and try out materials, assess what is being learned (by teachers and students), learn more mathematics and technologies, develop new teaching strategies, evaluate individual and collective teaching experiences, and disseminate the work.

At its inception, MMAP was intended to be both research and reform (Greeno et al., in press). We thought of the project as a step into new territories while recognizing it as a next step building on previous work in teaching and learning. It had direct links to many of the classrooms and ideas about learning and thinking that are represented in this book. In many ways, MMAP is a direct result of convergence of research and reform in research on learning and teaching. From the start of the project, we expected to grapple with issues of epistemology, cognition, teacher practice, and change in schools.

Conditions for change have been ripe and, as of today, MMAP continues toward its original goals. Although there is still much to accomplish, the MMAP community of teachers and researchers is over 60 strong, and the materials have been used by over 200 teachers and 40,000 students in five states. MMAP has been taking seriously the issues and dilemmas raised in this book concerning disciplinary content, identity, social participation, and community. We have taken seriously the task of creating and understanding widely adoptable environments where thinking and learning of the discipline is the norm for all students. We have been continually surprised by how our response to any particular critical issue or condition for learning brings new issues to the forefront. For example, we know that, although rhetoric about how all students can learn math is firmly in place, the belief in students' abilities to learn is not reflected in either school organization or pedagogical practices. Our units have group-based, problem-solving, and problem-emergent characteristics. They are designed to put students in design teams that encounter problems and constraints along the way and discover (with the help of the teacher) ways of using mathematics to help

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[2]These issues of applied mathematics practices were taken up more systematically in a research study called Math at Work by Rogers Hall at UC Berkeley.

them to solutions. We design the MMAP curriculum units specifically for students who have been traditionally underserved by school mathematics—girls, minorities, inner city, and rural students. This poses a challenge to predominant practices in schools where only the highest achieving students get access to courses and activities that are defined by large and complex problem spaces, demand creativity, give access to higher order mathematics concepts (without demanding a full competence with lower order prerequisite skills), enjoy and employ group work, and use performance-based assessments. These are environments that teachers say they imagine when they fantasize about what teaching could really be. The design of MMAP brings intellectual practices to all students *and* confronts some institutional facts in schools. It is concerned with reorganizing participation, achievement, and identity around school mathematics for both students and teachers.

It is clear how valuable our history of interaction with our research colleagues has been to us on our current work on school mathematics. We see the Thinking Practices symposium and this book grappling with the kinds of questions and issues that are raised every day in MMAP classrooms. The chapters in this book take up many of the theoretical, practical, and methodological issues impacting our work. As you read, we encourage you to become a member in the community of conversation about thinking practices.

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PART

I

PARTICIPATION AND IDENTITY IN PRACTICE

CHAPTER

1

Mathematics Reform and Teacher Development: A Community of Practice Perspective

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An intense effort is underway in the professional mathematics education community to alter the form and content of precollege mathematics instruction. Catalyzed by reports from the National Academy of Sciences (National Research Council, 1989) and the National Council of Teachers of Mathematics (1989, 1991), educational practitioners and policymakers have focused their attention on mathematics education reform. The reports have specified new goals—sometimes referred to as *world-class standards*—for mathematics education and have provided new descriptions of mathematical proficiency using terms like *reasoning, problem solving, communication, conceptual understanding,* and *mathematical power.* These reports offer an expanded view of mathematical proficiency, as well as indicate that high-level mathematical goals and outcomes should be expected of all students (Silver, 1994). However, the optimism of the reform documents that all students can learn challenging mathematics is counterbalanced by surveys and other research findings that suggest the deficiencies of conventional mathematics instruction and a pervasive absence of mathematics learning by the nation's students (Mullis, Dossey, Owen, & Phillips, 1993).

From the perspective of instruction, research evidence strongly suggests that conventional mathematics instruction lacks imagination and invitation to student engagement (e.g., Porter, 1989; Stodolsky, 1988). For too many students, conventional mathematics instruction, especially in middle and high school, has consisted of students passively learning alone and in silence, without the use of technological tools or physical models. In conventional mathematics classrooms, students typically solve exercises provided by a textbook or worksheet—exercises for which a student's task is to produce a stylized response to a narrowly prescribed question having a single correct answer that can only be validated by teacher approval and that is expected to be obtained without hesitation through application of the most recently taught procedure.

The rationale for instructional reform is clear and the rhetoric is compelling. Using an artistic metaphor, one could represent conventional mathematics instruction, with its emphasis on memorization and repetition as a black-and-white line drawing of a stick figure. In contrast, educational reformers have painted a stunning portrait of school mathematics with bright hues and rich textures that emphasize thinking, reasoning, problem solving, and communication. The reform vision not only offers an expanded view of mathematical proficiency and mathematics instruction, but also affirms that opportunities to attain high-level mathematical goals and outcomes should be made available to all students. In this view, mathematics classrooms for all students become places in which students engage actively with the mathematics they are asked to learn, in which discourse is a prominent feature of classroom activity, and in which personal meaning making and understanding are important goals of the socially situated classroom activity (Silver, 1994).

The reform vision's emphases on active meaning making and student-to-student communication in the classroom illustrate the increased attention being devoted to the social nature of mathematical knowing within the mathematics education community. The view that doing mathematics and thinking mathematically is a social practice is supported by recent trends in the philosophy of mathematics. In particular, Lakatos (1976) portrayed a social process of debate to illustrate the nuances of mathematical discourse and culture, and Kitcher (1984) developed an epistemology of mathematics based on the importance of shared meanings and not simply shared results. This work suggests that, to understand what mathematics is, one must understand the activities or practice of persons who are makers or users of mathematics, deviating from the more conventional view that understanding mathematics is equivalent to understanding the structure of concepts and principles in the domain.

Viewing mathematics as a practice as well as a knowledge domain challenges us to examine and accept social and cultural aspects of mathematics and mathematics education that have been largely ignored in the United States until fairly recently. The popular image of a mathematician is someone isolated in a paper-strewn study, but sociocultural perspectives suggest that mathematical knowledge is as much socially constructed as it is individually constructed and that the practice of mathematics is fundamentally a social practice. In brief, the argument is that mathematics is created using socially appropriated tools and conventions and that ideas attain validity only when they are accepted within the mathematical community (Tymoczko, 1986). In this view, communication and community both become central features of mathematical activity. If school mathematics is to be authentic in its relationship to the culture of mathematical practice, mathematics classrooms must become communities in which students engage in collaborative mathematical practice, sometimes working with each other in overt ways and always working with peers and the teacher in a sense of shared community and shared norms for the practice of mathematical thinking and reasoning.

There are important consequences for teachers in this emerging view of mathematics classrooms as environments for collaborative mathematical thinking. Teachers need to become more confident and competent in their own ways of knowing and doing mathematics. To orchestrate a group engaged in mathematical discourse or to help individuals or groups formulate and revise learning goals or problem-solving approaches, a teacher must possess broad, deep, flexible knowledge of content and pedagogical alternatives. Without such knowledge of content and pedagogy, teachers will be unable to quickly reformulate goals and relate students' conceptions to the characteristic intellectual activities, knowledge structures, and cultural norms shared within the larger mathematical community.

Adding to the challenge for teachers is the belief among many reformers that precise specifications for instructional environments that foster student thinking, reasoning, and problem solving cannot—and should not—be provided. Much of the current reform rhetoric is driven by a clear sense of what students should learn and how they should learn it. The rhetoric presents a consistent picture of the outcome goal: the student as an active, flexible, powerful constructor of mathematical meaning and solutions. However, a consistent and detailed image of instructional practices and programs that would be associated with such student outcome goals has not been theoretically or empirically developed. Current thinking within the field of mathematics education is that teachers must construct an instructional practice that parallels the constructivist epistemology of student learning. Hence, teachers are placed in the position of needing to create an instructional practice that encourages the complex and ambitious student learning outcome goals of the reform movement.

This charge to invent new forms of instructional practice is made more difficult by the fact that most teachers have had little or no experience as participants in collaborative learning communities. Thus, although the *Professional Standards for the Teaching of Mathematics* (National Council of Teachers of Mathematics, 1991) suggest the importance of "reflecting on learning and teaching individually and with colleagues," "participating actively in the professional community of mathematics educators," and "experimenting thoughtfully with alternative approaches and strategies in the classroom" (p. 168), the current situation is typically quite different. Mathematics teachers tend to work in isolation and with little or no motivation to change. For example, a recent survey of mathematics teachers found that only about half of the teachers at all grade levels saw their colleagues as a source of information on new teaching ideas and even fewer saw professional meetings as a source of such ideas (National Council of Teachers of Mathematics, 1992).

Much of the isolationism and conservatism that typically characterizes teaching is related to the nature of the teaching profession and the school bureaucracies within which teachers practice. Compared with other professions, the process of becoming a teacher lacks recognized gradations, as well as work-related support mechanisms to assist individuals to move from one stage to another. First-year teachers often receive teaching assignments that are the same as or more demanding than their veteran counterparts. For example, it is not unusual to find beginning middle-school mathematics teachers in the most impoverished schools teaching the maximum number of preparations to the most challenging students with little or no support. Despite calls for career ladders and mentoring programs, the conditions of an individualistic and *flat* profession—conditions that Lortie (1975) brought to our attention more than two decades ago—prevail.

Helping teachers move beyond a pedagogy of isolation and recitation is likely to require new forms of assistance. In the conventional practice of teacher education and development, the three major resources and activity structures are: (a) preservice teacher preparation in content (which is typically quite meager for elementary and middle-school teachers and which is often disconnected and decontextualized for secondary school teachers) and pedagogy (which is usually quite limited for teachers at all levels); (b) inservice staff development sessions, which are typically single-session encounters with little or no support for implementation; and (c) university-based, graduate degree programs, which often have an academic rather than an applied focus or which are quite general. These resources provide some support for teachers, but they are unlikely to be sufficient in the face of shifting pedagogical emphases and increasing intellectual demands in teaching.

What is needed is a new way to view teacher education and development as the building of communities of collaborative, reflective practice. In this view, teachers would come to see themselves as being joined with colleagues within their school in an effort to provide quality mathematical experiences for their students. Teachers would plan together, discuss each other's teaching practice, develop consensus on ways to evaluate their students' thinking, and support each other through difficult points in the change process. Such collaborative efforts were characteristic of the QUASAR Project. QUASAR (Quantitative Understanding: Amplifying Student Achievement and Reasoning) was a national educational reform project aimed at fostering and studying the development and implementation of enhanced mathematics instructional programs for students attending middle schools in economically disadvantaged neighborhoods (Silver & Stein, 1996). Launched in the fall of 1989 and operated at six school sites dispersed across the United States, QUASAR investigated the feasibility and responsibility of the proposition that students from disadvantaged backgrounds could and would learn a broad range of mathematical content, acquire a deep and meaningful understanding of mathematical ideas, and demonstrate proficiency in mathematical reasoning and solving appropriately complex mathematics problems. From the perspectives of both feasibility and responsibility, an important aspect of QUASAR was its extensive research and evaluation effort. Project staff based at the Learning Research and Development Center at the University of Pittsburgh have documented the goals, implementation, and impact of the site-based programs using a variety of methods, including classroom observations, student performance assessments, interviews, inventories, and the ongoing collection of naturally produced artifacts of project work at the sites.[1]

At the project sites, opportunities were available to QUASAR teachers to participate in collaborative working arrangements—forms of teacher support that represented departures from the conventional forms of teacher education noted earlier (i.e., preservice education, inservice education, university-based graduate degree programs). At each site, the mathematics teachers and school administrators collaborated with *resource partners* who were usually mathematics educators from a local university. Together they worked to develop, implement, and modify an innovative mathematics instructional program for all students at the school. A broad array of activities were undertaken at project sites, including curriculum development and modification, staff development, classroom and school-based assessment design, and outreach to parents and the school district at large. This network of collaborative, interrelated activities formed the foundation of their efforts to build the capacity of the school and the teachers to provide an enhanced mathematics program for each child.

These nonconventional forms of teacher support were not unique to the QUASAR project. For example, professional development schools are based on a similar philosophy regarding the need to provide sustained, collaborative, school-based relationships as a context for teacher development. Nev-

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[1]See Lane (1993), Silver and Lane (1993), Stein (1992), and Stein, Grover, and Silver (1991) for more details regarding the design of QUASAR's data-collection effort.

ertheless, the research community has not explicated how teacher development or, more specifically, teacher learning occurs in such settings. Although *teacher colleagueship* has been identified as an important variable in successful schools (Little, 1990) and in school reform (Fullan, 1991), detailed descriptions of *how* and *about what* teachers collaborate, as well as the mechanism by which teacher collaboration leads to teacher development or learning, have not been developed.

This chapter examines the utility of using some aspects of sociocultural theory, specifically the notion of *communities of practice* proposed by Lave and Wenger (1991), as a theoretical framework that may help describe how teacher learning occurs in collaborative, school-based communities. In particular, Lave and Wenger's notion of *legitimate peripheral participation* offers a perspective on learning that takes as its core premise that learning occurs as people engage in the activities of a community. It is our hope that this framework will assist us in the identification of critical features of teacher learning in collaborative settings—features that might very well be overlooked in more traditional forms of analyses. If successful, this description and identification of key features could be quite useful in designing similar reform-oriented efforts in other schools. Moreover, the analysis might also help identify features that should be strengthened in particular instantiations of school-based collaborations.

The chapter begins with a brief description of one QUASAR site—Portsmouth Middle School[2]—and the challenges that it presented to the QUASAR research staff as they attempted to understand the development of teachers there. It then moves to an overview of selected aspects of Lave and Wenger's theory and provides examples of ways in which they can be used to examine and describe teacher learning at Portsmouth. Finally, it concludes with a discussion of the contributions that viewing teacher development through a community of practice framework can make to our understanding of teacher learning in collaborative, school-based communities.

THE QUASAR PROJECT AT PORTSMOUTH MIDDLE SCHOOL

Portsmouth Middle School is located in an economically disadvantaged neighborhood within blocks of the largest low-income housing development in the Pacific Northwest. Most of the approximately 600 students are from the immediately surrounding neighborhood. Eighty percent come from fami-

[2]Throughout this chapter, the real names of places, people, and artifacts are used. An earlier draft was shared with the individuals about whom it was written, and all parties stated their wish to be identified by their real names rather than pseudonyms.

lies earning less than $10,000 per year; 60% live in single-parent households. The student body is ethnically diverse, with about 65% of the students Caucasian, 25% African American, and the remainder either Hispanic or Native American. Before their association with the QUASAR Project, Portsmouth's students had a reputation for consistently scoring at or near the bottom on annually administered district standardized tests in comparison with students at other district middle schools.

When the opportunity to apply for a grant from the QUASAR project emerged in the spring of the 1989–1990 school year, a small group of teachers collaborated with two mathematics educators from Portland State University (Linda Davenport and Linda Foreman) to submit a proposal. It declared their intentions to work together to provide a quality middle-school mathematics program for all the students of Portsmouth. Their application was strengthened by the fact that one of the teachers, Paul Griffith, had begun using an inquiry-based approach in his sixth-grade mathematics classes in the fall of 1989. Working with the assistance of Linda Davenport, Paul had been using Visual Mathematics (VM), an innovative curriculum that embodies many of the recommendations of the National Council of Teachers of Mathematics' (NCTM's) *Curriculum and Evaluation Standards*.[3] Their work had gained the interest and excitement of a number of teachers at Portsmouth who were eager to try the approach in additional mathematics classes. Both the teachers and mathematics educators viewed QUASAR as an opportunity to move from a single teacher's implementation of this innovative mathematical approach to a school-based model of instructional innovation.

Portsmouth Middle School was selected as a QUASAR site in May 1990. The mathematics faculty, in collaboration with the two resource partners, officially began their school-wide effort, which was guided by the philosophy and materials of the VM curriculum in September 1990. Based on a constructivist approach to the teaching and learning of mathematics, this curriculum views students as active participants in the construction of knowledge and teachers as facilitators of learning rather than dispensers of knowledge. Unique to the VM curriculum, however, is the important role assigned to visual thinking. Throughout the curriculum, visual models are developed as a means of providing students with more direct access to underlying meanings than would be available through an approach based solely on algorithms (Bennett & Foreman, 1991). Students are encouraged to use visual models as representational tools as they engage in mathematical reasoning and communication. Most of the activities are open ended, requiring that

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[3]*Visual Mathematics* is co-authored by Linda Foreman. It is being developed under the auspices of the Math Learning Center (Salem, Oregon) with support from the National Science Foundation.

students perform actions, make observations of the results of their actions, and, when possible, generalize from specific observations to abstract mathematical concepts and relationships. Throughout the curriculum, visual models, student communication, the use of multiple strategies, and integrated, instructionally embedded assessment techniques are emphasized.

Project data suggest that the efforts of the Portsmouth project participants had a positive impact on teachers, students, and the district as a whole. Evidence from documentation of classroom instruction suggests that the teachers used cognitively complex and challenging mathematical tasks in a manner that encouraged student responsibility for their own learning as well as student ability to communicate their mathematical understandings effectively.[4] Student performance on QUASAR's assessment instrument demonstrated consistent increases in their understanding of important mathematical concepts, as well as their capacity to reason and communicate about mathematical situations.[5] The students also fared well on more traditional measures of achievement used within the school district. For example, with each year of project participation, standardized test scores improved and increasing numbers of students were declared eligible for ninth-grade algebra. Finally, the positive outcomes of the QUASAR project at Portsmouth drew the attention of teachers and administrators district wide, leading to the development of a cluster-wide movement to adopt the VM curriculum in Grades K to 12.

These accomplishments were made possible by a wide variety of conditions and factors: (a) The resource partners provided appropriate forms of teacher development in the crucial early stages of the project, (b) VM is a coherent middle-school curriculum that systematically builds on students' experiences and knowledge, (c) the school administration was supportive especially with respect to hiring and placement decisions, (d) a pool of well-qualified candidates for teaching positions was available in the area, and (e) the QUASAR project provided many resources that otherwise would not have been available. Among the resources provided by QUASAR was support for an extensive array of teacher assistance activities.[6] The development of an understanding of how these varied forms of teacher assistance led to teacher learning is a crucial piece of the story at Portsmouth, revealing

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[4]A general discussion of findings related to instructional practices across four QUASAR sites over the first three project years can be found in Stein, Grover, and Henningsen (1996). The trends reported in Stein et al. (1996) are representative of the Portsmouth classrooms.

[5]The QUASAR Cognitive Assessment Instrument (QCAI) was developed to assess students' ability to reason, problem solve, and communicate mathematically (see Lane, 1993; Silver & Lane, 1993, for an overview of this instrument's design). A general discussion of student performance results across four QUASAR sites for the first three project years can be found in Lane and Silver (1994). The trends reported in Lane and Silver are representative of the Portsmouth students.

[6]The term *assistance activity* is borrowed from Tharp and Gallimore (1988).

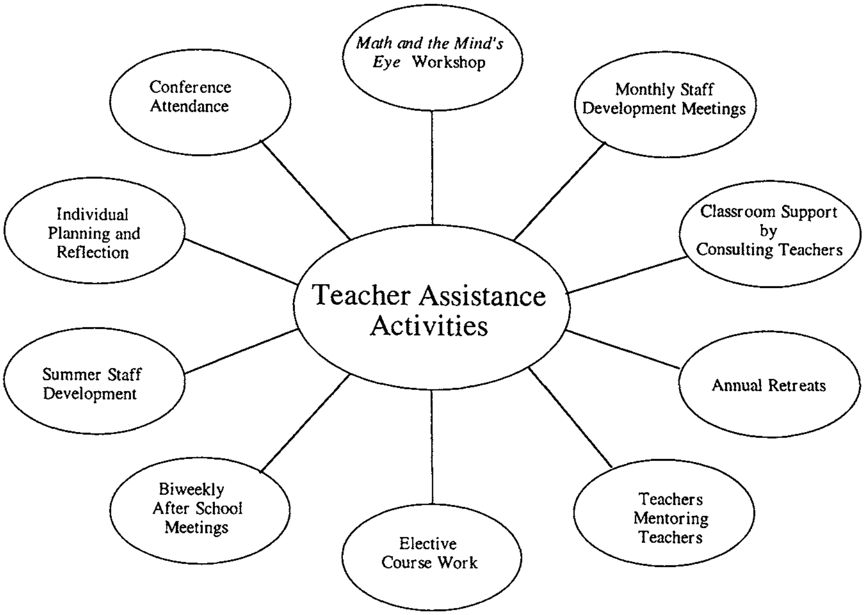

FIG. 1.1. Teacher assistance activities at Portsmouth Middle School.

the important role played by the community of teachers. Therefore, they are the focus of the following section.

Teacher Assistance Activities at Portsmouth

The assistance activities represented in Fig. 1.1 were identified by the project research staff in the fall of 1992 on the basis of review of the site's annual planning documents and end-of-year reports, as well as information available from ongoing monitoring of site activities. Figure 1.1 shows the number and range of assistance activities available to the Portsmouth teachers extended well beyond the traditional forms of teacher education discussed earlier. They included event-specific workshops, retreats, courses, and conferences; ongoing classroom-based support; and time for teacher–teacher interaction.

To prepare for teaching the VM curriculum, the Portsmouth teachers enrolled in two workshops: *Math and the Mind's Eye* (MME), Parts 1 and 2.[7] These workshops were designed to help teachers become familiar with visual thinking and its role in the teaching of mathematics, and they included readings related to the philosophy of the VM curriculum and the current

[7]The *Math and the Mind's Eye* workshops and materials (Bennett, Maier, & Nelson, 1989) were developed under the auspices of the Math Learning Center (Salem, Oregon) with support from the National Science Foundation.

mathematics reform movement, as well as extensive exploration of mathematics content based on a constructivist approach to learning. These two workshops were taught by the resource partners or their colleagues from PSU. Together they represented 60 hours of instruction.

The Portsmouth teachers' learning of mathematical content and pedagogy did not end with the MME workshops, however. Beginning in the fall of 1990, the Portsmouth mathematics teachers also participated in monthly, full-day staff development meetings. Led by the resource partners, these meetings provided time and encouragement for teachers to discuss the problems and triumphs associated with implementing an inquiry-oriented approach to mathematics teaching. Also built into the assistance activity network were classroom visits by consulting teachers—individuals who worked closely with the resource partners and whose main role was to assist with classroom implementation of VM. Additional opportunities for teacher learning included 1- or 2-day retreats that were held at the end of the school year, and elective coursework at PSU offered under the auspices of a specially designed program for the certification of mathematics teachers at the middle-grade level. Like the MME workshops, these courses were based on a constructivist model of learning and the use of visual models.

The teacher assistance activities also included time and encouragement for teachers to meet and work with one another. During the first two project years, selected teachers were released from a portion of their teaching duties so that they could be available to mentor their colleagues by providing materials, conducting classroom observations, or simply holding discussions with their colleagues about what was or was not going well. Teachers also met biweekly after school and for 2 or 3 weeks each summer to undertake various project-related activities. However, it should be noted that not all teacher interaction occurred during these formally set-aside times. The Portsmouth teachers taught in close proximity to one another, sometimes even sharing a room (i.e., two teachers taught mathematics in the same room, but during different periods). As a result, a considerable amount of informal, day-to-day sharing took place. The teachers even created a name for these occasions: *tagging up*.

The Portsmouth teachers also found that individual time to reflect was important, including time spent reflecting on videotapes of their teaching practice and writing in journals. Finally, teachers had the opportunity to attend a variety of conferences, including national NCTM meetings, biannual QUASAR meetings in Pittsburgh, and regional and district conferences.

When considered in total, the array of assistance activities illustrated in Fig. 1.1 is different from the limited ways in which teachers attempting innovation are typically supported (Little, 1993). Although some of the assistance activities can be seen as pedagogically structured, event-specific occasions for teacher assistance (e.g., MME workshops, elective coursework, monthly staff development meetings, retreats), others were more informal and ongoing (e.g., teachers mentoring teachers, ongoing classroom visits by consulting teachers, tagging up). Still others represented opportunities to actually do the work of the project. For example, during the summer staff development sessions and biweekly after-school meetings, teachers undertook a number of tasks related to the development of their mathematics program. These included realigning the curricular sequence to be more attuned to students' needs and testing constraints, developing classroom-based performance assessments, and designing activities to acquaint parents with the mathematics program and to recruit their support. Therefore, the challenge for the QUASAR research staff was to find an appropriate lens through which to view teacher learning under these conditions.

The task began with interviews in which teachers were asked how they perceived the various forms of assistance available to them. In the fall of 1992 (after 2 years in the project), teachers were asked to rank order the various activities shown in Fig. 1.1 from 1 to 10, with 10 representing the assistance activity that was most important to their overall learning and development and 1 the activity that was least important. In addition, they were asked to talk about the ways in which each of the assistance activities was or was not useful to their continued professional development. Their comments indicated that they valued various activities for different reasons at different times. One of the clearest patterns across teachers was their sense that the MME workshops were an extremely valuable source of assistance early in their tenure with the project. All teachers felt that these workshops helped them develop a sound philosophical base for understanding the mathematics reform movement and that they provided them with the opportunity to learn important mathematical content, experience good mathematics teaching, and begin to develop an effective mathematical pedagogy. These workshops—as well as the monthly staff development sessions and annual retreats—were led by the resource partners and were explicitly structured to provoke reflection on issues that the resource partners felt were important for the teachers to consider as the project proceeded.

As time passed, however, such structured opportunities for learning, in which the agenda was developed by the resource partners (in particular, the annual retreats and monthly staff development meetings), were perceived as increasingly less valuable. One teacher commented about the annual retreat that had been held the previous spring: ". . . there was a set agenda, and it just didn't meet our needs." All of these types of assistance activities received ratings of 5 or below from every teacher, indicating their perceived relative unimportance as compared with other forms of assistance.

However, by the fall of 1992, the teachers tended to perceive opportunities to work collaboratively with colleagues on substantive issues (e.g., curriculum planning and assessment development during summer staff development sessions) as activities that "they can't live without." The circles labeled *teachers mentoring teachers* and *summer staff development* in Fig. 1.1 each received ratings between 6 and 10 by all teachers. One teacher commented:

> Time to talk about curriculum and assessment. We need it desperately.... The biggest thing was this summer staff development because it was teachers mentoring teachers. You see, anytime that we get together and talk, because we have been through so many experiences, like and unlike, its amazing how we've come to the same point in our thinking. It's incredible. And what we can get done is just astounding. What we got done in a couple of days by ourselves, we are thrilled with it.... We were able to really get down and do that ... work that we needed to do. ... We're talking hard-core curriculum and assessment. That's what we want to talk about.

Another added:

> We were so excited with what we got done and we all felt a part of it. We are all using [the materials we developed] even though we have very different styles, and it has made a huge difference.

The teachers' remarks (and the overall pattern of their ratings) suggest that something important was happening between and among the teachers, especially as their tenure with the project extended. There can be no doubt that their experiences with the resource partners during the early project years were important initial sources of teacher learning, as was stated by the teachers. However, the story of their learning did not stop there. By the fall of 1992, the teachers clearly saw their interactions with each other in a variety of settings as important influences on their growth and development. After fall 1992, evidence from numerous interviews, observations, site visits, and teacher journals continued to paint a picture that highlighted the important role of communication and connection among teachers. By all accounts, the teachers had assembled themselves into a highly interactive and productive unit. Furthermore, they perceived themselves—and were perceived by others—as an identifiable group of individuals bound by their shared goal of developing an inquiry- and visually based approach to mathematics instruction in their classrooms. An appropriate lens for viewing teacher learning at Portsmouth, then, needed to be able to bring into focus the teachers as a group and the ways their interactions in a variety of settings led to teacher learning.

The QUASAR research staff concluded that the conventional models available for studying teacher learning and school improvement were ill-suited to that task. On the one hand, conventional models for examining teacher development feature individual teachers and tend to focus on the role that the individual's subject matter knowledge and beliefs play in his or her instructional practice. Little or no attention is devoted to the role played by social interaction with one's colleagues in the development of knowledge, beliefs, or improved practice. On the other hand, models of school reform that feature social interaction with colleagues pay little or no attention to the ways in which that interaction can lead to teacher learning. Lave and Wenger's community of practice framework was attractive because it focused on the role of social interaction in a community as the source of learning. In the following section, selected ideas from Lave and Wenger's theory of learning are discussed and their utility in describing and interpreting teacher development in the Portsmouth community is illustrated.

VIEWING TEACHER DEVELOPMENT AT PORTSMOUTH THROUGH A COMMUNITY OF PRACTICE LENS

Most research on teacher learning and development is grounded in psychological theory. As such, studies tend to assume that learning occurs within the boundaries of individual teachers' minds and actions. Lave and Wenger's work starts with the sociocultural premise that learning is "something that happens *between people* when they engage in common activities" (Bredo & McDermott, 1992, p. 35; italics added). Learning is seen to result from the fact that individuals bring varying perspectives and levels of expertise to the work before them. As individuals work toward shared goals, they *together* create new forms of meaning and understanding. These new meanings and understandings do not exist as abstract structures in the individual participants' minds. Rather, they derive from and create the situated practice in which individuals are coparticipants. Indeed, according to Lave and Wenger, "a community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage" (p. 98).

Adopting a community of practice perspective on teacher development channels attention away from analysis of the cognitive attributes and instructional practices of individual teachers and, instead, toward the collaborative interactions that occur among teachers as they attempt to develop and improve their practice. As attention is shifted from the individual to the group, the location of the phenomenon of learning changes as well. Instead of being located in the cognitive structures and mental representations of individual teachers, it becomes situated in the *fields of social interaction* (Hanks, 1991) among teachers. Learning becomes a by-product of participation in joint activities for which teachers have mutually held goals and to which they bring varying levels of expertise. The result of this new analytic viewpoint is that the unit of analysis shifts from the individual teacher to the social practice or activities in which groups of teachers engage. In the following subsections, two main ideas from Lave and Wenger's framework—learning through legitimate peripheral participation and development of identity through storytelling—are used to describe teacher learning in Portsmouth.

Learning Through Legitimate Peripheral Participation

How can analyses that focus on the activities in which teachers engage provide insight into teacher development or learning? Lave and Wenger viewed learning as an "integral and inseparable aspect of social practice" (p. 31). In an effort to further clarify and elaborate this somewhat nonintuitive conceptualization of *learning as practice*, Lave and Wenger characterized learning as legitimate peripheral participation in communities of practice:

> Learning viewed as situated activity has as its central defining characteristic a process that we call *legitimate peripheral participation*. By this we mean to draw attention to the point that learners inevitably participate in communities of practitioners and that the mastery of knowledge and skill requires newcomers to move toward full participation in the sociocultural practices of a community. "Legitimate peripheral participation" provides a way to speak about the relations between newcomers and old-timers. . . . It concerns the process by which newcomers become part of a community of practice. A person's intentions to learn are engaged and the meaning of learning is configured through the process of becoming a full participant in a sociocultural practice. *This social process includes, indeed it subsumes, the learning of knowledgeable skills*. (p. 29; italics added)

This perspective on learning suggests that teacher development should be examined in relationship to the communities of practice in which teachers participate. More specifically, teachers are seen to learn what is valued and practiced within their immediate circle of colleagues. Although teachers often participate in more distant communities as well (e.g., a regional network, a national association of mathematics teachers such as NCTM), their local community provides the most salient opportunities for consistent engagement and meaningful membership. Thus, the goal of analytic inquiry into teacher development is to identify the goals, values, and practices of the community and trace the trajectories of the participation of newcomers from peripheral to fuller and fuller forms of participation in the practices of the community. Within this framework, *teacher learning* is defined as movement from peripheral to fuller forms of participation, and mastery of knowledge and skills is viewed as coinciding with increasing involvement in the practices of the community.

Old-Timers and Newcomers in the Portsmouth Community

Figure 1.2 identifies the teachers who were members of the Portsmouth reform community at the time that this chapter was being written (winter 1994) and indicates the year in which they joined the project. The figure was specifically constructed to focus attention on the overall group as the unit of analysis not individual teachers. Although individual teachers are identified, it is for the purpose of showing their length of participation in the community relative to the other teachers' lengths of participation in the community. This data-display method has been a useful way to identify newcomers and old-timers at any given point in the project's history. For example, if the task were to identify old-timers and newcomers in the fall of 1992, the information in the figure suggests that Paul Griffith and Dorothy Geary were old-timers and that Chris Wickham was a newcomer. Susan Albright and Heather Nelson, having joined the community 2 years later than Dorothy (and at the same time as each other), would be classified as either new old-timers or old newcomers.

In reality, however, length of participation is not perfectly correlated with newcomer/old-timer status in the Portsmouth community. Additional information about these individuals, including the ways in which they participated in the community's activities (e.g., Who is at fullest practice? Who is on the periphery? Who has the broadest responsibilities? Who spends the most time?), suggests a slightly different classification. Paul and Dorothy still look like old-timers. In addition to their length of time in the community, both individuals were full participants in a broad array of the community's

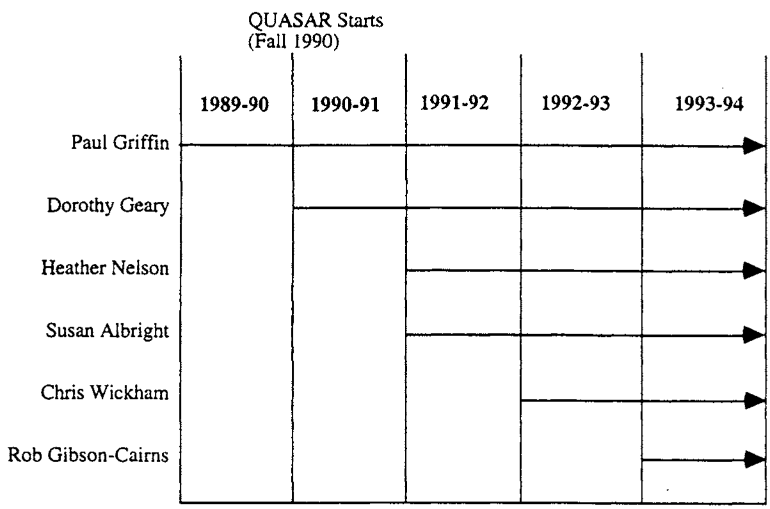

FIG. 1.2. Members of the Portsmouth reform mathematics community.

practices. Chris, who began his association with the community by assuming a role on the periphery, would continue to be identified as a newcomer. Susan and Heather, however, would not be classified together. Examination of their forms of participation reveals that Heather acted more like an old-timer even during her first year in the community. For example, she made presentations about their work and took a leadership role with respect to the development of their assessment system. In contrast, Susan displayed participation patterns more typical of newcomers. Although she went on in subsequent years to gain full status in the community, during her first year Susan spent most of her time participating in peripheral ways. For example, she listened more than talked during teacher group meetings at Portsmouth and she did not make presentations at local or national meetings.

Additional information about these two individuals reveals differences in the amount and kind of experience that each brought with them to Portsmouth. When Susan joined the community in the fall of 1991, she possessed no prior classroom experience and, consequently, no experience in teaching the VM curriculum, although she had taken courses that were based on the VM philosophy. Heather was a more experienced teacher who had taught the VM curriculum in another district for several years. In addition, Heather was well acquainted with the resource partners and had been involved with them in presentations and courses for several years. Despite her recent arrival to Portsmouth, Heather's form and degree of participation resembled Dorothy's and Paul's participation profiles (the old-timers) more than Susan's. Therefore, we refer to Heather as an *old-timer* and to Susan as a *newcomer.*

The prior exercise in classification highlights the nature of the role that participation plays in analyses performed within this framework. To ascertain newcomer/old-timer status, it is necessary to examine the ways in which individuals participate in the community's activities as well as length of participation. The case of Heather also points to the fact that most individuals participate in multiple communities and that their status in one community may have implications for their status in other communities. Heather's precocious status as an old-timer in the Portsmouth community stems largely from her veteran membership status in another similar community.

Participation Patterns in the Portsmouth Community

Having described the teachers at Portsmouth and their relative placement with respect to newcomer/old-timer status, an examination of participation patterns as an index of their learning is presented. A variety of methods could be used. At any given time, all members' breadth of participation across the full range of community activities could be examined. Here one would expect old-timers to participate in a wider range of activities, take broader responsibility for activities in which all members were participants, and spend more time and energy on community activities overall than do newcomers. Newcomers, however, would be involved in a significant subset of activities, although in a much more peripheral manner than would be old-timers. Another method would be to trace the trajectory of participation of one particular newcomer over time. For a newcomer who was granted legitimate access to the community, this would provide an intimate view, from the learner's perspective, of the unfolding of participation opportunities and how these opportunities allowed the newcomer to gain multiple and increasingly inside viewpoints on the community's work and values.

A third method would be to examine, in a more detailed way, one particular work practice of the community and the ways in which old-timers' participation differed from that of newcomers. A work practice of the Portsmouth community that heretofore has not been mentioned is teaching. At first glance, teaching might appear to be a difficult work practice on which to find differences in participation patterns. Unlike tailors or midwives, most teachers are thrust into full-scale teaching as soon as they are hired. The expectation is that the teacher will teach the same and as many classes (without assistance) on the first day of his or her hire as he or she will teach on the last day of his or her hire. Despite these prevailing norms, the Portsmouth community managed to provide a staged entry into their community. Newcomers were eased into teaching VM in a thoughtful manner—a manner that allowed old-timers to assist newcomers in meaningful and relevant ways. This staged development of participation offers a good window on teacher learning through legitimate peripheral participation in the Portsmouth community.

The pattern of teaching assignments according to newcomer/old-timer teacher status is shown in Table 1.1. The column headings indicate the year and stage of program implementation. Although school-wide implementation began in the fall of 1990, it unfolded over a 4-year period. With each consecutive year, one grade level became the new focus of implementation while another grade level was the focus of pilot work. As shown in Table 1.1, the implementation process can be classified into four stages: During Stage 1 (1990–1991), the curriculum was implemented in all sixth-grade classrooms and piloted in all seventh-grade classrooms; during Stage 2 (1991–1992), the curriculum was implemented in all sixth- and seventh-grade classrooms and piloted in eighth-grade and algebra classes; during Stage 3 (1992–1993), the curriculum was implemented in sixth-, seventh-, and eighth-grade classrooms and piloting continued in algebra classrooms; and during Stage 4 (1993–1994), the curriculum was implemented in all mathematics classrooms, including algebra. When a grade was being piloted, a few teachers (one or two) taught the courses at that level working out pacing and sequencing issues and/or field-testing materials. Once a course had passed through a pilot stage, additional teachers began teaching it. It is important

TABLE 1.1
Mathematics Teaching Assignments at Portsmouth Middle School

Teacher	*1989–1990*	*1990–1991 Stage 1*	*1991–1992 Stage 2*	*1992–1993 Stage 3*	*1993–1994 Stage 4*
Paul Griffith	1—sixth grade *	1—sixth grade 3—seventh grade	1—seventh grade 3—eighth grade 1—algebra	2—sixth grade 1—eighth grade 3—other	3—sixth grade 1—seventh grade 1—eighth grade 1—algebra
Dorothy Geary		3—sixth grade 3—other[a] *	1—sixth grade 3—seventh grade 1—other	2—seventh grade 4—eighth grade	2—sixth grade 2—seventh grade 1—eighth grade 1—algebra
Heather Nelson			2—sixth grade 3—eighth grade *	2—sixth grade 2—eigth grade 1—algebra	4—seventh grade 1—eighth grade 1—algebra
Susan Albright			2—sixth grade 1—seventh grade *	3—seventh grade	Special assignment[b]
Chris Wickham				3—sixth grade 3—seventh grade *	2—sixth grade 1—eighth grade 1—algebra 2—other
Rob Gibson-Cairns					1—sixth grade 5—other *

*Indicates the first year a teacher taught the VM curriculum at Portsmouth Middle School.

[a]*Other* refers to nonmathematics courses taught.

[b]Susan's position was cut for the 1993–1994 school year due to Paul's decision to return to mathematics teaching full time (he taught three classes in 1992–1993 vs. six classes in 1993–1994). Susan continued her involvement by taking responsibility for coordinating the operational and substantive details of the project.

to understand the different demands that a pilot-phase course places on teachers, as opposed to an implementation-phase course. A course in the implementation phase is much less demanding because the materials are more polished and there are other people in the environment who have previously taught the course. These individuals possess a *big picture* view of the course (and often the entire curriculum) and thus are able to offer assistance to those who are teaching an implementation-phase course for the first time. When individuals are teaching a pilot-phase course, they must be more self-sufficient. The materials are not as well-tuned, the big picture may not be in view, and there are not more experienced teachers in the immediate environment to whom to turn for assistance.

Returning to Table 1.1, the community members appear in the left column with an asterisk marking the first year that they taught the VM curriculum at Portsmouth Middle School. An examination of the table reveals clear patterns with respect to form of participation and newcomer/old-timer status. First, newcomers always began their association with the community by teaching sixth grade. This is significant because the sixth-grade curriculum was considered complete (including written suggestions for teachers) at the beginning of the QUASAR project (fall 1990) and, hence, the demands of teaching a pilot-phase course were never placed on newcomers. In addition, the sixth-grade course is easier mathematically. Finally, when newcomers teach the sixth-grade course, it is virtually guaranteed that they will be surrounded by old-timer colleagues who have taught the sixth-grade curriculum one or more times.

The opposite pattern of newcomer/old-timer participation is evidenced with respect to Algebra—the most challenging course taught by the community (i.e., the material is more difficult mathematically, the lessons are less polished and not as well piloted, and no teacher colleagues have taught it before). Here, the most senior old-timer taught it first (i.e., Paul in the 1991–1992 school year). By contrast, most newcomers built up to it gradually. For example, Dorothy taught it for the first time during the 1993–1994 school year—her fourth year in the community.

These patterns suggest a gradual increase in expectations as a teacher moves from newcomer to old-timer. To understand the ways in which newcomers became enabled to move toward fuller participation, however, it is necessary to examine more closely how old-timers and newcomers interacted around the work practice of teaching. Close inspection of Table 1.1 reveals a more subtle but potentially more important pattern with regard to this: Newcomers were never expected to teach a course that was not also being taught at the same time by an old-timer. For example, during the 1990–1991 school year, Dorothy (a newcomer) was assigned to teach three sections of sixth-grade mathematics while Paul (an old-timer) taught three sections of seventh-grade mathematics and one section of sixth-grade mathematics. Thus, Dorothy could turn to her more experienced colleague to seek advice about pacing, difficulty levels and expected student mastery, or interconnections of mathematical ideas. Similarly, during the 1991–1992 school year, Susan (a newcomer) taught two sections of sixth grade and one section of seventh grade; there were several old-timers who were also teaching sixth- and seventh-grade sections that year. Indeed, Susan and Dorothy formed a mentoring relationship that year as did Paul and Dorothy the previous year.

Evidence from teacher journals and interviews illustrates the extent to which newcomers appreciated and relied on the availability of more experienced teachers as they worked their way through VM material for the first time. During the 1990–1991 school year, Dorothy (a newcomer) and Paul (a relative old-timer) taught mathematics in the same room. In fact, Dorothy did not have access to a free room during her prep period so she would stay in Paul's classroom and observe his teaching. Although at first she complained about not getting work done during her prep time, eventually she came to enjoy it. Early in the first year, Dorothy wrote the following in her journal:

> I know I will need a place of my own, but I will also learn a lot working in the room while Paul is teaching. Today I didn't get anything done during my prep because I was interested in Paul's lessons.

Dorothy's appreciation of her close day-to-day contact with Paul continued and was expressed in an interview later that same year:

> I know that they would have thrown me out of the math program in one week if it weren't for Paul because Paul has everything organized. . . . I share a room with Paul, so we collaborate. . . . I see him a lot, like fourth period is my lunch and I always go in there and get ready for math during that time and he's usually there . . . and I can say, "God, I'm really feeling (*sentence not completed, but the intonation of her voice suggests exasperation*)." And he says, "Dorothy, I felt exactly the same way last year at this time" and he'll say, "You did this well and you did this well." He's in and out a lot when I teach.

Two years later (fall 1992), Chris (the new newcomer) made a set of similar comments about the usefulness of being surrounded by more experienced community members. (By now Dorothy is an old-timer.) He stated:

> I basically wonder how I'm doing. I'm constantly looking to Dorothy, Heather, and Susan and Paul on how I'm doing. They're the people that have the most basic, the most similar knowledge. . . . That's the only way I get a decent base about how I'm doing–is to be in contact with where they are, (with) what they're doing. . . . I just have no idea how it's going, if I don't. They're my

> baseline. ... And not that anybody says, "Do it this way." People say, "Well, this works this way for me. Try it." And (it) doesn't mean I follow it. ... It's a good rule of thumb.... I make my own decisions from it. ... If I didn't have that, I would be, I think, completely in the dark about how it's going.

Lave and Wenger portrayed learning in a community of practice as engagement in "a common, structured pattern of learning experiences without being taught, examined or reduced to mechanical copiers of everyday ... tasks" (p. 30). Even considering only the teaching aspects of the Portsmouth teachers' lives as shown on Table 1.1, a common pattern of engagement—gradually moving newcomers to more difficult and fuller forms of participation—can be discerned. Moreover, the previous quotations suggest nothing of being taught, examined, or reduced to mechanical copiers. Rather, they point to ways in which being a member of a community of practitioners provides meaning and context to a newcomer's learning experiences. Old-timer colleagues provided concrete suggestions about how classroom situations might be handled, always being careful to qualify those suggestions as something that worked for them not as prescriptions. In addition, conversations with the old-timers provided benchmarks—ways of gauging performance—as newcomers compared what they are doing and where they are in the curriculum to what their old-timer colleagues are doing and where they are. Finally, the old-timers provided the kind of encouragement that only someone who has been there can provide.

The Development of Identity

As peripheral members of a community, newcomers are exposed to much more than the community's cognitive activities. They also learn about what life is like in the community, what members do, how they talk, and what they value. As newcomers become more experienced and move on to positions of greater responsibility, they develop not only the requisite cognitive skills, but also the attitudes, motivations, and values of those around them. Individuals are seen to learn tasks hand-in-hand with the development of a sense of identity:

> As an aspect of social practice, learning involves the whole person; it implies not only a relation to specific activities, but a relation to social communities—it implies becoming a full participant, *a member, a kind of person*. In this view, learning only partly—and often incidentally—implies becoming able to be involved in new activities, to perform new tasks and functions, to master new understandings.... Viewing learning as legitimate peripheral participation means that learning is not merely a condition for membership, but is itself an evolving form of membership. We conceive of identities as long-term, living relations between persons and their place and participation in communities

of practice. Thus identity, knowing, and social membership entail one another. (Lave & Wenger, 1991, p. 53; italics added)

Placing the study of teacher development in a community of practice framework implies that motivation to learn is tightly tied to teachers' views of themselves as aspiring members of a reform mathematics community. The process of becoming part of the community is seen to be intrinsically motivating because it "confers a sense of belonging" (p. 111). As newcomers invest the increasing amounts of time, resources, and energy that are necessary to move toward full participation, they are simultaneously developing new knowledge and skills and, "more significantly, an increasing sense of identity as a master practitioner" (Lave & Wenger, 1991, p. 111).

Lave and Wenger suggested that language, especially storytelling, can play an important role in the process of learning and identity formation. The ways in which storytelling can support the formation of identity have been extensively developed by Cain (as cited in Lave & Wenger, 1991). After detailed study of an Alcoholics Anonymous (AA) community, Cain proposed that a major feature of successful learning in that community involves listening to old-timers' stories of personal transformation and then gradually learning to tell one's own story of change. A significant aspect of these stories is their inclusion of concrete examples of what types of behaviors constitute alcoholism and what behaviors are necessary to qualify as staying sober. Cain argued that these understandings are vital to new members because a lack of widespread consensus in the larger society regarding the definition of *alcoholism* allows many problem drinkers to deny that they are indeed alcoholics. In the process of listening to others' stories and learning to tell their own stories, new members are also learning these principles of AA and how to interpret their own behavior (past, present, and future) in terms of AA principles. As such, a member's past identity as a problem drinker (a drinking nonalcoholic) is acknowledged and his new identity as a sober individual (a nondrinking alcoholic) is gradually formed and strengthened.

Parallels between learning and the process of identity formation in an AA community and learning in a reform mathematics community can be drawn.[8] Newcomers to a community of inquiry-oriented mathematics teachers also listen to old-timers' personal stories of how they used to teach in a drill-like fashion as opposed to how they now teach for mathematical understanding. In these stories, newcomers can begin to catch glimpses of important as-

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[8]We were drawn to make these parallels because of similarities between (a) certain attributes of the two communities' tasks (i.e., they involve deep-seated changes in individuals for which they do not necessarily receive support from the society at large), and (b) the function that storytelling might serve in the two communities. Obviously, we do not mean to imply that the content of the problems faced by alcoholics and mathematics teachers is the same.

pects of the community's pedagogical philosophy and practices. Deeply embedded in context, these glimpses carry important messages regarding the forms of pedagogy that are valued by the community. This is important because, similar to the vague nature of criteria for alcoholism, criteria for what constitutes reform mathematics pedagogy may not be straightforward or unambiguously accessible in the wider culture of mathematics reform (see earlier discussion of the tentative nature of the instructional specifications for the reform vision). For newcomers, then, it is crucial that they gain access to concrete examples within their community of how to think about mathematics, how to plan and organize their lessons, and how to listen to and build on their students' understandings. These examples are available in a highly contextualized form in the stories told by more experienced community members.

After the newcomer begins to form an understanding of his or her community's criteria for how the new pedagogy differs from the old, he or she must learn how to relate these criteria to his or her own teaching. As the teacher learns to interpret the events of his or her teaching life in terms of these criteria and to tell his or her own story, he or she is concurrently building up an identity as a practitioner of reform mathematics and a knowledge base of criteria for pedagogical practice. As with the reformed alcoholic, success comes when the newcomer has learned to define him or herself with respect to the values and practices of his or her community.

Identity and Storytelling at Portsmouth

This discussion of identity and motivation suggests that places and times in which stories are told, both formally and informally, may be fruitful locations for data collection and analyses. Evidence suggests that two contexts for storytelling at Portsmouth—the telling of war stories[9] *within* the community and the delivery of formal presentations *outside* the community—each played an important role for the listener, speaker, and community.

Storytelling Within the Community. During their many hours of interaction, the Portsmouth teachers heard and learned to tell numerous stories about their work and their transformation from skills-oriented to inquiry-oriented teachers of mathematics. Although the QUASAR Project did not systematically collect data on storytelling per se, examples of storytelling came readily to the minds of researchers familiar with the site. For example, by the summer of 1992, the following war story had attained the status of community lore. In the transcript that follows, Dorothy was actually retelling

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[9]Lave and Wenger used the term *war story* to describe a personal account of an arduous, but illuminating, work-related experience.

(for the third time that the researchers knew about) the by-then famous story of her difficulties in learning to use student portfolios:

> The other thing that occurred was to describe my portfolios as "piles of files." And I found it just absolutely insurmountable. They were at my home, they were in my room. And I tried to fool people by always carrying my target portfolios and making sure that everything was filed in those because every time we went to a meeting we were supposed to bring portfolios. Those six portfolios had everything in them and the others were just spread everywhere. . . . It also made it very hard for me to use them as a grade at that point too. Then I was doing all right. I was able to handle those meetings and kind of hide my files. And then we had an inservice day that is now known as *the meeting.*
>
> At the meeting we were asked to, of course, bring our portfolios, only we were asked to bring a whole crate. That was really hard for me because by then mine were no longer in crates. They were piles of files. But I put some together and brought them. And our activity was to go through some files and then pick a kid and sit down and write a letter to a parent describing how/what the student had learned by looking at the portfolio. I mean, I looked through it—what I wanted wasn't there. And I became more and more upset, and other people were madly writing, and I was sitting there, and finally I just like threw everything up and cried. It was being videotaped. But I like to think I cried for everyone that day. And I was then told, "Hey, you do what you can do." And if it had been a (inaudible) or a fad diet, you know what I would have done: gone off it completely. But they told me to do what I could do, but they also kept me in the position of—I still brought my portfolios places. And I wasn't allowed to give up. And I'm glad I wasn't because I've made a lot more progress with portfolios than I have with (inaudible) or fad (diets).

From a community of practice perspective, what purpose did this story serve? Lave and Wenger's ideas would suggest that the community benefited because the story supported a "communal form of memory and reflection" (p. 109). Community members were all highly familiar with this story and cited it often. Newcomers benefited as well. According to Lave and Wenger, in the process of listening to war stories, newcomers learn knowledge and skills valued by the community, they learn the art of war-story telling, and they become legitimate participants in the community of practice. Embedded in Dorothy's story were some of the community's criteria for what constitutes a valid portfolio system: They must be more than piles of files; they must be well organized and maintained if one expects to be able to use them to assign a grade; and they should provide the kind of evidence that will allow description of what a student has learned mathematically. Also available to the motivated listener was a personal tale of the trails and tribulations of transforming to a reform teacher of mathematics. The inspirational message is: Although the odds may appear insurmountable at times,

TABLE 1.2
Presentations in Which Portsmouth Teachers Participated

Teacher	*1989–1990*	*1990–1991*	*1991–1992*	*1992–1993*	*1993–1994*
Paul Griffith	2–P *	P	P		1–P
Dorothy Geary		*	2–P	2–P	3–P
Heather Nelson		P	P *	2–P	4–P
Susan Albright			*	P	4–P
Chris Wickham				*	
Rob Gibson-Cairns					*

*Indicates the first year a teacher taught the Visual Mathematics curriculum at Portsmouth Middle School.

don't despair; others have felt that way, too. If you keep trying, progress will come.

Storytelling Outside the Community. Storytelling also occurred more formally outside the community in the form of presentations at national meetings (NCTM, NMSA), local conferences, and district-sponsored workshops. Table 1.2 presents an overview of the involvement of Portsmouth teachers in such activities.

Examining the pattern of presentations as related to newcomer/old-timer teacher status reveals a rough correspondence between storytelling outside the community and degree of status within the community. As individuals gained more status within the community, they were more likely to present to others who were not members of the community. This trend is especially evident for Susan and Dorothy.[10]

The correspondence between status within the community and presenting outside the community was noted in the case of AA communities of practice (Cain; cited in Lave & Wenger, 1991). The first time a recovering alcoholic formally tells his or her story to a potential newcomer constitutes an important step in gaining membership within the community. It is the first time that he or she feels that he or she "belongs enough to carry the message" (Cain; cited in Lave & Wenger, 1991, p. 82). A review of the outlines of the Portsmouth teachers' presentations provides information regarding the content of the message that was being conveyed. The teachers' presentations were often of a personal nature, chronicling their struggles as they attempted to revamp their practices. For example, the title of a fall 1993 workshop given by Heather, Dorothy, and Susan was "How to Do Perform-

[10] The reader is reminded that, because of her previous experience, Heather entered the community with an old-timerlike status.

ance Assessments and Still Have a Personal Life." Although the majority of the presentation consisted of mathematical ideas and examples of performance assessments that the teachers had developed, there were also many references to how things used to be in the old days, their many missteps and misgivings as they were initially designing the assessments, and their arrival at a new place where assessments were working for them without taking an undue amount of personal time.

From a community of practice perspective, what purposes were served by such a presentation? The personal nature of many of these presentations suggests that the teachers used them as a vehicle to help them construct a new identity for themselves. In the process of preparing for and delivering the presentations, the teachers reinterpreted the events of their lives in terms of important features of the new mathematical pedagogy that they were creating. They were developing a new way of seeing themselves as master practitioners of reform mathematics.

Of course these personal stories are also useful to the audience as well as to the person constructing them. Despite academicians' skepticism of anecdotes as convincing evidence of change in practice, personal accounts of journeys from conventional to innovative practice can be effective for teacher audiences if they provide concrete examples to which other teachers can relate. As with drinking alcoholics, procedurally inclined audience members may find so much of themselves in the conventional portrait that they are led to ask, "Is my way of teaching outmoded, or, worse yet, failing to prepare my students?" The frustrated reformer may find much of him or herself in the early struggles of reform work and be led to console him or herself, "A little more effort, changing this piece in this way might help." In fact, personal stories may be a particularly effective manner in which to convey principles of mathematics reform because most publicly sanctioned definitions are fuzzy; buzzwords with various personal interpretations abound. A contextualized story has a better chance of hitting home by providing a set of criteria by which to recognize conventional as compared with reform practice.

Finally, how can learning to tell personal stories motivate and assist the learning process of newcomers? Before presenting their own stories formally, newcomers at Portsmouth had many opportunities to hear the stories of old-timers around them and begin to formulate their own personal stories. For example, during Susan's first year in the community, she attended all of the monthly staff development meetings, all of the after-school and summer teacher meetings, and was part of untold numbers of informal discussions. In the process, she heard many war stories. The spring of her first year at Portsmouth, Susan attended the national NCTM meeting but did not make a presentation. Rather she sat in the audience as her old-timer colleagues presented.

What was being learned through this process? A community of practice perspective suggests that Susan was learning how to talk as a member of the community and learning what it means to be a practicing member of the Portsmouth community of mathematics teachers. As she listened to stories of the old-timers around her, she began to understand the pedagogical philosophy and instructional approach that they were in the process of constructing. Examples of the developing philosophy were embedded in their personal accounts. For example, Dorothy's war story (detailed earlier) contained important pieces of information regarding key elements of establishing a valid portfolio system.

Extending the parallel to the AA community would suggest that Susan was also learning what episodes of her work could reasonably serve as evidence of the new pedagogy. During the monthly meetings, she would have had opportunities to try out pieces of her story, first in response to something she might have heard from an old-timer (e.g., "oh yeah, something similar happened to me") and then by her own initiation. In the process, Susan learned to interpret and reinterpret aspects of her own past and present teaching life in terms of the new pedagogy, gradually developing her own identity as a member of that group. Speaking formally about her practices and development as a reform teacher would be considered a demonstration that she could do it and would herald her arrival at a particular status within the community. Indeed this did occur. As shown in Table 1.2, Susan made one formal presentation during her second year in the project and four during her third year. Near the end of her third year, Susan was invited to do a presentation at an international conference on classroom assessment. Although Susan had previously collaborated with colleagues on assessment-related presentations, this marked the first time that Susan's individual expertise and status were recognized.

CONTRIBUTIONS OF A COMMUNITY OF PRACTICE PERSPECTIVE

The introduction to this chapter argued that a new way of viewing teacher education as the building of communities of collaborative, reflective practice was needed. In this concluding section, the contributions that a community of practice framework can make toward increased understanding of how teacher learning occurs in such settings are discussed. The contributions fall into three broad areas: providing a model that integrates social interaction with the analysis of learning, broadening the scope of vision regarding the sources (or settings) for teacher learning, and providing an integrated way of thinking about motivation and learning. Each of these is discussed, contrasting the community of practice approach with more conventional approaches where appropriate.

From Individuals to Communities

Conventional ways of viewing teacher development take the individual teacher to be "the nonproblematic unit of analysis" (Lave & Wenger, 1991, p. 47). Although never explicitly stated, this assumption underlies most lines of research on teacher development, including the expert–novice teacher literature (e.g., Leinhardt, 1989), the teacher socialization literature (e.g., Lacey, 1977), and studies on teachers' ways of knowing (e.g., Calderhead, 1988). In addition, most current studies are heavily influenced by cognitive psychological theory—an approach that views learning as consisting of changes in the ways knowledge is structured and represented in individual teachers' minds. The goal of most analyses conducted within a cognitive psychological framework is to trace concomitant changes in the individual teacher's knowledge, beliefs, and instructional practice.

Increasingly, the teacher development literature is becoming sensitive to the social context within which teacher learning occurs. Changes in teachers' knowledge, beliefs, and instruction are often placed in the context of staff development efforts and/or the school settings in which teachers work. However, these contextual features of teacher development are often portrayed as a stage on which teacher thought and action are enacted; that is, contextual detail remains static and noninteractive with the analysis of learning. Highlighting the nonintegrative nature of such analytic methods, Lave (1991) referred to them as *cognition plus* approaches.

Within mathematics education, the tendency to focus on teachers as individuals is readily apparent in the recent wave of teacher change and learning-to-teach studies: the case of Ms. Daniel's journey from college preparation to her initial years of teaching (Borko, Eisenhart, Brown, Underhill, Jones, & Agard, 1992), the series of case studies of California teachers as they attempt to make sense of the reform framework (Ball, 1990; Cohen, 1990; Heaton, 1992; Peterson, 1990; Prawat, 1992; Prawat, Remillard, Putnam, & Heaton, 1992; Putnam, 1992; Remillard, 1992; Wiemers, 1990; Wilson, 1990), and the set of cases of experienced teachers' transformations after their exposure to constructivist philosophy in SummerMath for Teachers (Shifter & Fosnot, 1993). All of these investigations focus on the individual teacher as the unit of analysis. Although each provides important information about the social context of teacher development, contextual detail is treated more as a catalyst for (or barrier to) the change process, rather than as an integral feature.

By contrast, Lave and Wenger's model provides a way to integrate context and learning. Rather than treating teacher collaboration as a noninteractive and unarticulated context variable that provides a backdrop to the individual change process, learning is viewed as an emergent property of participation in communities of practice. More specifically, social context is concretized as the work patterns of the community; learning is seen to occur through increasing engagement in these practices. As such, the learning of knowledgeable skills is inherently tied to the social situations in which individuals participate. This framework has been applied to the study of individuals developing into competent teachers of mathematics. As such, teacher learning has been situated within the fields of interaction among teachers as they engaged in a variety of work practices related to the reform of mathematics instruction.

Multiple Sources of Teacher Learning

Another important effect of using this framework has been the expansion of the boundaries surrounding what is considered to be a source of teacher learning. Within mathematics education, the sources of teacher learning have often been quite limited. For example, most of the research that has focused on the learning processes of novice teachers has focused on one source—the teacher education program—as the wellspring of teacher learning (e.g., Borko et al., 1992; Eisenhardt, Borko, Underhill, Brown, Jones, & Agard, 1993; National Center for Research on Teacher Education, 1988; Schram, Wilcox, Lappan, & Lanier, 1989).[11] Most research on veteran teachers has placed a great deal of emphasis on the content and form of staff development experiences as the source of teacher learning (e.g., Simon & Shifter, 1991). Although both of these types of investigations have yielded important insights into possible connections between teacher learning and pedagogical experiences intentionally designed to educate teachers, they may not be capturing the whole story.

Examining teacher development from a community of practice perspective leads to a focus on the learning processes of teachers, not on pedagogical structures for teaching teachers. Lave and Wenger (and other sociocultural theorists) argued that learning occurs all the time regardless of whether explicit teaching events have been arranged. Individuals learn by participating in the day-to-day activities of community members around them:

> . . . this viewpoint makes a fundamental distinction between learning and intentional instruction. Such decoupling does not deny that learning can take place where there is teaching, but does not take intentional instruction to be in itself the source or cause of learning. . . . (p. 41)

Hence, the focus of analysis shifts away from pedagogical activity and toward an analysis of the structuring of the community's work practices and

[11]Although Ball (1988) proposed that teachers develop knowledge of and about mathematics from their experiences as students (K–12), no serious analyses that we know of have been done on teachers' experiences as students as a source of teacher learning.

learning resources. Lave and Wenger referred to this as the *learning curriculum*—that is, a sequence of learning opportunities that are driven by the ongoing work practices of the community. In other words, the curriculum is the practice of the community; learning is conceived as changes over time in social participation patterns in the work of the community.

This new perspective of learning as inseparable from social practice suggests that we need to broaden our view of what constitutes sources or opportunities for teacher learning. At Portsmouth, we widened our lens to include a host of activities in addition to those that would have been featured in more conventional analyses of teacher learning. Many of these activities occurred during times that teachers met informally and/or gathered to do the work of the project. As such, they shared the characteristic that they were not intentionally designed by a teacher educator or staff developer as an educational experience for the teachers. Rather, they were occasions during which the teachers worked together to accomplish something about which they all cared. Sociocultural theorists call such work *joint productive activity*, meaning that individuals came together with a shared goal and worked toward a joint product that was meaningful to all participants. According to sociocultural theorists, these occasions are fertile grounds for learning because individuals bring different levels of expertise and varying perspectives to the work. With high levels of motivation, participants use their differing perspectives and ability levels to move forward and learn.

The depiction of assistance activities in Fig. 1.1 tends to hide these occasions of joint productive activity. However, a number of types of ongoing community activities at Portsmouth had the characteristics of joint productive activity. These included sustained efforts to increase parental knowledge of and involvement with the mathematics program, ongoing work to adjust and augment the VM curriculum, the development of an assessment system, and efforts to build bridges between the middle-school program and the mathematics programs in the elementary and high school grades in their district. These work activities represented opportunities for newcomers to work side by side with old-timers. Although old-timers took on the most time-consuming and difficult aspects of the work, newcomers were most always present during meetings, planning sessions, and postwork events. This provided newcomers with the opportunity to gain varied views of what old-timers cared about and why. It also allowed newcomers to contribute to the community's work in peripheral, yet relevant ways.

Thus, a community of practice perspective has served to highlight a new set of activities as opportunities for teacher learning—activities that might otherwise have been overlooked or given only minor status. Before our acquaintance with the theoretical construct of legitimate peripheral participation, we often described these nonteaching settings as *informal learning* *opportunities*, although we grew increasingly dissatisfied with this view of them as ancillary, second class, and not integrated into a full explanation of teacher development. Legitimate peripheral participation has provided a framework for integrating these experiences into an overall explanation of teacher learning.

Learning and Motivation

A third contribution of the community of practice framework is the manner in which it has encouraged us to think about and explain motivation for teacher change. Consideration of the motivational processes that accompany teacher learning is absent or underdeveloped in most accounts of teacher development (Goldsmith & Schifter, 1993). How do teachers become motivated to undertake the difficult, time-consuming work of learning new skills or replacing old skills with new ones? As a research community, we have few theoretical frameworks for explaining the sources and mechanisms of ongoing motivation for teacher change. Most appeals to motivational processes focus on motivation as a catalyst or initial prompt to change. For example, constructivist theories of learning suggest that individuals become motivated to change when their customary ways of performing no longer work. The disequilibrium produced when old, ill-fitting structures are imposed on new challenges propels people to reorganize and develop new modes of thought and action.

Lave and Wenger argued that most frameworks for understanding motivation and learning, including constructivism, impose an artificial boundary between the whole person (and his or her goals/motivation) and the learning of knowledge and skills. They argued that, in the final analysis, all conventional learning models rely on the learning mechanism of internalization. This places a disproportionate emphasis on cerebral activity and reduces the learner to a set of cognitive structures and processes. The whole individual, and his or her relations to the world, they argued, is strikingly absent.

This internalization mechanism appears to underlie the way in which teacher development is characterized within mathematics education as well. The *stuff* to be learned includes such things as mathematical concepts and skills, how students learn mathematics, new ways of thinking about what constitutes mathematical activity, new pedagogical forms, the NCTM Standards, and so on. Concordantly, we measure the effectiveness of change attempts by the extent to which teachers appeared to have internalized the to-be-learned knowledge and skills. References to affective dimensions of teacher development are typically limited to variables that are tightly tied to pedagogical philosophy, mathematical knowledge and beliefs, and confidence in self as teacher (e.g., Stein & Wang, 1988; Thompson, 1992). Rarely do investigations expand to include affective attributes of the teacher as a whole person beyond his or her role as a teacher.[12]

Within the community of practice framework, motivation is tightly tied to one's view of oneself as becoming a member of a community. This is seen to involve the development of an identity as a master practitioner. Few, if any, studies of teacher development have examined if or how successful teachers develop identities as master practitioners of inquiry-oriented mathematics. As the challenges of mathematics reform have become more clear, however, consensus has grown regarding the profound nature of the change that is demanded of teachers. Cohen and Ball (1990) aptly captured the complexity and difficulty of changing one's pedagogical approach with the phrase, "changing one's teaching is not like changing one's socks" (p. 163). Indeed, the reform movement challenges most ways that the majority of teachers have come to view themselves and their role in the teaching and learning process. Hence, viewing the transformation from a skills-oriented to an inquiry-oriented teacher as a journey involving personal identity development is quite appropriate.

This chapter provided examples of ways in which the process of identity formation was facilitated through the telling of stories both within and outside of the reform teacher community at Portsmouth. Heretofore dismissed by most researchers, storytelling by and for teachers has been shown to be an important vehicle in teachers' learning processes. Our analysis and the resulting understandings lend insight into how motivation for the long, hard work of reform might be initiated and sustained.

CODA

The purpose of this chapter was to examine the utility of *communities of practice*, as proposed by Lave and Wenger, as a theoretical framework for describing how teacher learning occurs in collaborative, school-based communities. Toward that end, several features of teacher learning in collaborative settings have been highlighted: the importance of participation and access to all forms of practice, the multiple sources of learning opportunities in school-based collaborations, and the manner in which language and storytelling can foster motivation, development of identity, and learning of knowledgeable skills.

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[12]Exceptions are studies conducted within the framework of adult development—studies that build on developmental psychological stage theory (e.g., Oja, 1980; Sprinthall & Thies-Sprinthall, 1983). In this line of work, teacher development is charted in relationship to growth in major personality variables such as ego strength and moral development.

The work in this chapter represents a beginning. The examples that have been provided from the Portsmouth community may or may not be representative of teacher learning in other school-based reform efforts. The Portsmouth community benefited from a number of conditions that made it possible for a reform community to thrive. An analysis of these conditions (perhaps by contrasting Portsmouth with a school-based reform effort that failed to thrive) would be necessary to identify those factors associated with the successful establishment of reform mathematics communities. Also needed are analyses of how communities evolve in response to larger social, institutional, and historical conditions. The Portsmouth case has been presented as an established and somewhat static community that, of course, it is not. Additional analyses would lend insight into forces that are interacting with the community and thereby continually altering its shape, form, and function.

The work in this chapter represents a beginning in another important way. The purpose was not to replace conventional, individualistic forms of analyses with a sociocultural analysis. Rather the goal was to illuminate areas of the teacher development landscape that, although becoming more prominent in current reform efforts, have tended to remain in the shadows with more traditional methods of studying teacher development. As conceptions of the nature of teaching continue to evolve to include the norms of collaboration and contexts such as school-based decision making, the ideas and approaches suggested by sociocultural theory in general and a community of practice framework in particular should become increasingly relevant. Nevertheless, various approaches highlight different features and hence bring different strengths and weaknesses to the task of understanding teacher development. The challenge is to use the various approaches in appropriate ways and, ultimately, coordinate them in a manner that leads to a fuller, deeper explanation of teacher development within the context of mathematics reform.

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CHAPTER

2

STUDYING TEACHING AS A THINKING PRACTICE

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In popular images of thinking practices, we imagine practitioners working together on problems, developing shared vocabularies to make assertions about how to solve them, and using agreed-on rules of evidence and modes of reasoning to resolve disagreements about what is good, true, and right. We believe that if young people are to learn what subjects like mathematics are all about, they too should engage in collaborative work on problems, develop a meaningful vocabulary for proposing solutions, and defend their reasoning in a community of peers. These aims raise questions about who should teach these practices and how they should be taught. Does one learn to do mathematics from doing it with others? Are there ways to communicate about the doing that make it possible to understand practice from the outside? Raising these questions takes us quickly to the question of what schools are for and what people who teach in them should know.

I come at these questions from three distinct but related perspectives. For one, I am a teacher of elementary mathematics in a public school. What of mathematics should I be teaching? How should I be teaching it? What of mathematics do I need to know to teach it? For another, I am a teacher educator in a university, responsible for preparing novices to enter the profession. In this role, the same questions arise, here in relation to pedagogy: What should I be teaching? How should I be teaching it? What of pedagogy do I need to know to teach others to teach? My third perspective is that of a scholar: I study teaching as a practice and attempt to communicate the findings of my studies to others. In this role, I also teach others what I have learned.[1] From all three perspectives, I am faced with trying to understand the intricate relationships between doing and knowing, knowing and teaching.

As a teacher who is also a student of teaching practice, I work on pedagogical problems, develop a vocabulary with which to make assertions about how to formulate and solve them, and invent rules of evidence and modes of reasoning to support my arguments. I structure my work with others, both teachers and scholars, so that I have opportunities to engage in collaborative work on problems, develop a meaningful vocabulary for proposing solutions, and defend my reasoning in a community (Heaton & Lampert, 1993, Lampert & Ball, in press). In these ways, my work as a teacher shares certain features of the thinking practices around which this symposium was organized. As I am often reminded, I am not—by current standards, anyway—a typical teacher. More common in teaching is the individual practitioner who reasons privately about what is good, right, and true often while fending off the barrage of pedagogical solutions that are promoted by teacher educators, policymakers, curriculum developers, researchers, and administrators. The image is one of insiders who do teaching and outsiders who believe they know something that teachers should know and do.

This chapter examines the dichotomy between insiders and outsiders and considers why it might make sense. It also explores the notion—perhaps romantic—of a place somewhere in between inside and outside where communication about the nature of practice might occur. I move between questions about school learners acquiring knowledge of practices like mathematics and school teachers acquiring knowledge of teaching. I look at historical efforts to address the problem of communicating about practice and its products in mathematics and at how this problem was addressed by my own education as a teacher. I consider whether it is my unusual approach to combining teaching and scholarship—being a university professor who teaches fifth-grade mathematics—that leads me to view teaching as a thinking practice, or if teaching should be so regarded in more typical kinds of situations. Threaded through my examination of the problems that arise in my own efforts to study and communicate about practice are more general questions about communication among practitioners and between practitioners and nonpractitioners. Through all of this, I beg the reader's indulgence as we take a tour of my particularly peculiar hall of mirrors.

THE PARADOX IN KNOWING PRACTICE

Toward the end of the "Thinking Practices" symposium, Leigh Star (chap. 5, this volume) posed a challenge to the participants: Do research and know

[1]Throughout this chapter, I use *teach* and *communicate* interchangeably.

its outcomes in a way that incorporates the personal. She called this: "getting the self into science." She reminded us of the tension between the messiness of persons doing research and the clean-cut products of research. My writing and talking about teaching over the past 10 years has been an attempt to bring the persons who do teaching and learning and the messiness of their everyday work into the academic conversation about the nature of practice. In 1985, I wrote,

> The teacher's emphasis on concrete particulars in the description of a classroom problem distinguishes the perspective of practice from the perspective of the theory builder. This distinction has received considerable attention in the literature on teaching.* Another fundamental though less familiar difference involves the *personal quality of teaching problems as seen through the eyes of a practitioner.** Who the teacher is has a great deal to do with both the way she defines problems and what can and will be done about them.* The academician solves problems that are recognized in some universal way as being important, whereas *a teacher's problems arise because the state of affairs in the classroom is not what she wants it to be*. Thus, practical problems, in contrast to theoretical ones involve someone's wish for a change and the will to make it.* Even though the teacher may be influenced by many powerful sources outside herself, the responsibility to act lies within. Like the researcher and the theoretician, she identifies problems and imagines solutions to them, but her job involves the additional personal burden of doing something about these problems in the classroom and living with the consequences of her actions over time. Thus, by way of acknowledging this deeply personal dimension of teaching practice, I have chosen not only to present the particular details of [other] teachers' problems, but to draw one of these problems from my own experience. (Lampert, 1985, p. 180; italics added)[2]

In writing about my own teaching and the practice of other teachers from the perspective of practice, I have been attempting to do what Star called "getting the self into science." I have done this because my analysis of the work of teaching suggests that the teacher's self is one of the tools of the trade or, as James Garrison (1995, p. 3) put it, "the teacher is the most fundamental technology in educational practice."

Studying practice from the perspective of *my* practice means that what I know is lodged in a place both personal and public. This place—between the inside and outside of practice—is where I locate myself in the study of teaching. It is also where school learners are located in their study of mathematics. The goal of their doing and studying these practices in school is to learn the relationship between creating knowledge and solving problems by creating knowledge and solving problems themselves. One goal of educational research, perhaps well served by research like mine that takes

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[2]See original for footnotes.

a personal perspective of practice, is to better understand the relationship between creating knowledge and solving problems in schools.

School learners, studying mathematical or scientific practice, and I, studying teaching practice, have two different kinds of audiences or communities of study with whom we might communicate. One is local: the teacher and the other students in the class for school learners, the other teachers in my school for me. In these local settings, we can see what one another is doing and how it changes as we learn new things. These communications can be a regular part of practice and sometimes they are even required to get the work done. The other kind of communication my students and I must engage in is public. I want parents, employers, and taxpayers to know what school learners in my classroom are learning without having to watch them do it. I want other teachers, policymakers, and researchers to know what I am learning about teaching without requiring them to visit my classroom. In communicating between the personal and the public, one moves out from the work of the practice and into another kind of work. The public cannot simply see what we do and learn. For school learners, educators struggle to invent performance evaluations and portfolio assessment to address this problem.[3] Teachers who write about their own teaching labor to find a voice, language, genre, or way of talking and writing about what we know that is not simply borrowed from more specialized academic discourses (Cochran-Smith & Lytle, 1993; Fleisher, 1995; Richardson, 1994). Why is it so hard?

Practitioners who remain on the inside of their practice do not need to face this communications problem; the messiness of practice is part of what they expect to communicate about in doing the work. Outsiders do not need to face it either. Commonly, all that outsiders want to know of scientific work are its impersonal products. They can often use the products of practice without appreciating the processes of knowledge production. If one wants to know about the knowledge-producing practice, in addition to knowing about the products of that practice, the tension cannot be ignored. If one wishes to be both on the inside of practice doing it and on the outside communicating with others about it, the tension is central. When questions about knowing or understanding practice are juxtaposed with questions about teaching and learning practice, we must acknowledge a paradox: If one learns a practice by engaging in a practice, one knows something that nonpractitioners do not know, but what is known cannot be taught except to other practitioners.

There seem to be two ways out of this paradox in contemporary writing about schooling. One way out is to embrace apprenticeship models of education and look to what ordinary folks do and know of mathematics. If

[3]The headline of a recent article in *Education Week* is telling: "Even as Popularity Soars, Portfolios Encounter Roadblocks" (Viadero, 1995).

we think of students' parents, neighbors, and teachers as folks who know what students need to know, then interacting with such people around math problems in an apprenticeship mode will get them the education they need. This approach has some merit, but avoids hard questions about equity and social mobility. When this resolution is applied to learning teaching, we have new teachers learning teaching from experienced teachers, leaving little room for innovation. Another way to circumvent the paradox of learning practice, and one that has been particularly common in K–12 schools, is to argue that what students need to learn is a better understanding of the extant products of practices like mathematics. The study of teaching, too, can be largely focused on the products of the inquiry of others and this is how it is often conducted in universities. Articles in research journals are amalgamated into textbooks for foundations and methods courses. From this perspective, what is to be understood is not the practice, but its products. It is assumed that these products are worth knowing, but the question of how they relate to being able to solve problems and create new knowledge remains unresolved.

A Historical, Mathematical Perspective on the Paradox

Arguments about whether one should engage learners in messy and creative disciplinary activities as a method of teaching them about the discipline are at least as old as the foundations of university education in the 16th century. At that time, instruction began to move away from having novices engage in disciplinary discourse as a method of education and toward lecturers preparing and publishing synoptic representations of knowledge in their fields and delivering them to learners (Ong, 1958). My research on teaching and my work as a teacher involves me in these arguments as I try to figure out how to represent my pedagogical and mathematical knowledge to nonpractitioners. From my perspective as a knowledge creator in the field of pedagogy,[4] I join company with scholars in many other fields who have tried to figure out how to communicate about what is known in their practice to people who are not their apprentices. As a mathematics teacher, I struggle with what and how to tell my fifth-grade students of what I know about mathematical practice and its products (cf. Chazan & Ball, 1995).

Some scholars have resolved these questions in favor of representing what is to be known as a formal synoptic framework rather than representing knowledge production as an activity engaged in by practitioners (e.g., Floden & Klinzig, 1990). As a result of their influence on university level mathematics instruction, for example, the textbook is generally accepted

[4]For the purposes of this chapter, I leave alone the question of whether I am also a knowledge creator in the field of mathematics.

what is taught and learned. When two former calculus students meet and want to size up one another's competency, for example, the name of the textbook they used is an acceptable shorthand for describing what math knowledge they have in common. Typically students judge the quality of one mathematics course in comparison to another by asking "how far they got in the book," assuming that the chapters of the book are a linear representation of the important ideas taught and learned in the course.

This contemporary set of standards for measuring knowledge in mathematics was strongly influenced earlier in this century by the Bourbaki project. Bourbaki established the foundations of modern mathematics in the 1930s. According to its authors, this work was carried out in the hopes of "putting into the hands of future mathematicians an instrument which would ease their work and enable them to make further advancements" (Cartan; cited in Steiner, 1984, p. 9). The Bourbaki project had a fundamental influence on mathematics education at the university level and was the inspiration for the new math movement in elementary and secondary education. I consider it here because the way in which the Bourbaki project was conceived starkly illustrates the paradox in communication between insiders and outsiders to a practice.

The members of the Bourbaki project asserted that the changes in mathematical practice that had caused what they were doing to be called *modern*—changes in how one might reason about mathematical questions and what counted as evidence in a mathematical argument—were not being reflected in the material taught to university students. They decided to write a new and definitive text, laying out all of what was known in mathematics at the time. In the process of producing their *Elements de mathematique*, the Bourbaki group came to define what was meant by *axiomatics*. They reified the nature of mathematical structures by formalizing the process of establishing abstract mathematical certainty. To teach others about the creation of new ideas in mathematics, Bourbaki did not propose a system of apprenticeships, but rather the collection and organization of mathematical truth represented in terms of logical and coherent connections among pieces of the whole.

Making a slippery distinction between inventors and teachers of mathematics, Bourbaki asserted that this approach was required because the professors who were to teach modern mathematics to future mathematicians were not as gifted as the creators of these new ideas. The Bourbaki project maintained that its members had the authority to communicate mathematics by synthesizing it into an expository form, and professors could share in their authority by using the synthesis as a guide to what should be taught. As Dieudonne (a Bourbaki project member) commented,

> Communication between mathematicians by means of a common language *must* be maintained ... and the transmission of knowledge cannot be left ex-

> clusively to geniuses. In most cases it will be entrusted to professors.... As most of them will not be gifted with the exceptional "intuition" of the creators, the only way they can arrive at a reasonably good understanding of mathematics and pass it on to their students will be through a careful presentation of the material, in which definitions, hypotheses, and arguments are precise enough to avoid any misunderstanding, and possible fallacies and pitfalls are pointed out whenever the need arises.... It is this kind of expository writing that has been, I think, the goal of those mathematicians [called] "formalists" from Dedekind and Hilbert to Bourbaki and his successors. (cited in Steiner, 1984, p. 10)

Dieudonne did not assume that mathematical geniuses had either the time or the talent to communicate what university students need to know.[5] He asserted that they were not skilled at the kind of expository writing that can be understood by nonpractitioners.

Not all writers of mathematics textbooks assume that definitions, hypotheses, and arguments should be presented to new learners in formal and precise terms. Some current reforms of mathematics teaching at the university level involve even nonmajors in research apprenticeships with mathematicians. A widespread new program for teaching beginning calculus is based on a problem-driven pedagogy derived from the principle that "formal definitions and procedures evolve from the investigation of practical problems" (Hughes-Hallet et al., 1992, p. v). Contemporaries of Bourbaki also took this route. For example, Clairaut (1920) rejected the axiomatic theorem-proof presentation of mathematical knowledge and asserted in the preface to his text on geometry:

> If the first originators of mathematics presented their discoveries by using the "theorem-proof" pattern, then doubtlessly they did this in order to give their work an excellent shape or to avoid the hardship of reproducing the train of thought they followed in their own investigations. Be that as it may, to me it looked much more appropriate to keep my readers continuously involved with solving problems, i.e., with searching for means to apply some operation or discover some unknown truth by determining a relation between entities being given and those unknown and to be found. In this way, with every step they take, beginners learn to know the motive of the inventor; and thereby they can more easily acquire the essence of discovery. (cited in Steiner, 1984, p. 12)

The metaphor of a *train* that Clairaut (or perhaps Steiner in translating Clairaut) used seems somewhat inconsistent with Clairaut's purposes (i.e.,

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[5]Hans Freudenthal (1991) questioned whether the structuring of knowledge in the Bourbaki and other cases should be considered a creative intellectual act. His question has implications for how we think about what it means to be inside or outside of a practice structuring the knowledge of that practice. I do not take this question up here.

the inventor's thoughts might not be as linearly organized as a train). They might be organized more like a web or a traffic jam at the Place de La Concorde. Clairaut's emphasis here is on the genesis of knowledge and the flexible and dynamic process of linking ideas that support it. In using ideas to create new knowledge, the mathematician does not structure them in the same formal way that they would be structured for communication. In the process of the mathematician's learning something new, process and content are inextricably linked. What Clairaut called "the motive of the inventor" cannot simply be written down and learned from reading. Clairaut implied that mathematics cannot be adequately learned unless one is searching for and discovering mathematics in the process of working on problems. Clairaut's distinctions between creating and communicating mathematics are, like Bourbaki's, slippery. He asserted that the originators of mathematics are motivated to present their discoveries in a formal manner, but leaves the mathematics learner in the realm of "continuous involvement with problems."

Bringing the Paradox Home

From a pedagogical point of view, it is notable that Clairaut recognizes the potential hardship involved in following another's train of thought, even as he advocated that teaching and learning should engage students in that process. In my mathematics classroom, my students and I experience daily the hardships involved in following other students' trains of thought. I worry about representing what gets taught and learned in the continuous process of working on problems so that I can explain it to parents or teachers at the next grade level. When students are actively engaged in projects but do not seem to take away the mathematics the project was intended to teach, I tend toward despair and wonder if Bourbaki was right. Perhaps, as Dieudonne said of professors, I am not gifted with the capacity to appreciate mathematical invention and I would be better off communicating precise definitions, hypotheses, and arguments. At least the students would learn something and it would be something that their parents and future employers would recognize as knowledge.

I also find myself attracted to the approach taken by Bourbaki when I confront the problem of communicating what I know about pedagogy. I worry about how to prepare new teachers in the context of university courses or how to compose a 15-minute synopsis for an academic audience that communicates the results of my most recent inquiries into the work of teaching. When I try to represent what I know about practice to nonpractitioners in formal communications like academic journals and course syllabi, I wonder if I should be thinking in terms of the logical organization of findings I can contribute to the knowledge base. I look over the texts intended to be used in elementary mathematics methods courses and wonder if my students—engaged in investigations of the problems of practice—will be able to answer the questions at the end of the chapter. If they cannot and they do not do well on the test they need to take to get their teaching licenses, am I being a responsible teacher?

At the same time, I recognize that when one strives, as Bourbaki did, to make definitions, hypotheses, and arguments "precise enough to avoid any misunderstanding," the conversation moves away from knowledge of and for practice (cf. Clark & Lampert, 1986; Lampert & Clark, 1990). Perhaps because I am a knowledge-producing practitioner, I am inclined to follow the advice of Clairaut and engage my students in thinking with me about the problems of practice even though it is harder than crafting and delivering a good lecture. As my fifth-grade mathematics students and I struggle to follow one another's trains of thought, we simultaneously engage with big intellectual questions like: What makes a good definition? What happens if I change the conditions under which this problem needs to be solved? As my teacher education students and I strive to learn how to deal with problems in the classroom, we too enter this realm of exploring what it means to know something and wonder about how knowledge is related to action. How better to dig into these questions than to face them personally, head on?

Rather than trying to resolve these dilemmas to make the paradox of knowing practice go away, I have tried to understand why they arise in the first place and how they might be managed. Here I offer several alternative but related explanations of why I believe the paradox is here to stay in my own work. I also question whether it is similarly intractable in the case of school learners studying thinking practices in school.

Explaining the Paradox Part 1: The Problem of Belonging

Communication about any subject usually occurs within the boundaries of a discourse community. This community shares a sense of the meaning of the terms it uses to talk about common experiences, and it also shares standards about what is accepted as evidence for assertions. To belong to such a community, one makes a tacit agreement to use its syntax and semantics. As we move from beginning practitioners in a community of discourse to full-fledged members, we acquire and influence insiders' ways of thinking, talking, and knowing.

When we expect students and teachers in schools to learn and teach mathematics by doing it, we are asking them to adopt the insiders' ways of knowing, but not for producing new knowledge in the field. Students' and teachers' purposes in the classroom are different from scholars' and scientists' in the academy. At the same time that students are arguing about what knowledge is true or useful in relation to a problem at hand, they need to be acquiring a repertoire of the tools that professional knowledge makers have made available. On the one hand, they must be insiders to learn how to use these tools and why they are important. On the other hand, they must be outsiders, standing back as Bourbaki did, to connect their knowledge of the domain and communicate what they are understanding. We ask learners—both in school and teacher education—not only to know the practice, but to be able to represent what they know and connect their representations with those created by other communities of discourse.

To study teaching and teach it to others, I have had to learn more than how to teach. I have needed to invent and learn multiple discourses. Developing a voice with which one can speak to both practicing teachers and university researchers means accepting multiple standards about what counts as justification for the statements one wishes to assert and it raises difficult questions about how one's audience takes what is being asserted (Olson & Astington, 1993). It means both belonging and not belonging. I often feel like a two-way ambassador: I feel I need to know enough about the culture of the place I am living in to interpret the place I have come from to members of that culture and yet I do not belong to it. This holds whether I come from the school or from the university. I need to belong to both the school community and the university community and learn the terms of discourse in both. As in the language of a lifelong ambassador, what I am trying to say gets constructed in a form that is shaped by the history and politics of relationships between two distinct communities, making it seem that I belong to neither.

Do ordinary scientists and mathematicians both practice and try to study and teach others about their practice? We might find many examples of such practitioners with apprentices, but what of the effort to communicate practice to others whose educational intentions are more general? There are philosophers, sociologists, and sociolinguists who study and write about practices in disciplines like mathematics in which they are not practitioners. To what degree do we trust them to communicate the dynamic, messy quality of what goes on in practice, given that they are constrained by the frameworks and standards of their own fields? Journalists, too, purport to put us in practitioners' shoes or at least in their offices, but on what basis are they judging what matters about what is going on? These questions are relevant to me as I grapple with how to portray my teaching practice and they are relevant to all of us as educational reformers as we try to figure out what it is about the thinking practices we want students to learn in school and how they will learn it.

Explaining the Paradox Part 2: The Problem of Authority

That some people are teachers and others are learners implies that some people know something that other people do not. We commonly refer to those who know more as *authorities* on a given matter. If we want to learn about a practice, how would we identify someone who is an authority? How does one become an authority on practice? What are the differences between knowing more about how to do science or mathematics and knowing more *about* science or mathematics? Between knowing more about how to do teaching and knowing more *about* teaching? These distinctions are endlessly debatable. I speak about them here from my own position as one who claims to have some authority in the field of pedagogy.

Among teachers and school administrators, there is a deep and continuing ambivalence about looking to university researchers for knowledge that might be useful in practice. Teachers do not routinely read the scholarly journals where researchers report their findings. In fact, they find such journals to be almost incomprehensible and certainly not about the same endeavor in which they are engaged. At the same time, there is a kind of mystical reverence for this work—an admission that it must be done by people who are better educated, if not smarter. When one chooses to work in a school in the course of generating such knowledge, the ambivalences take on different forms, but they do not disappear.

As a practitioner who is also a university researcher, I find myself in the position of trying to establish the authenticity of my ignorance and puzzlement in the face of many teaching problems while needing to justify why I am a professor and teacher educator. Part of my role as a teacher educator is to communicate to my fellow and prospective teachers that teaching is a problematic and uncertain practice in which researchers' answers cannot simply be applied to practical questions.[6] Yet my partial presence in the school where I have worked (and the fact that I also spend part of my time working in a university) has meant that I have to face the question of what sets me off from the people who teach all day every day. I need to continually reconsider what it is that gives *me* the authority to write articles and teach the very courses that my school colleagues were required to take to get their jobs. If the quality that distinguishes me is something about knowledge, what is it that I know that they do not know? The questions that go through my mind, and are sometimes recited aloud by someone in my vicinity, go something like this: If you are smart enough to be a professor of education, why can't you figure out how to get everyone in your class how to understand fractions? or sit still through a 45-minute lesson? or participate civilly in a discussion with their peers?

This expectation that I can somehow solve the problems of practice because I am a researcher does not come only from my fellow teachers. Many researchers who come to visit expect to see perfect implementations of the latest theories of mathematics education, and they are often surprised

[6] There is, of course, an analogy here with what we want school learners to appreciate about problem solving in mathematics (see Lampert, 1990).

at the messiness of what actually occurs. In their world, teaching is the place where the knowledge they produce gets applied, and of course they assume that I possess the knowledge in question because I am a fellow researcher. So it is surprising to see a flawed case of reformed mathematics teaching. My conversations with them have an odd character because much of what I know about teaching is based on a different kind of evidence than what they know about teaching.

What I am describing here with regard to pedagogical knowledge is similar to the situation I put my fifth-grade mathematics students in when we work on problems like "how far does a car go in 10 minutes if it is traveling at a constant speed of 50 miles per hour?" without teaching them the formula for relating quantities of time, speed, and distance or even teaching them how to manipulate fractions with unlike denominators or carry out long division with remainders. A visitor to my classroom who observes a 10-year-old working hard to find the multiple of six that is closest to 50 by adding successive columns of six identical numbers might wonder if this student really should be in third or fourth grade rather than fifth. Yet when that student pauses from her labors and asks, "How many numbers *are there* between 8.3 and 8.4?", it is clear that she is doing some pretty sophisticated mathematical practice (Goldenberg, 1995). Some practitioners might recognize that she is on the edge of understanding why computers cannot do arithmetic accurately. It is not surprising that my students and I have difficulty explaining how much they know of mathematics to their peers and their parents.

The ambiguity of authority with which my pedagogical expertise and my fifth-grade students' mathematical expertise is regarded might also be understood by analogy to the battles between pure and applied mathematicians or between practitioners of physics and engineers. One can imagine conversations among these different kinds of practitioners that would not be unlike those I described having with researchers who come to my classroom for a day to study my teaching. Who considers whom to be an expert? What does the knowledge of one kind of authority lend to the work of the other? These parallels are relevant to practice-oriented educational reform as we try to figure out when students are working on real problems in mathematics or science. Do we look to classic theoretical conundrums like the infinity of numbers between 0 and 1 for models of what students should grapple with in classrooms? Should they be working on practical problems like figuring out how to collect the data necessary to lobby the school board for an additional drinking fountain? If students know how to approach a problem of this latter sort, are we satisfied to say they know mathematics? What would we think if a distinguished number theorist were unable to mount a mathematically sound argument to the school board?

Explaining the Paradox Part 3: Telling Knowledge as the Subject of One's Own Study

Practice is doing. The study of practice begins in the setting in which a particular practitioner acts. To study practice means that one cannot succeed by limiting the focus of one's inquiry because it is the breadth and complexity of those actions across multiple settings that are being investigated. Yet in the course of attempting to tell about any practice, even if the telling is in the first person, one necessarily formalizes what has been learned, leaving out some aspects of the experience and highlighting others. For any inquiry into practice, there are many possible stories to tell. For every story that is told, there are many possible meanings to interpret. Stories about practice are not mirrors of experience: Like all texts, they are constructed by the author with certain intentions in mind. When one is writing about oneself, no description seems adequate to the experience, and yet without description what is learned remains private and unexamined. I have access to special knowledge as the teller of my own teaching stories, but I also am constrained by the limitations of any medium to express the multiplicity of what I know.

Although it is my aim to retain the richness and complexity of what is going on in what I write about my teaching, being in the middle of it makes me painfully aware of the impossibility of telling the whole story. Language, even supplemented by other media, is simply inadequate to capture my experience and knowledge of teaching practice. It is inadequate even to capture all of the aspects of an event, to say nothing of representing the constellations of feelings and intentions imbedded in that event. That I can have more of a sense of the whole of what is going on than any observer is both a blessing and a curse when I try to write about it.

This judgment about the inadequacy of language to represent my experience of practice is not only one that I have constructed inside of my self. Sometimes listeners hold me to a higher standard of verisimilitude than they would other authors of case studies of teaching because I *am* the teacher I am portraying. Other kinds of writers about teaching are excused for leaving out considerations of gender, political context, parental relations, or subject matter because these are outside their fields. As a teacher, I cannot ignore any of these domains; as a writer, I am expected not to ignore them.

A parallel in the work of school learners studying practice by doing it themselves occurs elsewhere in this volume (see chap. 4). O'Connor tells the story of Paulina, a sixth grader, who with everyone else in her class had done an experiment to figure out the best ratio among lemon juice, water, and sugar in lemonade. For reasons you can read about in chapter 4, Paulina's data were not included in the graph of data when the class produced a report of its statistical conclusions. In her analysis, O'Connor examined how other students in the class responded to the mathematical and social exclusion of Paulina and her data point. The relationships that various students had with Paulina and others in the class were a significant factor in the mathematics that Paulina was able to do in this setting. If we were to hear the findings of this study of practice from Paulina's point of view, or from the perspective of any of the students who were involved in this controversy, the flavor of their relationships would probably not be left out. Should they be?

For Paulina and her classmates, studying mathematics involved coping with the shifts in relationships that resulted from having her data left off the graph as well as trying to understand the mathematical practice of graphing data. These complications arose precisely because they were studying mathematics by doing mathematics. For me, studying teaching means taking account of how and when relationships with students enter into my knowledge of practice. The complication that those relationships introduce into my studies would not be there if I were not the teacher, but neither would I be able to understand a fundamental element of teaching practice. For both Paulina and me, it is a struggle to separate what we learn about the practice we are studying from what we experience as practitioners. However, what we can learn is different than what we could learn from reading about the practice or listening to someone else tell us what they know about it.

COMMUNICATING BETWEEN THE INSIDE AND OUTSIDE OF PRACTICE

Acknowledging the paradox involved in learning about practice, how does one represent practice in a way that can make sense to both insiders and outsiders? I have written extensively about my attempts to do that with elementary mathematics (Lampert, 1990, 1992, 1994; Putnam, Lampert, & Peterson, 1990). Here I focus on how and why it might be done in teaching and teacher education.

To represent the perspective of practice to teachers, researchers, and policymakers, I tell stories about things that happen in my classroom. I do this to express something of the dramatic quality of what goes on, but also because narrative enables me to represent something that I think is universally important about teaching. The story is not a replay of what happened. Rather it is a window on how events and relationships among the participants intertwine to produce a particular outcome. In stories of mathematical pedagogy, as in all stories, there is a narrative description of an event. Overlaying this description, there is also the "state–breech–crisis–redress" cycle in which good or evil ultimately prevails (cf. Bruner, 1986). As the person who both experiences the crisis and is responsible for its redress, I have the capacity to identify elements of the work of teaching that are not available to observers.

For example, the turning point in a piece I wrote about teaching my fifth graders the meaning of numbers written in decimal form is a moment when one of the students in the class announced, just as the lunch bell was about to ring, that .0089 is a negative number because it is less than zero and several of his classmates chime out in agreement (Lampert, 1989). This was a definite breech in the conversation from my point of view as the teacher because I know that .0089 is *not* a negative number. The students' thinking in this matter was interesting and would be recognized as such by many observers. For me, it also signaled a pedagogical crisis. The kind of teaching that I am trying to do respects students as sense makers and so I could not simply correct this assertion. At the same time, I want to teach in ways that honor mathematical traditions and make it possible for my students to communicate with others who honor those traditions, so I could not accept the students' assertion as a curious invention. Neither could I simply label the student *wrong* until I found out why he said what he said. At the same time, I wanted to be a good citizen of the public school in which I was teaching, and the lunch servers were waiting for my class in the cafeteria.

Studying practice in this situation is not only a matter of studying the complexity of the problems I faced. It also requires an examination of what I *do* about them. As a researcher in mathematics education, I was in a position to learn not only about how fifth graders think about mathematical concepts in the context of a school lesson, but about how the timing of my interventions in this and subsequent lessons could affect their thinking. I am also a researcher *on teaching*. From that perspective, this incident provided an opportunity to learn what sort of work teaching is. Because of the ethical responsibilities in my relationship with my students, I needed to recognize the potential for study in this turn of events, as well as do something about it (cf. Cohen, n.d.; Welker, 1991). I was thrust into a domain of teaching practice that seems crucially important and valuable—trying to figure out why a 10-year-old might think that a number written as a decimal is less than 0 while figuring out how I was going to convince him that this did not make sense while respecting him as a sense maker, *and* doing all this without incurring the wrath of the lunchroom staff. Unlike researchers on children's thinking and learning, I did not create this problem to study it. I did what I did *to teach*. In contrast to others who have become teacher researchers in university settings (e.g., Wong, 1995), I did not decide to become a teacher to study problems that I was interested in as a scholar. I became a university researcher to better understand and communicate about a practice I had already been engaged in for more than 10 years.

From Knowing to Communicating: Dissolving the Dualism?

The stories that I tell about my teaching are created after the fact with the purpose of communicating fundamental elements of my practice. There are three activities that produce the narrative inquiry: (a) doing the practice, (b) examining it, and (c) constructing a story about it. As I study practice as well as do it, I do all three.[7] When I compose a narrative from the perspective of practice, the point is not one-way telling as in announcing, but a two-way kind of storytelling: communicating one's experiences to others, checking on what is understood by the listener, and revising one's language to achieve some shared meaning. To help us understand the practice of teaching, the story needs not only to celebrate an event but also to draw out its meaning to some community of readers. This requires my learning the language and rules of discourse of each community with whom I would communicate and creating a language of practice that is comprehensible to each.

If I am to succeed as a teacher–scholar, and if school learners are to succeed in learning mathematics by doing problems that take them into this domain, it seems we might need to recognize a third kind of discourse that is neither a discourse for practitioners to talk with one another about their problems nor a discourse that mimics the focus and detachment of academia. Such a discourse would be built from communication in which local negotiation about meaning among speakers with differing perspectives has the potential to create a new kind of discourse about practice (cf. Schwab, 1978). It is not hard to imagine that creating and nurturing such a middle ground might improve both teaching and learning.

This somewhat romantic notion has some grounding in the social psychology of George Herbert Mead. Mead's theory of the self includes the idea that the person is both an actor and interpreter of action in society. Mead worked in the tradition of pragmatism, bent on attacking the classic dualisms—individual versus social, mind versus body, nature versus culture, fact versus value, objective versus subjective—with a harmonizing logic (Strauss, 1956). This tradition of thought has given me the inspiration to imagine that it is possible to be both a practitioner and a researcher without suffering from a paralyzing personality disorder.

In Mead's terms, the person's identity emerges from the integration of *me* and *I*. *I* is the force that determines action—the will to make a unique imprint on the environment rather than simply reacting to it. *Me* is a member of various overlapping and nonoverlapping social groups and understands

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[7]I do not wish to portray doing and thinking as separate, sequential activities. See Schon (1983) on the interaction of "reflection-in-action" and "reflection-on-action" in teaching and other practices.

action as it is variously interpreted by these groups. The *I* is continually involved as an agent in ongoing action, whereas the individual becomes aware of self through the reflective *me*, which organizes the response of others to the *I*. What distinguishes Mead's theory from other ways of thinking about persons-in-action that were popular when he was writing is the assertion that the person is a dynamic integration of the agentive *I* and the responsive *me*. This assumption of integration contrasts sharply with theories of the self that understand the person as a responding organism, whose behavior is a reactive product of what presses on him or her from the outside (society), the inside (psyche), or both (Blumer, 1971; Erickson, 1995).

As a teacher–scholar, I have been trying to know and tell about teaching both as the *I* who initiates action in the messy circumstances of practice and as the *me* who participates in a community of scholarly discourse about this practice to understand it. The *me* attempts to tell stories about the *I* by describing what I do in terms that are familiar to various subsets of the academic and professional community. My stories are validated as research to the extent that readers find them to be adequate analyses of practice (cf. Mishler, 1990). How are we to think about the findings of this research?

Communication as an Attempt at Mutual Understanding

Perhaps it would be useful to introduce more rigorous ways of talking about what it is that is acquired from doing and studying practice. One result of studying a practice like mathematics or pedagogy is what might be called *understanding*. This belongs to the individual practitioner and serves to justify one's actions to one's self. Representations of such understanding might be recorded in a private journal. Another kind of result of studying practice might be what is commonly called *knowledge*, perhaps produced by individuals, but shored up by public argument supported by evidence. Understanding is assumed to be a product of private experience, contemplation, and reflection, whereas knowledge is a product of intellectual work done according to a community's accepted set of rules. Through contemplation and reflection, one might get to understand what is called *public* knowledge and even learn to use it, but this is not the same as producing it.

Neither understanding nor knowledge in the sense that I have caricatured them here seems to be the appropriate term for what I am trying to produce about the practice of teaching. Although it puts me in a powerful position, I am unhappy with the claim that, as a practitioner, I have some kind of universally applicable knowledge of teaching and everyone else who teaches should also have this knowledge. I am equally unhappy with calling what I have *my own understanding*, in the sense of saying that what I know is private and relevant only to the particular problems I face in my classroom.

Returning to Mead's theory of the self, what seems to be at issue in this epistemological conundrum is integrating the *I* who initiates action and the *me* who tries to understand and name action in ways that are meaningful to others. The works of Lev Vygotsky and M. M. Bakhtin and the writings of their contemporary interpreters have helped me find a way out of this conundrum—to understand that it is in the attempt to communicate with members of different speech communities that the "unsatisfactory stalemate between individualistic subjectivity and abstract objectivism" can be resolved (Bakhtin, 1986; Emerson, 1981; Holquist, 1990; Vygotsky, 1978; Wertsch, 1985). What gets created in the act of trying to communicate is a new understanding—neither particular to my private experience, nor entirely shaped by the need for universal principles, but a tool to aid all of our attempts at shared understanding. In Morson's (1981) interpretation of Bakhtin,

> Speech is *inter*locution. Understanding is active, is responsive, is a process. The process of understanding includes the listener's identification of the speaker's apparent and concealed motives and of the responses that the speaker invites and hopes to forestall. (p. 6)

Let me try to give an example of how this helps me think about how I write or talk about my teaching. One of the things that I have been exploring in my teaching is organizing the daily agenda around multifaceted math problems instead of a list of mathematical topics. I do this to see if the topics I want students to learn about will emerge from students' work on the problems. Understanding this piece of my teaching puts me at a crossroads between the way *I* would describe what is going on and how I imagine that various speech communities might understand *me* trying to address this problem.

In an attempt to be true to both the *I* and *me*, I chose to title a paper/talk about this aspect of my teaching "Covering the Curriculum, One Problem at a Time" (Lampert, 1991). This title was deliberately chosen with an eye toward communicating something about the crossed perspective between the way some learning psychologists might view the kind of teaching I do and the way some teachers might view it. Psychologists (and the educational reformers they have influenced) have a reputation for denigrating teachers' worries about covering the curriculum; they assert that what is important is understanding and that just getting through the textbook is not an indication that anyone is learning anything. Their theories of learning support the idea that students will benefit from deep and sustained involvement with a problem. I agree. As a teacher, however, I cannot only see learning mathematics in terms of constructing knowledge in the context of an attempt to make sense of a single problem. I also need to think in terms of which topics and procedures are taught and hopefully learned in which grade. If I were to speak to my fellow teachers in the same way that I speak to my fellow researchers about doing one problem at a time, they would be quick to point out that "it won't work in my classroom." By including the idea of covering the curriculum in my title, I am seeking to forestall this response, at least long enough to get my audience to listen to the *one problem at a time* part. I know, from working in a school every day that one cannot simply dismiss the idea of covering the curriculum—that the curriculum represents something like a treaty between the school and the community. Yet by including the phrase *one problem at a time* in my title, I seek to avoid researchers dismissing what I have to say on the basis of my being preoccupied with covering the curriculum. What I am trying to invent here is a way of talking about practice that stands back from practice while taking the point of view of practice.

Refining this kind of interlocution assumes a kind of localized exchange, wherein meaning is negotiated and appropriated as such by the people who participate together in communicative events. It posits a level of study somewhere between the teacher as an individual, thoughtful practitioner who keeps a private reflective journal and the teacher who views elements of practice in terms of the discourse structures of one or another scholarly community. In between, we might think of the teacher as collaborating with others in the thoughtful study of practice and creating a way of writing and talking about practice that satisfies both other practitioners and specialized nonpractitioners who want to understand more of what teaching is all about. In the United States at least, there is currently very little of this *middle* sort of work going on. Should there be more? Would it contribute to teachers' capacities to teach subjects like mathematics from the point of view of practice?

SHOULD PRACTITIONERS ALSO BE SCHOLARS OF PRACTICE?

Despite these wonderfully integrative theories about the nature of the self in communication with others, it is possible to imagine a world in which practitioners stand on one island learning to do practice by apprenticing with other practitioners and scholars stand on another island using telescopes with fancy lenses studying what practitioners do. Why should we try to build a bridge? The notion that *only* teachers can know teaching seems spurious. The notion that teachers do not have the time, interest, or intelligence to study the problems of practice is equally unwarranted.

Current reform efforts suggest that teachers need to be engaged in the study of practice to carry on the kind of teaching that is recommended (Ball, 1994; Cohen & Barnes, 1993). In their chapter in this volume, Rogers Hall and Andee Rubin (chap. 8) place themselves with those who would have teaching be more of a thinking practice. They suggest that the kind of study of my practice that I do might be the kind of thinking that more teachers need to do to create opportunities for children to learn the thinking practices. In several places, Hall and Rubin say that, as a teacher, I faced difficult intellectual challenges. They also say that one reason my work is worth studying is because it can provide an example for an alternative way to structure the work. Instead of dismissing what can be learned from my practice because I am not a typical teacher, Hall and Rubin speculate about whether the sorts of resources I have might be more broadly distributed.

One of those resources is the capacity to produce and reflect on artifacts like those on which Hall and Rubin drew to do their study: a teaching journal, observers' records of lessons, video and audio records, records of children's work, and investigations into their thinking. Another of those resources is the time and institutional support to think and talk together with others about the problems of practice. Because these are available to me, it is possible for me, other researchers, and intending teachers to study my teaching, the kind of teaching that I do, and the practice of teaching more generally (Lampert & Ball, in press). I agree with Hall and Rubin that (a) teaching in schools in the ways that have been suggested in this volume pose difficult intellectual challenges for teachers, and (b) a broader distribution of resources to cope with these challenges is imaginable (Stigler & Stevenson, 1991; Talbert & McLaughlin, 1993).

A Bit of Pedagogical Autobiography

Suggesting that teaching can become more thoughtful with resources like those available to me is one avenue to reform. Changing teacher education might be another. As a beginning teacher, I was taught to engage in teaching as a practice that requires planning, strategizing, problem solving, evaluation, and reflection. I have rarely acknowledged the people who taught me to teach or the institutions in which we worked together. I wish to do so here partly by way of suggesting that the kind of teacher–thinker–researcher I am grows out of a tradition of practice that is rich in potential contributions to our current thinking about school reform, although it is little mentioned in contemporary debates. I began the practice of teaching secondary school mathematics in 1969. At that time, I learned to teach primarily from Stephen Krulik, who was my professor at Temple University and the supervisor of my classroom internship as part of Temple's Master of Arts in Teaching program. I began teaching elementary school in 1974. My most important teacher at that time was Pat Carini, director of The Prospect Center and its joint teacher education program with Antioch Graduate School of Education.

Like Krulik, Carini both taught me in seminars and supervised my work in classrooms.

What was strikingly similar about these two experiences was that both Krulik and Carini taught their students to teach by having us work, both inside and outside of our classrooms, on authentic intellectual problems in the fields we would teach. The purpose of this work was not only to learn about the work of problem solving in the domains we would be teaching, but also to learn about problem solving in teaching. Krulik and Carini assumed that, as teachers, we would be creating curriculum and reflecting on students' learning in various domains and that a deep knowledge of those domains would improve our capacity to do these tasks thoughtfully. We worked on a random set of real mathematics problems in Krulik's seminar, chosen by him to cross the boundaries of school subjects and provoke our thinking about what and how to teach. Working with Carini, we read real books—both children's and adult literature, both fiction and nonfiction—and we worked on projects like rewiring a classroom or drawing a tree as a way of thinking about what knowledge is and how it might develop in learners. In both programs, curriculum materials were regarded as resources to be consulted, not cookbooks to be followed. In both programs, I was expected to engage with the practices I would be teaching in school as an opportunity for inquiry into the questions of what and how to teach.

I learned more from Krulik and Carini than the practices of mathematics and social studies and literacy. Because of the constructive way in which my education as a teacher was organized, I also learned to take responsibility for designing teaching using my knowledge of these practices. I learned that curriculum and instruction were jointly created by students, teachers, and materials and that much of what happened during lessons could not be planned for or predicted. I learned to prepare for encounters with students by thinking through the central ideas of what we would be working on together and to anticipate where in the terrain of the subject matter we might wander. I learned to study my own practice as a resource for improving it. I learned to think in teaching and with other teachers, and I learned that our thinking and talking together was a source of knowledge about practice. I learned that such knowledge was tentative and open to revision—that the validity of my pedagogical principles needed to be assessed and reassessed in each new situation. I learned that the connection between knowledge and action was not a matter of direct application, but a matter of managing multiple and conflicting truths about what I should do. I learned a language for talking with others about teaching and acquired the disposition to do so.

Because I was put in a position of being simultaneously responsible for producing and using pedagogical knowledge, I was able to learn some things about knowledge in general—particularly about how principled or synoptically organized knowledge relates to practice. I learned that post hoc descriptions of how problems of practice get solved do not translate directly into solutions to new problems. I learned the difference between acquiring knowledge and creating knowledge for one's own use. I do not think I ever heard the term *social constructivist* as a beginning teacher. Looking back on what I did, it seems like an appropriate label for my cognitive activity. As a high school teacher, I participated with a team of other teachers in trying to define what was worth learning, how it might be taught, and how we might evaluate whether we were succeeding. As a teacher of young children, I spent many afternoons in conversation with my fellow teachers poring over children's paintings, block constructions, and graphic representations of quantitative relationships trying to describe the child's understanding and designing the next appropriate activities for our classes. I read books and took courses, but all of the knowledge I used was subject to negotiation in these forums of practice.

Earlier Sources of Inspiration

This way of conceiving of teaching and the teacher's role is rare and unusual, but it is certainly not limited to Krulik, Carini, and me. It is part of a tradition that was especially lively in this country at the time that John Dewey and his contemporaries were producing pedagogical scholarship and educating teachers. Fortunately for me, this tradition has survived alongside the more dominant trends to implement teacher-proof curriculum and instructional activities and to replace teachers' engagement in intellectual practices with course requirements in the disciplines (e.g., Ben Peretz, 1990; Connelly & Clandinnin, 1988).

One of Dewey's contemporaries and one of my heroes is Lucy Sprague Mitchell. Mitchell was a teacher, teacher educator, and researcher on teaching. She is one of a remarkable collection of educational reformers who combined scholarship with practice in America in the early part of the 20th century. She wrote a book about teaching geography in elementary school that is considered to be a classic among teachers who regard themselves as pedagogical designers. In this little book, Mitchell ties the practical with the intellectual in her observations about what teachers need to do and learn to bring children to the point of making and understanding geographical relationships. In the section on the teacher's role in this process, she said:

> It becomes the first task of a teacher who would base her program with young children on the exploration of the environment to explore the environment herself. She must know how her community keeps house—how it gets its water, its coal, its electric power, its food, who are the workers that make the community function. She must know where the pipes in her room lead to, where the coal is kept in the school, when the meters are read and by whom; she

> must know the geographic features which characterize her particular environment and strive constantly to see how they have conditioned the work of which she is a part and how they have been changed by that work. (Mitchell, 1934/1971, pp. 16–17)

The teacher is to explore ideas firsthand as a basis for knowing what and how to teach. There are two parts to this knowledge. One part is the exploration—actually finding out the geography of the setting in which one lives and works, finding out what constitutes the practice of geography. The other part is personalizing the findings of that exploration by reflecting on what the study of geography enables us to know about our own work and about how our thinking contributes to the design of our physical and intellectual environments. There is yet a third kind of knowledge required to connect all this to teaching and perhaps it is this kind of knowledge that Hall and Rubin imagine will be produced if more teachers have the kind of resources that have made my work possible. Mitchell went on to say about the teacher's explorations of geography:

> And when she knows all this and much, much more, she must keep most of it to herself! She does not gather information to become an encyclopedia, a peripatetic textbook. She gathers this information in order to place the children in strategic positions for making explorations. ... (Mitchell, 1934/1971, p. 17)

If I can take a leaf from Mitchell's book, I would define my autobiographical study of teaching practice as an effort to gather information to place myself and others who seek to learn about *teaching* (including researchers of the sort represented at this symposium) in a strategic position for making explorations. Together we can use this information and our interpretations of it to understand practice from the point of view of practice. We can appreciate that the teacher's self—a thinking self—is a tool in pedagogical practice, and perhaps we can mobilize the resources to improve both personal and institutional capacities to design practice so that school learners can also think.

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CHAPTER

3

TRAJECTORIES OF PARTICIPATION AND PRACTICE: SOME DYNAMIC ASPECTS OF THE THINKING PRACTICES OF TEACHING, EDUCATIONAL DESIGN, AND RESEARCH

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The chapters by Stein, Silver, and Smith and by Lampert present innovative and stimulating perspectives in which they focus on participation by teachers in practices of teaching and discourse about teaching. Both of these chapters have significantly advanced my understanding of practices and communities of teachers, and also have advanced my understanding of the theoretical concepts of participation, communities of practice, and personal identity. I hope that in these comments I can convey my strong enthusiasm about both of these contributions, and can also communicate a framework that I believe highlights some of the conceptual advances that they provide.

These chapters emphasize dynamic qualities of participation in communities of practice. The dynamics involve changes in the ways in which individuals participate in practices and changes in the practices that they participate in.

Stein, Silver, and Smith focus on trajectories of the participation of teachers in their local teaching community. They are concerned primarily with progressive trajectories in which individuals' participation was initially peripheral and became increasingly central in the community, in terms of the framework introduced by Lave and Wenger (1991). They concentrate on a variety of ways in which the community engaged in discourse about their teaching practices, and how these discourse activities both supported and provided evidence of the teachers' development.

Lampert focuses on trajectories of a different kind, involving movement of an individual's activity between communities of practice. Lampert's autobiographical report is based on her participation in practices of teaching and in discourse practices of educational research. She is concerned primarily with challenges of communication and construction of shared understanding in the research community about teaching practice when her knowledge is grounded in her practice and the discourse of the research community is organized differently from the discourse of practitioners.

These discussions provide important conceptualizations of practice, both at a general level and especially regarding teaching. The epistemological issues they raise concerning knowing and learning in teaching and in discourse about teaching are fundamental for the task of developing the conceptual framework in which knowing is considered as sustained participation in communities of practice.

COMMUNITIES OF PRACTICE OF AND ABOUT TEACHING

Stein, Silver, and Smith and Lampert discuss activities in at least five kinds of communities of practice. Relations between the activities in these communities are especially important.

First, the classes that teachers teach are communities in which they participate with their students. Second, groups of teachers in their schools form local communities of practice in which they interact as colleagues. Third, teachers participate in larger communities of teachers and other educational practitioners in professional societies and other settings where teaching practice is discussed. Fourth, there are local communities of educational developers and researchers that work together on projects that develop materials for teachers to use in their work and conduct studies of the teaching and learning practices of teachers and students. Fifth, there are larger communities of designers and researchers who interact professionally at meetings and through publication of their materials and research reports.

These communities are organized differently to accomplish different functions, although the functions are interrelated. I believe it is useful to consider these communities in terms of the main problems that their activities focus on. The activities of a community include performing routines and resolving problems, in Dewey's (1910/1985; also see Burke, 1994) sense of a problem as an aspect of a situation that requires a departure from the normal way of acting and understanding. It is useful to think of the activities as being organized so that different functional purposes are central in different communities. These differences in functional organization lead to differences in the kinds of problems that are addressed in the practices of communities.

Classrooms are organized to accomplish educational goals of student learning and assessment. The problems that classroom activities focus on are difficulties of student learning, which can be understood differently according to different views of education. In the classrooms at the Portsmouth Middle School, and in Lampert's classroom, the major emphasis is on students' growth in understanding mathematical concepts and principles, including their ability to participate in discourse practices of mathematical inquiry.

A local community of teachers conducts discourse about problems that arise in the participating teachers' classroom practices and focuses on experiences of participating teachers in resolving those problems. This discourse is aimed toward providing examples and ideas that can be helpful to individual teachers in resolving the problems that arise. Larger communities of teachers conduct discourse about problems that are salient in their constituents' practices, and address those problems in a more general way.

Communities of developers and researchers are concerned with problems of classroom practice, but the problems that are primary in organizing their activities are related to classroom practice indirectly. Educational developers' primary function is to construct materials for use in teaching and learning. The main problems that arise in this activity are issues of design and production of materials and curriculum. Educational researchers' primary function is to develop information and conceptual systems that can be used to explain significant phenomena of learning and teaching. (This view follows closely discussions by Kitcher, 1981, 1993.) The main problems in research arise when there are phenomena that cannot be explained with the currently available conceptual resources, or when attention is given to inconsistent or vague aspects of the available concepts and principles. Of course, issues of classroom practice play significant roles in the discourse of communities of developers and researchers, but the participants of these communities are not personally and directly accountable for resolving the problems that arise in classroom teaching.

One constraint that is applied more strenuously in research practice than in teaching practice is a constraint of consistency of meanings of symbolic representations. Ambiguities in the meanings of theoretical concepts and symbols are an impediment to the main goal of research, because they make it difficult or impossible to determine whether some phenomena are problematic, or whether some proposed change in an explanatory method actually solves the problem it is claimed to solve. In practice, consistency of meanings can be less crucial, especially if practioners recognize that they necessarily will face trade-offs between values and principles and treat statements about their practice as providing advisory guidance, rather than hard-and-fast prescriptive rules.

On the other hand, constraints of immediate usefulness are applied more strenuously in discourse about practice than they are in the discourse of research. Advances in research often require exploring consequences of hypotheses that are implausible or impractical, and therefore require setting aside the constraint of implementability, at least temporarily.

Research communities also have discourses of methodology, in which constraints of usefulness play a more salient role. These discussions develop out of problems of action in the conduct of research, generally involving conflicts between constraints that arise when a method that is used to achieve some scientific purposes is shown to be inadequate respecting another desirable characteristic of scientific practice.

TRAJECTORIES IN AND OF A LOCAL COMMUNITY OF TEACHERS

Stein, Silver, and Smith focus on activities of the local community of teachers at Portsmouth Middle School. Individuals have trajectories in their local communities, and Stein, Silver, and Smith's main focus is on trajectories of individual teachers' activities in their local community from more peripheral to more central participation. A central finding in their discussion is that teacher learning is deeply embedded in the ongoing work activities of teaching, rather than being a product of specially designed workshops and courses.

Along with trajectories of individuals' participation within a community, the community itself functions dynamically with trajectories of its practices as it progresses or declines in different aspects of its activity. The community of Portsmouth teachers was committed to a trajectory of adopting a set of teaching practices associated with the movement to reform mathematics education according to ideas such as those in the NCTM Standards.

Stein, Silver, and Smith emphasize the successful functioning of this local community in supporting trajectories of practice by these teachers in their classroom work, especially in regard to the trajectory of the community's progress in adopting the practices of reformed mathematics education. They emphasize that participation in local communities of teachers can be a crucial factor in supporting fundamental change in teaching practice, and that focusing on the resources of local communities of teaching practice could be an important new direction in providing resources for teachers' professional development.

Trajectories of participation by individuals occur, not only within communities, but across communities as well, and the trajectories of individuals in moving from one community to another are important in understanding how personal identities are shaped through their participation in communities. Stein, Silver, and Smith illustrate this in their example of the teacher who came to the Portsmouth School from another school where she had been active in the reform of mathematics education. The similarity of purposes and problems in these two communities supported a transition in which the newcomer's participation was functionally more like that of longer-term members of the Portsmouth community.

Stein, Silver, and Smith's account emphasizes the role of story-telling in the participation of individuals, both within their local community and in their participation in larger communities where they gave presentations. Stories often represent experiences of personal growth and accomplishment, arising out of problems and conflicts that occur in practice, such as the challenges of using portfolios of students' work in fostering and assessing their learning. The stories that are shared in a community also illustrate shared values and principles for which members expect to be held accountable. Stories also are an important means through which the community interacts with the broader communities in which it participates. The Portsmouth community's participation in larger communities of teachers included presentations that represented their experiences and emphasized challenges and accomplishments that reflected their shared commitments and values. In these presentations, members of the Portsmouth community who spoke on behalf of their local community contributed to the identity of the Portsmouth group and to their own identities in the larger teaching communities.

Just as there are trajectories of participation involving the interactions of individuals within a community, so there are trajectories involving the interactions between different communities of practice. In addition to their observations about individual teachers within their local community, Stein, Silver, and Smith also noted changes in the interactions of that community with other communities. Part of the Portsmouth community's trajectory involved the relative values of workshops organized by their university resource partners and interactions among themselves. The teachers reported that early in their work of implementing the new curriculum, workshops organized by the university resource partners were extremely valuable, but that later in the project their most valuable resources were collaborative interactions within their community.

Stein, Silver, and Smith are, themselves, participants in communities of researchers–the local and distributed community that conducts the QUASAR project, and the larger community of researchers and developers that includes the contributors and most readers of this volume. Through their chapter in this volume and other writings, they contribute information to the research community about important characteristics of the Portsmouth community's activities. Their roles in the Portsmouth community were different from those of the teachers themselves, and this affects the kind of testimony that they are able to give. Although Stein, Silver, and Smith were not engaged directly in the teaching activities of the Portsmouth community, they have been engaged in coordinating activities of development and organizing discussions of practice, along with their research efforts. As researchers, they are concerned with the adequacy of explanatory concepts, and their chapter presents a proposal, with supporting evidence and argumentation, for using concept, communities of practice, to understand important aspects of the professional development of teachers in their efforts to change their practices along the lines of mathematical education reform.

TRAJECTORIES BETWEEN TEACHING PRACTICE AND RESEARCH DISCOURSE

Lampert presents reflections on her own activities of teaching, studying her practices of teaching, and communicating in the research community. She discusses challenges that are presented by discourse practices of the research community to communication of knowledge that is grounded in the experience of teaching practice.

The trajectories that Lampert describes are between different communities in which she participates. As a teacher and teacher educator, she participates in the practices of teaching and discourse about those practices with other teachers. As a researcher and scholar in the study of education, she participates in the practices of constructing knowledge and explanatory concepts about activities and processes of teaching and learning.

Lampert's chapter testifies to significant discrepancies that exist between knowledge that is grounded in teaching experience and the discourse of knowledge-building in the research community. Like many readers of this volume, I can testify that the difficulty is symmetrical. That is, when I participate as a teacher educator or as a researcher in a discussion with teachers of problems of teaching practice, I find that the criteria of significance and warrants for claims about practice are quite different from those that I am accustomed to in discourse that is grounded in research.

For communities to progress, there have to be sources of problems. An important vehicle for the generation of new problems is to become aware of ways in which the community's present problems are viewed from another perspective. Lampert, and others who participate in multiple communities, move along trajectories in which they can contribute perspectives of each community to the other's discourse, and her identity in the research community, as well as her identity in the teaching community, is influenced by knowledge of other members of both communities so that in each community she can bring the perspective of the other to bear on understanding the problems and issues that arise.

Lampert's discussion points toward an understanding of reasons for the discrepancies between discourses in communities of teaching practice and of research about teaching. Problems that arise in any practice need to be resolved in action that maintains the continuity of activity and satisfies as many of the significant constraints of the practice as possible. The crucial constraints of teaching practice are about constructing and and maintaining conditions for students to learn, in real time, with constraints on what they learn based on the concepts and principles of subject-matter domains. The crucial constraints of research practice are about constructing and extending systems of information and explanation in a subject-matter domain, expressed in systems of symbolic representation.

Lampert's example of the student who claimed that .0089 is a negative number illustrates the difference well. As Lampert commented, this event presented a problem in her teaching activity because it made it difficult to maintain two of the constraints that are important in her teaching practice. One of the constraints is that students are respected as sense-makers; the other is that students should learn the mathematical concepts and principles that are correct according to standard mathematical practice. Many of the actions available to a teacher would satisfy one of these responses and violate the other. A resolution of the problem that satisfies both of the constraints is an achievement of practice, when it can be found, and sometimes such a solution is not available. Teachers who discuss their practices construct understanding of types of problems that arise and of types of resources and responses that they can use to resolve such problematic situations.

Lampert's report of this event could also present a problem in the practice of research. This could occur in a discussion of concepts and principles that are used to explain performance in tasks and discourse that involve mathematical concepts and symbols. The example might be used to support a claim for the generative nature of children's understanding of quantities and numbers, or to illustrate an idea about misconceptions in children's understanding of the concept of decimal numbers, or to dispute a generalization about children's abilities to engage in conceptual discourse about numbers. This would be recognized as a problem if it was accepted that the phenomenon was relevant for an accepted method of explanation, but that the method was inadequate for constructing a satisfactory explanation of the phenomenon.

Like Stein, Silver, and Smith, Lampert emphasizes the role of stories in the communication of knowledge grounded in practice. Lampert's discussion also uses the idea expressed by James (1890) and Mead (1934) as a contrast between "I" and "me," the subjective, experiential self and the self as an object of reflection and analysis. It may be significant that Stein, Silver, and Smith's discussion reports stories as an important factor in teachers' communication about practice, but does not use stories from their experience as a major vehicle of their own exposition. Stories may provide a crucial resource for communicating essential features of a practice, including the experiential richness and challenges of problematic situations and access to resources for their resolution. The development and evaluation of explanatory concepts and methods, however, may require the kinds of exposition and argumentation that are common in the discourse to which we are accustomed in the research literature. Indeed, in her research articles Lampert (e.g., 1990) combines narratives with extensive discussions that explain how the stories illustrate types of phenomena that are relevant to theoretical concepts and principles of learning in classroom activity.

CONTRIBUTIONS OF THESE CHAPTERS TO TRAJECTORIES OF RESEARCH AND PRACTICE

Research communities have trajectories, as do all communities of practice. Indeed, the authors and editors of this book perceive a possible trajectory of the community of educational research to which we hope our efforts will contribute. This trajectory involves the development of methods and theoretical concepts that can move our inquiry and explanatory systems about thinking toward a stronger understanding of practices of learning and teaching.

Stein, Silver, and Smith's chapter contributes to the research trajectory by extending the concept of learning through legitimate peripheral participation. This idea, introduced by Lave and Wenger (1991), provides a valuable perspective on the development of practices of teaching, and Stein, Silver, and Smith's use of the idea adds valuably to the concept, for example, in showing how participation in local communities and in larger professional communities are interdependent. Their chapter also raises the important prospect of developing new resources for professional teacher development that would focus on facilitating the activities of local communities of teachers. Their findings emphasize that the work of teaching should be understood as an activity of learning that is crucial for teachers' professional development, and resources for learning within communities of teachers may be more productive than resources for activities that remove teachers from the settings of their work and interaction with local colleagues.

Lampert's work has also contributed fundamentally to the effort toward the research goal of a more adequate explanatory account of teaching practice, in presenting reports and analyses of phenomena that require modification of prevailing concepts and principles of learning to better account for the ways in which students and teachers interact in their discourse about mathematical concepts and representations. Her chapter in this book contributes to the trajectory in another way, involving methodological considerations. Her claim in this chapter is that there are significant misalignments between the modes of discourse in research and the character of knowing in practice. This claim presents an important challenge, which might be addressed by attempting to achieve better alignment between the discourses of practice and research, or by better understanding how the differences serve different functions within the two communities, and using that understanding to strengthen both discourses as resources for each other's progress.

These two possibilities should both be pursued. Lampert's chapter, and most of my comments here, contribute to the second possibility by trying to clarify some differences between the two discourses and how they function in the practices of the teaching and research communities. The first, stronger, possibility would require a formulation of problems in which the conceptual understanding that can be achieved in research would also serve as resources for practice. This is a goal toward which some significant efforts are underway. One example is in the work of Brown, Campione, and their associates, exemplified by Brown, Ellery, and Campione's chapter in this volume, in proposing and evaluating *first principles* as hypotheses of assumptions that underlie practices and that provide explanations of those practices. Such principles can be the topic of reflective discourse within practices as well as of critical discourse in research about the practices. Stein, Silver and Smith's chapter can be understood as contributing a candidate for such a first principle, the principle that trajectories of individual teachers and communities of teachers can be facilitated strongly by organizing the community's activities appropriately.

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CHAPTER

4

THE MISSING DATA POINT: NEGOTIATING PURPOSES IN CLASSROOM MATHEMATICS AND SCIENCE

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The "habits of mind" and "thinking practices" engaged in by scientists and mathematicians are currently an implicit or explicit pedagogical goal in a number of reform documents (e.g., American Association for the Advancement of Science, 1993; National Council of Teachers of Mathematics, 1989) and take on various descriptions there. A number of chapters in this book refer to or explore the roles of various social and intellectual practices in both the school and real-life versions of science and mathematics.[1] There is much that is problematic in the relationship. What are thinking practices and habits of mind? Which mathematical or scientific thinking practices are appropriate targets for socialization in the classroom? How—specifically—can classroom activities or arrangements support the development of any of these disciplinary practices or habits of mind?

Not much research has addressed these questions directly. Instead we find expressions of belief that inquiry math and science or experience-based and hands-on activities afford students the opportunity to do real math and science, as if there were some simple relationship between what happens in the classroom and what happens in the laboratories of industry or aca-

[1]This interest augments but does not replace another, which emphasizes the factual, conceptual, and procedural contents of the disciplines and their pedagogical derivatives.

deme. This view obviously cannot form the basis of realistic curricular reform. Neither will the opposite assumption—that the classroom and lab are incommensurable. We are taking the view that it will not be possible to understand the relationship between any classroom practice and any disciplinary habits of mind without studying that relationship closely in the context of the complex work of real teaching.[2]

Therefore, we propose to start from the perspective and practices of a classroom teacher. Discussions of math and science teaching can legitimately proceed from abstractions such as *scientific habits of mind*, but such abstractions may be so remote from classroom realities that insights about them may never find application in any real classroom. We think it is important that at least some research on students' scientific thinking start with the study of teaching practices. Our attempts to understand and change math/science learning and teaching depend in part on close descriptions of the contexts in which such learning and teaching take place. This chapter closely examines a recurrent discourse practice orchestrated by the second author, Lynne Godfrey, in her sixth-grade classroom: examining a particular instance closely to discover what kinds of affordances it might provide for mathematical/scientific thinking. In exploring this example, we have occasion to consider some of the similarities and differences between what takes place in classroom math/science and what takes place in the larger world of scientific work.

CONSTRAINTS AND GOALS OF THE CLASSROOM VERSUS THE LABORATORY

The events described in this chapter took place in Lynne Godfrey's sixth-grade class in a public school situated in an urban area in the Northeast. Godfrey and the school have both participated in the Algebra Project (Moses, Kamii, Swap, & Howard, 1989) since its earliest days.[3] At the time of the events described here, Godfrey had more than 6 years of experience leading extended discussion-centered, experience-based lessons in the fifth and sixth

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[2]The same observation can be made about the other half of this picture: A world of trouble lurks under the phrase "the intellectual practices of the disciplines." Besides the difficulties of finding even a limited consensus about these, the question remains as to which practices would be relevant for consideration in elementary math and science.

[3]The Algebra Project transition curriculum is an inquiry-based transitional algebra curriculum aimed at preparing middle-school students to understand the basic distinctions important to algebra learning. It places central emphasis on communicating about mathematics through both large- and small-group discussion. Its explicit purpose is that of preparing minority students to succeed in algebra—a gatekeeping subject that is essential for access to careers in mathematics and science.

grades. These episodes took place in late fall of the school year; O'Connor had been observing several days a week in Godfrey's classroom for over a year.

In this particular case, Godfrey was not teaching the Algebra Project Transition Curriculum, but instead was piloting materials developed by Moses that were informally called the *lemonade concentrate curriculum*. These were intended to introduce students to aspects of the mathematics of ratios and the representation of situations involving ratios. A number of researchers have included juice mixtures as the situation through which ratio problems are developed, either for teaching or research purposes (see e.g., Karplus, Pulos, & Stage, 1983; Lesh, Post, & Behr, 1987). These juice mixtures are usually presented in a written narrative format with pictures and students are asked to reason about them on paper. In this case, the students engaged in an extended first-person experience with sugar and lemon juice, actually mixing various concentrations and then rating them according to their sweetness or sourness.

For over a month, the students spent several days a week creating concentrates. Guided by questions in their workbook, they explored ratios expressed as fractions, investigating whether equivalent fractions such as 2/3 and 8/12 expressed ratios of sugar to lemon juice that would yield what they called "equivalent concentrates" (i.e., concentrates that tasted the same). They also explored whether concentrates would receive the same sweetness rating if they had a fixed difference between the numerator and denominator (e.g., one spoonful more lemon juice than sugar, as in the concentrates 2/3 and 7/8). These activities were intended to cause students to construct rich, context-specific understandings of the relations within a ratio (between numerator and denominator) and between ratios. Such understandings have been found to be weak in most students' mental representations of the domain (Lesh et al., 1987; Smith, 1990).

At the point our episode begins, each student had generated several ratios of sugar and lemon juice and each resultant concentrate had been rated for sweetness by several tasters, as in Fig. 4.1.

Before we go on to narrate our focal episode, however, we present another episode from this class as background. It introduces several obvious but important differences between the work of laboratory scientists and that of students and teachers. These differences arise out of the divergent responsibilities of teacher and lab director and the different knowledge

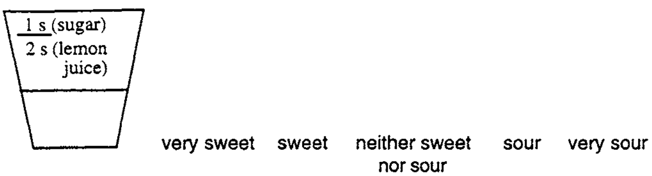

FIG. 4.1. Lemonade concentrate sweetness ratings.

states inhabited by students and lab workers. The following vignette (excerpted from O'Connor, 1996) provides an entry point to these differences. It took place in Lynne Godfrey's classroom a few weeks before the episode described in this chapter.

> Group E was composed of three girls, Jennifer, Chloe, and Sarah, and one boy, Ted. One day the four wanted to mix a new lemonade concentrate, in the ratio of four spoons of sugar to five spoons of lemon juice, in order to explore how different the taste would be from their previous mixture, a 3/5 mixture. This group already had decided that mixtures labelled by equivalent fractions were "the same," and now they wanted to explore what they were calling "similar fractions," those only one numerator or denominator unit away from their concentrate ratio. They decided to add one teaspoon of sugar to a mixture they already had—a 3/5 mixture—to create the new 4/5 mixture. Just as the group was adding the spoonful of sugar, Sarah announced that she saw a problem: since all four group members had taken tastes of the concentrate, they would be adding the extra spoonful of sugar to a cup containing an unknown quantity.
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> At first the others had trouble understanding this, then Ted leaped in with an objection. If they took Sarah's point into account, it would take "too much time" to remix the concentrate, they'd get behind—it was "not an important point." The disagreement escalated. Sarah, Chloe, and Jennifer all became angry at Ted, and their conflict suddenly resonated above the background noise. All heads turned towards Group E as Ted finally yelled "Look! I'm not getting a million dollars from the government to do this! This is a half hour math class!" A few seconds of complete silence followed this shouted declaration, then other groups turned back to their work. (O'Connor, 1996, pp. 499–500)

Sarah's intuition was a good one and, if taken up, could have generated some important sense-making.[4] One of Godfrey's goals is to promote possibilities for complex thinking and to allow students to stretch themselves to their intellectual limits. Students who ask and answer such questions are grappling with difficult issues that present a welcome intellectual challenge. Sarah is a student with the ability to ask and pursue such a question without

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[4]To see why Sarah is right, consider the slightly simpler case of adding 1 teaspoon of sugar to a 2/4 concentrate—one consisting of two spoons of sugar and four of lemon juice—a total of six spoonfuls of concentrate. The resulting mixture will be in a ratio of three sugar to four lemon juice, and that ratio will describe any amount of the concentrate no matter how many tastes one takes. However, if we take a cup of the same 2/4 concentrate, but three of the six spoons of concentrate mixture have already been drunk by tasters, then adding one teaspoon of sugar after the tasting will result in a mixture that has sugar and lemon juice in a 2/2 (or 1/1) ratio, not 3/4. Sarah's observation provides a good example of the ways hands-on or inquiry science and mathematics can lead students to think actively about the complex relationships among mathematical, physical, and symbolic entities.

a great deal of support from the teacher. Why did Ted react in a way that quashed her inquiry? He does not frame his comment as a personal attack; rather he dismisses the activity itself. It is "just a math class." She should not waste her time (and his).

This vignette crytallizes several important differences between lab and classroom. Some of these differences are obvious and widely observed.

> The usual high-school science "experiment" is unlike the real thing: The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time. (American Association for the Advancement of Science, 1993, p. 9)

From our point of view, however, what has not been sufficiently noted is the way these obvious differences result in constant challenges for the teacher who is trying to support science and math inquiry. This chapter focuses on three such challenges: problems that arise out of the goals and responsibilities of the teacher in an inquiry classroom. We lay out these problems by comparing the realities of classroom and lab.

The Missing Perspective Problem

First, members of a lab or working group already share views of what a significant and solvable problem is and of how to solve it within the discipline. They also share at least some views about the significance of their current task within the larger field. Yet in classroom science and math, these cannot be givens. We can call this the *missing perspective problem*; it is multifaceted. Working scientists already possess a great deal of common knowledge and background that allows them to make the same inferences and see the same broad trajectories of possibility. In the classroom, the teacher's goal is to support the building of inventories of shared knowledge and expectation among the members of the classroom; students cannot be assumed to share a disciplinary perspective on the problem in which they are engaged. It is even less likely that they will share the teacher's perspective on the proximate instructional purpose of the activity they are carrying out. She cannot explain to them the many pedagogical purposes embedded in an activity because they lack the conceptual framework and metaknowledge to appreciate those purposes. For two important reasons, then, the activity lacks the significance and articulated purposes found in lab science.

The Authenticity Problem

In lieu of real purposes, some teachers substitute their own authority as the sole motivating force in getting the work done. However, most teachers with a commitment to inquiry science and math find this a distasteful last resort: When students are authentically engaged, they bring to bear their intelligence in far more interesting and powerful ways than when their engagement stems from a desire to "do school" successfully. This brings us to the second problem, which arises out of the first. Relying on their shared understanding of purposes and goals, members of a laboratory generally believe (albeit to varying extents) that they are engaged in a meaningful activity with real results—results that will have consequences in their work world. Their own roles in that activity, however minor or menial, are intrinsically important in ensuring a valid and clean outcome. As many writers have pointed out over the years, this is not true in schools. Rather, many students see themselves as engaged in meaningless activities with no consequences outside the class period. Students may see their own (or others') contributions as intrinsically unimportant even inside the class period and, in many cases, they are right. We might call this the *authenticity problem*.[5]

Problems of time and space exacerbate the authenticity problem: In a lab, the work takes as long as it must take. If well-formed results are not forthcoming, another experimental run is tried or a new version of the experiment is designed. The physical setup of the lab exists to support this effort. In a classroom, open-ended experiments without a known result[6] are usually untenable due to timing, storage, and so on. The authenticity problem is always lurking in the background and can undermine even the most valiant attempts at hands-on, experience-based teaching. The problem is particularly acute when the activity is a long-term, collaborative endeavor that must engage the whole class in complex forms of cooperation.

We see the prior classroom vignette as an example of these problems. Ted virtually denies that the activity is worth his real effort. We see this in other group conversations later in the year: Ted expresses the view that "all this talk is really a waste of time." Yet it is the talk that is assumed by hands-on inquiry supporters to provide the vehicle for thinking more deeply about mathematics and science. Presumably, if a student like Ted does not

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[5]Many educators assume that hands-on or inquiry approaches ameliorate this problem, but in fact these are also easily viewed as just doing school. A few examples of authentic classroom activities, where for example students engage in solving a real local pollution problem, often make the local newspapers, providing a shining ideal of students engaged in systematic and powerful thinking. Even if these could become more common, much learning must take place in contexts where no real problem—in this maximal sense of real—is being solved; where learning is proceeding for its own sake in the context of an isolated classroom.

[6]We mean here a result known to the teacher.

accept the assigned activity as real, at least for the moment, he will not pursue the kind of deeper sense-making that Sarah seems to be striving for. Furthermore, his lack of belief (or, perhaps more accurately, his unwillingness to suspend disbelief) can disrupt the work of others, even the whole class. How is a teacher to evoke belief (or even the willing suspension of disbelief) from all of the students all of the time? This is particularly difficult because the students necessarily lack both her perspective on the purpose of the activities and the discipline's perspective. The authenticity and missing perspective problems frequently conspire to render instructional activities flat and uncompelling.

There are myriad reasons that students decline to enter cooperatively into the local world of inquiry set out for them by the teacher. One reason may be the student's belief about what constitutes real mathematics or science activity. Another might be that the student lacks respect for other students due to prejudices based on class, race, sex, or other factors–the activity cannot be important because these others are taking part. A third reason might be that the student believes the teacher truly does not intend the activity for him or her or believes him or herself to lack the abilities necessary to engage successfully in the activity. (This is clearly not Ted's problem.) What strategy can recapture the participation of all these students? Probably none; nevertheless, the teacher must go on attempting to maximize belief and engagement.

The Equal Participation Problem

This brings us to yet a third problem, missing from the previous AAAS statement: Teachers who are morally committed to ensuring access for all students to whatever intellectual benefits an activity might provide feel a constant imperative to make sure that everyone find some way to participate effectively. In classrooms like the one we describe here, a hands-on exploration of some phenomenon is not limited to the most able students, however much that might facilitate matters. The same cannot be said for directors of a working lab, where participants are deliberately screened in the hiring process and are often assigned to a fairly limited role. The lab director in a university setting may actually have a mentoring role that involves an obligation to include novices in activities as they gradually develop expertise, but this model is still much more hierarchical and product-driven than an elementary or middle-school science or math class, where students with a wide variety of interests, skills, and preparation involuntarily grouped together in a classroom are called to participate collaboratively in learning activities. We can call this the *equal participation problem*. This problem forms a backdrop to the study of classroom mathematics and science practices: It suggests that they should be framed with attention to moral and intellectual dimensions.

Within the context of the Algebra Project, this moral commitment concerning the microdetails of classroom participation grows out of the philosophy that underlies the entire project:

> At the heart of the math-science education issues, however, is a basic political question: If the current technological revolution demands new standards of mathematics and science literacy, will all citizens be given equal access to the new skills, or will some be left behind, denied participation in the unfolding economic and political era? Those who are concerned about the life chances for historically oppressed people in the United States must not allow math-science education to be addressed as if it were purely a matter of technical instruction. (Moses et al., 1989, p. 423)

The Algebra Project philosophy requires that each teacher actively create access for each child—a considerable task in any classroom. In a classroom like this one—with a wide range of social class and ethnolinguistic backgrounds represented—the students add to the challenge by bringing their own attitudes and prejudices into the interactional equations that must be solved. As the previous vignette indicates, the authenticity and equal access problems interact in complex ways. Students can make it effectively impossible for teachers to create access for them (and even sometimes for others) in a variety of ways and for a variety of reasons.

As suggested in O'Connor (1996), the two problems sometimes reinforce each other for an insidious reason: For some of the more able students, the realness, and thus the value of an activity, is inversely proportional to the number of others it includes, particularly if those others are not viewed as intellectual equals. For some of the less able students, the perception that others are racing ahead of them results in a decision that this is not for me. To make matters worse, the arrogance of some of the more able students is easily perceived, leading even very able—but less confident—students to conclude that this must not be for me and to settle back to watch others carry the ball.

Classroom Goals as Simultaneous Equations

The three problems just described are certainly not the only things that differentiate lab science from classroom science, but they exemplify the sorts of differences that arise out of the unavoidable commitments of teachers. In effect, teaching goals and constraints like those described earlier form a set of simultaneous equations: An experienced teacher will seek a solution for this simultaneous set. His or her solution will be some pedagogical configuration that satisfies each problem, constraint, or goal to some satisfactory degree, allowing the teacher to make progress on his or her goals in parallel.

It seems to us that classroom teaching unavoidably has this property: Teachers are always in the midst of seeking a way to satisfy multiple (sometimes conflicting) goals and obey multiple constraints. The classroom thinking practices that we hope serve as a springboard to more complex forms of mathematical and scientific thinking exist within the fierce demands of classroom teaching. Unless we study them from that perspective, we will not appreciate their power as solutions to complex sets of problems, and we will not be able to ground curricular or pedagogical reform in a realistic model of the contexts of teaching.

The delicacy and complexity of the teacher's task cannot be overstated. The balance between real—and thus complicated—inquiry and full—and thus heterogeneous—participation is often extremely difficult, if not impossible, to maintain. Yet within a classroom with the moral and intellectual commitments of this one, the effort must be made, throughout the curriculum, every day throughout the year. We see the teacher's choice of participation structures and activity types as being a crucial part of the balance.

What activity structures and discourse practices could simultaneously satisfy these three constraints: the missing perspective and authenticity problems, and the equal access problem? Any teacher who has tried the method of requiring serial participation—stipulating that each person must contribute his or her views in turn—knows that this frequently results in a tedious and ritualized recital during which the thread of inquiry (and students' interest in it) can be lost. How does one create a classroom community in which all students have access to the floor and in which there is at least a chance that each student's contribution will be productively entertained, regardless of whether it carries the day? This requires enlisting the authentic cooperation of all class members—something that can no sooner be commanded into existence in a sixth grade than it could in any adult work setting one might imagine.

This complex accomplishment—this balancing—must be in place if classroom science and math activities are to lead to the development of scientific habits of mind for all students in an inquiry classroom. The rest of this chapter describes a discourse practice engaged in by Lynne Godfrey in the sixth grade mentioned earlier. It is a discourse practice that at first looks puzzling, but on analysis seems to provide a partial solution for the simultaneous problems described herein. We discuss its origins in service of the teacher's overarching goals, whether it serves to promote particular scientific habits of mind in the students, and whether it may allow students to explore complex concepts central to the particular material under discussion. Our purpose is not to present this as an example of an ideal instructional practice, nor is our purpose to critique it. Rather, it is to present in detail a particular instance of this discourse practice, after which we will be in a position to contemplate its properties and the affordances it might create for socializing students into certain thinking practices of mathematics and science.

PAULINA'S MISSING DATA POINT

Overview

On the day in question, all students were to enter on a graph their first ratio–the one they had chosen to mix on the first day of the lemonade concentrate curriculum. The graph's vertical axis indicated spoonfuls of lemon juice and the horizontal axis marked off spoonfuls of sugar. Although the students did not know it, the graph was to be used to explore several aspects of the relationship between the conventional space of a Cartesian graph and the meaning of the values they were plotting. They would observe that equivalent ratios lie on a single line (and could eventually discover the intuitive underpinnings of *slope*). They would also discover that the concentrates that had been rated as relatively sweeter would lie within the direction of the bottom right quadrant and the relatively more sour concentrates would lie toward the upper left quadrant. In addition to exploring the possibilities of cartesian space, they would become further acquainted with the mechanics of data entry in such a representation. The students would go through the process of (a) finding the ratio numerator on the x axis and somehow marking this point, (b) finding the ratio denominator on the y axis, and (c) finding the intersection of the two lines extending up and rightward from these values, respectively. They would then label the point with their initials and with an ordered pair representation of their lemonade concentrate ratio.

At the beginning of the session, as the students all sat in a circle in the area designated for discussion, Lynne began to ask students to enter their concentrate value onto the large piece of graph paper tacked to the wall. The range of y values (lemon juice quantity) was 0 through 50 and the domain of x values (sugar) was 0 through 31. One by one, over a period of 10 minutes, each student entered his or her value. The group members also made sure that their own personal records of other students' data points were accurate. Then Lynne called on Paulina.

Paulina realized that she had somehow failed to record the value for lemon juice in her original lemonade concentrate. She knew that the quantity of sugar she had used was two and a half spoonfuls, but in her notebook the lemon juice quantity was recorded only as somewhere between 10 and 22 spoonfuls. About five students seemed genuinely upset by this and turned to Lynne to ask what should be done. Lynne quickly turned it back to the class and posed this question: So, what are we going to do about Paulina's? The 20 sixth-grade math class members seated on the floor in a small area (10′ × 8′) discussed this topic for the remainder of the math class that day–approximately 35 minutes, through 184 turns. The discussion continued into the next day's math class, taking about 25 minutes and encompassing 141 turns.

During that discussion, four solutions were proposed in rough form and collaboratively refined into the following choices, which the class voted on:

1. The class should leave Paulina's lemonade concentrate out of the data set.
2. Paulina should use the average of 10 and 22 for her lemon juice value.
3. Paulina should make a new lemonade concentrate mixture and rate its sweetness, and those values should be used in the data set.
4. Paulina should try to reconstruct the quantity of lemon juice she had originally used by mixing up all the potential concentrates she might originally have mixed (2.5 spoons of sugar to 10 spoons of lemon juice, 2.5 spoons of sugar to 11 spoons of lemon juice, etc.). Then she should try each one, seeing if her memory were jogged by any concentrate in particular.

A great deal of active participation took place and intensity of interest was high. Finally, a vote was taken on the second day and the plan was carried out.

Negotiating Solutions to Unplanned Dilemmas

At this point, many readers may ask (some incredulously, if experience serves us) why it took so long to make a decision about this issue. What did Godfrey see in the unexpected dilemma that warranted spending so much time? What needs were satisfied and what goals were met in taking large portions of two lessons to discuss the unplanned dilemma—the missing data point? It turns out, on reviewing the ethnographic record collected by O'Connor over 2 years, that this question could be posed about several similar occasions throughout the year. Such unplanned dilemmas occurred a number of times through the school year. At least six or seven times, Godfrey would undertake to initiate and sustain a group discussion about possible solutions. Often the group discussions took an entire class session or longer—more than what most outside observers would expect a teacher to allocate to a problem that was not a planned part of the curriculum. To O'Connor, the observer, these sessions seemed to have an intense and vivid quality. Engagement was invariably high. Students seemed to experience these times as special. They would refer to them months later: "Remember the time we were trying to decide what to do about Paulina's missing concentrate?" The incident and its details seemed far more memorable than ordinary lessons.

This is the practice we examine next: In response to an unplanned dilemma of a particular sort, the teacher resorts to open-ended group discussion focused on reaching a group decision about how to proceed. What happens in each instance of this recurrent discourse practice is the same, generally speaking: The dilemma is laid out, students offer their solution strategies, Godfrey gradually aggregates these into groups of similar suggestions, and students align themselves with particular positions. In the process, reasons in favor of the speaker's own position are given, but arguments against the positions of others are formulated and responded to both by interested and third parties. Finally, it is usually the case that a vote gets taken and the winning solution is somehow implemented. Consensus agreement is an ideal that was sought, but rarely reached. The recurrence, intensity, and memorable quality of these episodes reflect a special aspect of Godfrey's classroom culture, a discursive practice that she purposefully orchestrates.

We might call this practice *negotiating a solution to an unplanned dilemma*. Two other similar episodes are described in Godfrey and O'Connor (1995) and O'Connor (1992). In the sections that follow, we examine in detail what happens during an instance of this activity, looking to see how the activity satisfies Godfrey's goals and constraints and how it provides access for students into some thinking practices or habits of mind associated with mathematical and scientific exploration.

FLAWED DATA IN CLASSROOM AND LAB

From the first instant, this episode reveals the depth of difference between the lab and the classroom. The dilemma in Lynne's classroom is what to do about a missing data point. Viewed from the perspective of many lab sciences, the decision about a flawed or incomplete piece of data is straightforward: When in doubt, throw it out. Editing rules or conventions about what to do with flawed data arise within the social milieu of every lab. Leigh Star (1983), a sociologist who has studied the work of laboratory scientists, claimed that "a rule of thumb pervades science: all data contaminated by error are discarded" (p. 221). From the perspective of classroom science, the corresponding decision is not so clear. In the lab, the decision about flawed data occurs against the background of a common understanding about the role and significance of each data point. The contribution of each data point to the larger project is well understood, thus a decision about when that contribution is threatened can be easily secured. These decisions are underwritten at the deepest level by the participants' understanding of the purpose of the work.

In the classroom, as stated earlier, this shared disciplinary perspective does not exist. Neither the discipline-based nor the pedagogical purposes of the activity are necessarily accessible to the students. Without a clear picture of the meaning of the flawed data point in terms of a larger goal, how can a decision be made about what to do? Any decisions about how to proceed must be grounded in some larger question, a question that is rarely addressed in classroom life: Why are we doing this?

A brief review of the proposed alternatives illustrates how much the plan for action depends on the actor's view of the larger purpose. The first suggestion, leave out Paulina's data point, echoes the scientist's rule of thumb. Yet Paulina's data point is her contribution at this phase of the activity. If it is thrown out, she is no longer represented on the graph. Depending on one's view of the significance of Paulina's symbolic participation, one could simply decide to choose a value arbitrarily (such as the average of 10 and 22), thus ensuring her presence on the graph. What about the sweetness rating that accompanied her concentrate? An arbitrarily chosen value would not have a sweetness rating. An arbitrarily chosen data point would be stripped of any meaningful history and would be merely a sentimental inclusion. Yet her original value, as the long class discussions reveal, is not recoverable from any records. Should she undertake to create a real new concentrate (Plan 3), or should she go to elaborate lengths to reconstruct the true original concentrate (Plan 4)? What hangs on the choice?

We show that, as the discussion proceeds, the students who propose and debate these alternatives are uniformly trying to get at this bigger question: What is the purpose of our enterprise here? Although this question is never explicitly voiced, it forms the background against which particular solutions are evaluated. Thus, Godfrey's discourse practice instigates and supports a general scientific thinking practice: the attempt to evaluate the consequences of alternative action plans against the larger purposes of the enterprise. Although the topic is certainly not one that laboratory scientists would debate for 2 days, the practice is one that permeates serious intellectual work in math and science at any level.[7]

Proposals About the Missing Data Point

What follows is a reduction of 2 days of discussion about the decision: 184 speaker turns on Day 1 occurring over roughly 35 minutes, and 141 speaker turns on Day 2 occurring over 25 minutes. Transcript sequences are interspersed with commentary.[8] Student discussion of various plans and purposes did not follow distinct, neatly ordered paths. Thus, the description

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[7]Of course the habit of anchoring one's action plans to one's larger purposes is not limited to scientific contexts—in some sense any rational action plan requires this. However, the habit of assiduously seeking to clarify one's goals and purposes and tighten the linkage between one's minute choices and largest purposes is perhaps developed more fully in the contexts of science than elsewhere.

[8]The transcript has been edited in several ways. Disfluencies, hesitations, and overlaps have been largely removed. When turn numbers are discontinuous, it indicates that some turns have been deleted; these were either disciplinary interruptions or irrelevant or redundant comments. Individual turns sometimes contain ellipses: These indicate that redundant, irrelevant, or uninterpretable material has been deleted in this version. Turns have been renumbered for this chapter: Turn 1 is Turn 162 in the original transcript. Turn numbers are preceded by a 1. or a 2. to indicate whether they occurred on Day 1 or Day 2. A single slash indicates nonfinal prosody, a double slash indicates sentence-final intonation. Bold typeface indicates prosodic prominence of some sort, either pitch or amplitude. Length is marked with a colon.

that follows is only roughly organized according to the sequence of topics in the 2 days of conversation. The reader will notice that several threads are interwoven throughout discussion of each of the alternative plans of action. First, some students are concerned with the social and pragmatic consequences of each plan for their fellow students, whereas others are concerned with the consequences of each plan for the interpretability of the data set as a whole. Second, it quickly becomes clear that many students know that, to find a solution to their dilemma, they should choose a plan that is sensitive to the larger purpose of their activity. It also becomes clear that the larger purpose of their activity is inaccessible to them for some interesting reasons.

Within a short time after Godfrey poses the question on the first day, the first three options described earlier (discard data, approximate old value, generate new data) have all been introduced by students.

1.2	Lynne:	**An**gie's question is/ so what are we going to do about Paulina's **con**centrate/ anybody have any suggestions/ ideas/ **th**oughts on that/ Larry?
1.3	Larry:	you can just draw a question mark//

The first student response notably misses the mark: Larry is viewing the graph as an unstructured wall chart. If there is a missing value in the ratio, it cannot be entered into the graph at all as an ordered pair. Lynne redirects the students. They are not just looking for something to write down on the graph paper; what is needed is a value for the missing data point.

1.6	Lynne:	you just draw a question mark// if we're going to use this information/ um/ to do **oth**er activities/ what do we do about Paulina/ that's the question/ cause we/ we'll need the **num**bers/ and we don't have/ **a** number for Paulina's amount of/ **lem**on juice/ so what/ what are people's ideas about that/ Hilary?//

Notice here that Lynne indirectly addresses the future history of the data point. She implies that there will be a reason to keep Paulina's data–to "do other activities" for which "we'll need the numbers." The enterprise is circumscribed as one that will require quantitative data, but nothing else is said. During the first few minutes, the first major choice point emerges–some argue that the data point should be discarded, others that it should be reconstituted in some way. The first actual solution to appear is the suggestion that the group could use the available data to generate a replacement that would at least approximate Paulina's original value for lemon juice. It is closely followed by the suggestion that Paulina's data point could simply be deleted.

1.7 Hilary: choose the number half way between/
1.8 Lynne: we could choose a number be**tween** ten and twenty-two/ half way be**tw**een/ u:m/ **B**ecky//
1.9 Becky: ... or/ you could just not **use** it //

Almost immediately students begin to offer strategies for rediscovering Paulina's original choice. Jane suggests guessing what her original lemon juice value was.

1.13 Jane: You could make a **guess** because of what **su**gar she has.
1.14 Lynne: We could make a guess based on the amount of sugar she has? How would we make that guess?
1.15 Jane: Well, she has/ two and a half spoonfuls of **su**gar/ **twenty-two** ... I mean she **mi**ght have done it but/ I don't think so/

Jane seems to think it implausible that Paulina could have "done it"—that is, could have chosen the extreme value of 22 spoons of lemon juice for her original concentrate. The students have now been making concentrates for a month, so they know that a concentrate made of 2.5 spoons of sugar and 22 spoons of lemon juice would be unbearably sour—essentially undrinkable. Thus, Jane seems to be arguing that we might be able to rule out at least some of the possible values of lemon juice in the range of 10 to 22 spoonfuls, purely based on their plausibility as one of Paulina's original choices given the small quantity of sugar in the mixture.

Almost immediately, Sarita argues for discarding Paulina's data point.

1.19 Sarita: I don't think we should use it at **all** either be**cause**/
if we have/ ... the **su**gar/
but we're not sure of the lemon juice? ok?
we won't know what it **tast**es like/
how it **sh**ould taste/
cause we don't **know**/ what the **re**al one is/
so if we use it/ and we're not really having the **tru**th/
it **might** be the right one/ but it might **not** be/
and we want/ what the **tru**th is/
we want it to taste like it **sh**ould taste/
and it might not be he:r **con**centrate ...

Sarita shows here that her construal of the situation involves an understanding of Paulina's data point as indexing a particular experimental observation: Paulina, along with everyone else, generated an original concentrate—the first one. She suggests that the observations or data collection must be uniform: Each point must be generated under comparable conditions or it will not be "true." When the first concentrate was composed, it consisted of a ratio and an associated sweetness rating. Arbitrary choice of a lemon juice value paired with Paulina's 2.5 spoons of sugar will result in another concentrate altogether—one that might taste quite different than the one Paulina originally mixed. Thus, if the class simply selects an arbitrary lemon juice quantity for Paulina to use, the chain of inference from original data collection to future inquiry would be broken because the causal relationship between the ratio and the perceived sweetness would be lost. Truth of the data point seems to involve both its origination (Paulina) and some sort of internal coherence.

Sarita is the first student to express an opinion about the reasons for a particular solution to the dilemma. Although there is no evidence that Sarita knows the purpose of the graphing exercise, she senses that the purpose of the overall activity should in some way determine the solution of the missing data point dilemma. Lynne revoices this, establishing the linkage between the original conditions of data collection and further findings and inferences based on the data.

1.20 Lynne: O.K./ O.K./ because we might/ we might **choose** the number that's half-way between/ or we might choose a**noth**er number/ make up **that** concentrate/ and then not find the same things that Paulina found when she tasted the concentrate she **did** make/

A little later, Ted calls into question the efficacy of any attempt to recover the original value. He doubts that any method will result in a dependable rediscovery of the original value.

1.38 Ted: well/ **I** was going to say/ these were supposed to be the number of our **fir**st concentrates/
1.39 Lynne: M-mm/
1.40 Ted: so if she made another one/ it wouldn't really be **accurate**/ I mean/ it would be the accurate **num**ber but/
it's not her **first** concentrate/

Ted is reiterating Sarita's point: A data point composed of a new value will not have been generated under the same conditions as the original. Lynne pushes him to make explicit his reasoning: What makes him think that a new concentrate would not be equivalent to the first one for the purposes of this exercise?

1.41 Lynne: M-hm/ it's not going to be the **fir**st concentrate Paulina ever made in this room/ and/ so what if it **is**n't?/
is there some **re**ason why you think/
if she makes another one/
it can't be counted as the first one?/ Ted//

1.42 Ted: cause it's kind of like a **make-up** one/ . . .
it's like/ it's like/ . . . in the first one she made/
she didn't/ keep track of how much she had/
so this one/ this would probably be like her . . . **twent**ieth/
because/ people who made a lot of concentrates/ I mean/ they wouldn't/do the same thing// if you hadn't called it the **first**/
you could call it a **make**-up for her first/

1.45 Lynne: Is there a difference between a first concentrate and a twentieth concentrate?

1.46 Ted: well/ in the/ in the am**ount** there isn't/ but/ just if you're thinking about the numbers like/ . . . **now**/ she knows a lot . . . about com**par**ing and/
what amounts are going to **tas**te right and/
and like half and/ four-eighths and/ three-sixths will taste the **same**/ or whatever xx/
she didn't **know** that then/ so she would have more **kn**owledge now and the concentrate might/ be a lot **dif**ferent now/ then if she had done it **th**en//

Ted's comments reveal that he is thinking about the differences in Paulina's knowledge states now versus when the original concentrate was mixed. Conditions have changed–the meaning of Paulina's data point will be different now even if she chooses or mixes it herself. So Ted is concerned with more than who originated the data point. Like Sarita, at this point Ted is concerned with the relationship between the conditions under which the data was collected and the possible inferences that can be drawn about the data. However, note that this concern with the potential validity of a new data point is going on in the absence of any clear idea about the purpose of the lemonade concentrate graph. Without a clear idea about the purpose of the graph, the students cannot truly come to a final conclusion about whether a newly chosen concentrate value will be equivalent to the original one. The question "equivalent with respect to what purpose?" cannot be answered.

Steven, a thoughtful student who wants to be a marine biologist when he grows up, agrees with Ted that if Paulina makes an entirely new concentrate it will not be like her first one. However, he points out that if she keeps the sugar value the same as the first concentrate and picks the average of 10 and 22 as some have suggested, it will not be identical but at least close. Steven is focusing on the relation between data point value (lemonade concentrate value) and potential data point meaning: How close does a substitute need to be to be close enough? This line of thinking suggests that Steven is considering the logic of the inference chain: How close does the new value have to be to support the same inferences as the old value? The logic of any chain of inference in an experimental activity is at least partially determined by the type of problem to be solved, and Steven does not have full access to this.

Steven is apparently working with the idea of how a data point is related to the meaning of the larger object of which it constitutes a meaningful part. On the second day of discussion, several other students touch on the same topic. They voice concern about the strategy of leaving out Paulina's data point. Leaving out her data point will have an impact on the actual results of future projects—specifically, future inferences based on the graph. Sarah projects a hypothetical situation in which the class would query the data set at some point in the future. In a discussion about the plusses and minuses of leaving out Paulina's data point, she describes a scenario in which the absence of Paulina's concentrate value would undermine the validity of the data set as a whole.

2.13 Sarah: a minus might be/like/like/if we had to do a project using everybody's/um/then/we wouldn't have **hers**/to **do** it// . . . then/it wouldn't be/**accurate** . . . cause/like if we were finding an **average** or something/it wouldn't be **accurate**/cause/one of them would be **missing**//

Notice that Sarah has a notion of accuracy that crucially involves representation of all members of the class. The average she is envisioning is not simply an average of all values in a data set. If it were, then accuracy would be determined only by the available values and the accuracy of the computation. Rather, she is talking about the validity of any statement about the class as a whole derived from the data set. If all members of the class are not included in the generation of data points, the meaning of the outcome as a statement about the class as a whole will be weakened. Although nothing more has been said about the purpose or meaning of the graph, Sarah assumes that it must have something to do with the whole class. This kind of assumption is well founded given the nature of much inquiry math and science in schools. We return to the differences between this assumption and those that underlie lab science later.

Later Jane displays a similar understanding. In discussing plusses and minuses for the "choose the average" plan (give Paulina a value that is the average of 10 and 22 spoons of lemon juice), Jane objects that this will somehow destroy the internal consistency of the data set. It may allow Paulina to be represented, but it will invalidate certain kinds of inquiries that might lurk in the future, for which the class would have to use this data set. Like Sarah, Jane is imagining a possible inquiry that the data might support: Nothing like this has actually been proposed.

2.52 Jane: . . . a minus to that [using the average] is/
that . . . it won't be the one that she made up **first**//
and . . . if you were trying to **do** something/
like to see how you can prove/

> . . . **how** you **like** the **first** concentrate you make
> and the **last** concentrate you make/
> it wouldn't **be:** your first **con**centrate/
> so you wouldn't be able to **do** it//

The contributions discussed so far show students grappling with the logical meaning of the missing data point within a larger—presumably intellectual—purpose. They are attempting to evaluate its use as a link in a possible chain of inference: What set of criteria does the data point have to satisfy to count as a legitimate member of the graph?

Alongside these contributions occurred others in which students displayed concern with the social meaning of the missing data point. In an experience-based classroom activity like the lemonade concentrate curriculum, the norm is that each student must have a comparable piece of the action. In this case, to be fair, each student must have a data point. Some of the following excerpts suggest that the conditions under which the data point is generated do not matter; what matters is that the same person gets to generate a data point. This position, in which the data point stands as a token of participation for each student, emerges most clearly in the second day of discussion.

Lynne starts the second day of discussion by reviewing the options. She asks students to give plusses and minuses for each of the options, starting with the first one: throwing Paulina's data out. It immediately becomes clear that the most salient drawback to this option for these students is the fact that Paulina will not be included. Steven begins by groping to express this worry: ". . . the minus is that Paulina would be in—sort of—she, she won't be—" Lynne fills in: "She won't be represented by a concentrate?" Steven looks worried and says, "yeah." Several other students allude to this scenario, asking what Paulina will do if, in the coming weeks, all the other students are given activities to carry out with their first concentrate value. Jane worries that Paulina might feel left out.

Paulina then asks whether leaving out her data point would "cut my chances for participation." Lynne looks through the activities remaining in the book and concludes that it would not. She reassures Paulina: "O.K. I'm looking through the following papers to see if you'll be left out if you're not represented, a:nd the answer i::s . . . you will **not** be left out. You can still do the work without having your concentrate on there [the graph]."

These students' concerns show that they are viewing the situation primarily as a school activity like other school activities, in which a paramount value is access to participation. This is a value clearly shared by the students and Lynne. As the conversation continues on to the other solution options, we can see that the value of participation is motivating some of the students' suggestions that a completely new concentrate value should be provided for Paulina. In these students' turns, there is little emphasis on the meaningfulness of the relationship between the conditions of data collection and the eventual interpretation of data.

During this part of the discussion, some students seem to agree that Paulina has to participate—that simply choosing a new value is an easier plan of action relative to those that require remaking and retrying new concentrate values in an attempt to find the original. At this point, Lynne seeks to clarify the overall goal:

2.42 Lynne: O.K. /well/like/I need to ask a question//
is our **goal** here/ if we decide that Paulina needs to make another concentrate/
is our **g**oal in having her make another concentrate/
to get her to make a concentrate that's **clos**est/
to the one that she/ o**rigi**nally made/
or is our goal just to have her make a**noth**er **con**centrate so we can/
add her data to the **rest** of the data that we already have/ or/

Students respond to Lynne's attempt to clarify the purpose. Some students seem to be assuming that Paulina is simply looking for a number to substitute into her ratio. This, like the strategy of mixing a new concentrate value, accords with the view that Paulina just needs a token to participate. On this view, the average of the possible values 10 and 22 will give an adequate approximation and will keep Paulina in the group inquiry process as well. Ted lays out the contrast between making the concentrate and just using the numbers, sounding dubious that anyone would go to the trouble of actually making the concentrate.

2.44 Ted: **I** thought she was going to be like/she wasn't **mak**ing the concentrate/ . . .
that would be what her concentrate **was**/she would say//
Do you mean like/**mak**ing the concentrate like/**p**utting things in/and like/**mak**ing the concentrate?
. . . I think if/ . . . she was going to use them/ that she could just use those **num**bers/

Ted, the student who loudly reminded his colleagues that "this is just a half-hour math class" in the vignette presented earlier, is arguing now for a plan that will give Paulina a value to use in entering a data point—a value that will take minimal investment of time and effort. The day before, Ted had wondered about the linkage between the conditions under which her original value was collected and the inferences that could be made about the data. Today, the second day of discussion, he seems to be arguing that, for purposes of doing math/science activities, any value will do as long as it maintains the normal state of affairs in which each student has a token with which to participate. This stance is actually more characteristic of Ted than the one he evinced the day before. Throughout the year, Ted would—sometimes loudly—object to the amount of time spent discussing alternative viewpoints, generating multiple solution paths, and following up unplanned occurences such as this.

Paulina seems to concur with this view at one point during the second day. Given that she will be represented in the activities, that she is unlikely to remember the exact value, and that the averaging method is the easiest, the averaging method may be the best compromise.

Finally, we turn to the fourth proposed plan of action: Try for an actual reconstruction of Paulina's data point. Students' proposals about ways to reconstruct Paulina's actual lemon juice value range from simple (guessing) to complex (an elaborate testing procedure to jog Paulina's sense memory). This type of proposal emerges early on the first day.

1.24	Angie:	Well/ um/ she could make another concentrate/ or she could take a wild guess to/ um/ what she **thi**nks it was?
1.28	Lynne:	take a **wild** guess?
1.29	Angie:	ah/ not really a **wil**d guess/ but like/ ah/ a guess to what she thinks it **migh**t have been//

Angie proposes to directly tap Paulina's own capacity to retrieve the information from memory. Soon another student, Molly, picks up the idea introduced by Angie. Molly directly questions Paulina, asking her if she remembers whether her first concentrate was sweet or sour. It becomes clear that Paulina is not only missing the lemon juice value, but is also missing the sweetness rating. Paulina does not remember at first, but then one of her teammates recalls something: "I remember—she kept going 'ugh, it's sour.' " Molly then suggests that attempts to reconstruct the original concentrate should aim at a sour mixture. However, it soon becomes clear that this is a dead end. Almost any value of the possible range of lemon juice quantities—from 10 spoons to 22—would be rated as sour.

Molly then makes the first suggestion that proposes an explicit strategy to reconstruct the original value. She suggests that a likely concentrate value be mixed and then given to Paulina—perhaps she will recognize it as her original concentrate. Jane's turn, immediately following, may be an expansion of this suggestion:

1.72	Jane:	um/ well/ when **aft**er we had done our concentrates/ our **team**mates/ tasted them// so maybe her **tea**mmates could help you//
1.73	Lynne:	oh/ cause her teammates might even remember/ or have some/ record of what her concentrate **tas**ted like//

Molly's suggestion reveals her construal of the situation: The linkage between Paulina's original experience with lemonade concentrates and her official data point is crucial. It should be maintained, and the class should allocate time and effort toward restoring the original value. She seems to be expecting that the class could succeed at this effort: The original value could be reconstructed.

At this point, Alex introduces an interesting objection to Molly's proposal. He seems to be assuming that any effort to reconstruct the value will fail and, at best, the reconstruction will be a substitute for the real value that is lost in the past: One cannot assume reliability in running the same experimental subject again.

1.78	Alex:	um/ well/ Molly's idea is good/ but like/ it would never be a **fi**rst one cause like/ if I got a **d**og? and then/ he ran a**way**? and my mom/ like/ got a dog exactly **li**ke him?
1.79	Lynne:	M-mm/
1.80	Alex:	and **g**ave him to me/ and I I'd probably know/ it wasn't/ the dog I had be**fore**//

Next Steven contributes further to this analogy. He continues Alex's weirdly sentimental assessment of Paulina's missing concentrate value.

1.84	Steven:	I kind of think/ um/ I agree with **Al**ex cause/ like/ **I** once had / you know a dog that **died**/ and my mom said/ that the **ne**xt dog that we get is going to be just **like** it/ . . . and I said/ to her/ but it's not going to be the same **do**:g/ not the sa:me ni:ce do:g/ calm and fun to play with/ and/ so/ I agree with Alex . . .
1.87	Lynne:	that when your first dog dies the second one's not the same?
1.88	Steven:	yeah/ right//
1.89	Lynne:	O.K./ Hilary//
1.90	Hilary:	well/ I think these concentrates are **not** like **d**ogs.

Hilary, also an excellent student in math and science, flatly rejects the analogy the two boys had somewhat dreamily been pursuing. She goes back to the suggestion that Paulina may have written down the sweetness rating of her concentrate in an earlier part of the workbook, where the taste was supposed to have been written down. Hilary is seeking a way to reconstruct the original value, but Alex and Steven have indicated that they too think the original value is extremely important.

Lynne soon calls on Tony, a student whose contributions to discussions are often long turns that are seemingly tangential and difficult to follow. As background to his suggestion, it is important to know that, during the preceding weeks as the students investigated the question of whether equivalent fractions would taste the same, they had figured out that students' expectations about the matter might bias their judgments. To ensure unbiased judgments, they devised a blind tasting procedure that involved both coding of the concentrates and blindfolding of the taster. This activity was intensely followed by all and was designed and redesigned by the group to get rid of taster bias.

In this turn, Tony is intensely involved in making his suggestion—a suggestion that O'Connor as participant-observer found completely opaque, but that Godfrey seemed to have no trouble interpreting. What he suggests is that the group prepare a set of concentrates made up of all the possible values Paulina might have used using the blind tasting procedures the class has developed. Tony predicts that, like a wine taster, when Paulina tastes the correct one she will recognize it. (Tony's turn is reproduced here relatively unedited.)

1.98 Tony: um/ well/ I don't agree/ with um/ doing the testing/ um like/ drink um **mak**ing another concentrate/
but if if we came/ if it came down and we **did** have to do that/ then we would have to like **d**o that/ um/ **choic**e thing again/ like when/ we/ because we were **bli**ndfolded
and then we'll say/ like **which** is **which**/
and **may**be **m**ight **gra**dually come **back** to us/
she'll re**mem**ber/
cause/ if if she blanks out **all** the rest of the concentrates that she **tasted**/ then/ and then she drank **this** certain one/
then she tried **all** all through ten and twenty-two/ **ma**ybe and/ **af**ter we'll give it like fi:ve **mi**nutes/ so the taste would/ um/ disap**pear** and then it might come **back** to her and/
and she might say well um/ it was/ it was sort of like **this**/ but it was more on **this** side/ of ...
of the um/ of how it tasted than **this** one/ and then she'll/ we would **ski**p this part/ this one would be **out** of it/ so that'd be one **less** and then/ and then you narrow it down/ until you get one/ that you/ and that she says well/ **this** is what it tasted like/ and so I think/ I think it's going to be **hard** for me/ but I can/ I can/ if I can just remember a little more about what I did/ and I know I have like/ two and a/ and then I'll say/ **oh**/ well/ and so and so and you see/ when you put/ you try um to help that person by/ making sweet and sour ones/ because/ then she/ then that person/ you **don't**/ we don't really have any evidence that/ oh it was sweet or it was sour/ but she **thinks** so/ so/ if sh/ if she thinks a little more harder about it/ maybe it might

come **back** to her and she'd remember it because that happens to me too!

1.101 Lynne: Leon what do you think about Tony's idea?

1.102 Leon: I think it's a really good idea!

At least Lynne and Leon seemed to have no trouble understanding the proposal. Lynne quickly gives a revoiced and clarified version of Tony's proposal.

1.103 Lynne: So/ let me just repeat Tony's idea again which was/
if Paulina/ was blindfolded and we made up concentrates/ and used all of them that would have two and a half spoonfuls of sugar/
because that's what she had in her first concentrate/
and **then**/ there would be/ a concentrate that had two and a half spoonfuls of sugar **ten** spoonfuls of lemon juice/
then the next one would be two and a half spoonfuls of sugar **elev**en spoonfuls of lemon juice and **so** on/ Tony/ all the way up to **twenty-two sp**oonfuls of **le**mon juice/ and she'd keep tasting each one/
and like between each one she'd take the water or wait a few minutes/ before she tasted the next one/ to see which one/ reminds her the most of the one that she made in the first place?/

1.104 Tony: **yea::h/**
Yea::h and/ and what after she drinks it/ she would say/ well **this** one/ **no**/ this one doesn't taste like **that**/ so this is **out** of it/ this is out/ of/ out of the section so/ we don't bother with this one/ and we keep on going until/ we narrow down between these two and then/ she'd taste it and then she'd say/ m-mm/ well **this** one/ it it's coming back to me/ and then we'd try to fi/ get all the um/ like from um books and people around her in a group/ and then/ and with **that** and with um/ this/ my **idea**/ and for/ and with **help** from her teammates that/ which/ she wrote where they wrote it down and stuff/ maybe that might give us a **clue**/ of what it is/
narrower and narrower /
instead of ten and twenty-two it might be/ it might cut down/ to like/ two and/ four**teen** or two and **six**teen/ then/ and then we can still narrow it down **more**/
because we won't be using **every** single number/

1.105 Lynne: **I** get ya/ **I** get ya/ so the ones that she e**limi**nates/ we just take a**way**

Tony's proposal injects into the discussion a new element. He proposes that, by using this multiple challenge approach, the students will be sure to re-create the particulars of the moment when Paulina originally tasted her first concentrate. The re-creation of the critical elements will allow her memory to move from reconstruction to recognition.

A long series of turns follows, in which some students (most notably Ted) attempt to defeat Tony's proposal by deeming it implausible. Although many of them seem intrigued at the possibility of actually finding Paulina's original concentrate, their arguments tend to run along the same lines: How likely is it that after more than a month Paulina will recognize the correct lemonade concentrate? During this month, she has been tasting dozens of other concentrate values. Why should she remember her first? Tony continues to insist that when she tastes the original concentrate it will come back to her.

It becomes clear that Tony's proposal is not simply to help Paulina come close to the original value. It is to remember with certainty what that value is—to recognize it. Tony's certainty that the plan will work suggests that he is a person who can recognize tastes. Like perfect pitch, it is an ability that not everyone has. It is clear the class is divided between those who see this as a plausible strategy and those for whom it makes no sense (or those who want to claim it makes no sense).

After some skeptical comments from other students, Lynne poses a question to Paulina, making the proposal a target for inquiry:

1.151 Lynne: can I ask something? whether the group chooses to use Tony's suggestion or not/ . . . would you be willing to undergo that test afterwards anyway?
to see if it were possible to have your **brain** and your **t**aste buds and/ the information from your **t**eam members all working to**ge**ther to get you to the (answer)
and to see if in fact/ if something like that would happen that/
it would go like/ **d**ing! this is the concentrate!

Paulina agrees that she would be willing to try that to see what would happen. After this, Sarah (the student whose question Ted dismissed in the prior small-group vignette) provides a warrant for Tony's implicit theory of sense memory based on an experience of her own in another modality:

1.168 Sarah: well/ it's about Tony's idea/ um/ well/
I think that/ it's worth like/ trying cause/ it's sort of like yesterday was/ was **pic**ture day/ and **two** **y**ears ago I had my/ my passport picture taken?
cause . . . my passport/ expired/ so um/ . . .
there was a woman who took it/
and then I totally forgot about it/
and then **yes**terday/ it was the **s**ame **wo**man/
and I **rec**ognized her then/

> but I hadn't . . . even/ remembered her at **all** before that/ then
> I **rec**ognized her **yes**terday when I saw her again? . . .
> so I think that/ it might be sort of like **th**at/
> like/ Paulina tasted it/ a**while** ago and then she forgot/ what it tasted like/ then if she tasted it again then it would/ then it would be like tasting the same **thing**//

On the second day, it becomes apparent that a number of students are attracted to Tony's proposal, but there are some obstacles. For one thing, it will be messy and time-consuming. Yet few are willing to dismiss it completely. Larry steps in and suggests a new methodological twist–one that elegantly solves the problem of time and messiness. Larry suggests that the averaging method (find the average of 10 and 22) and Tony's taste test plan could both be incorporated in a solution. He proposes what is in effect a binary search algorithm as an improvement to Tony's proposal: Make up a concentrate using the middle value–2.5 spoons of sugar and 16 spoons of lemon juice (the average)–and give that to Paulina to taste. If she thinks her original concentrate was sweeter than that, her potential set of concentrate samples would be cut in half: She would only have to taste the values of lemon juice lower than 16 spoons. If she thought her original concentrate was more sour than the middle concentrate, she would only have to try the concentrates in the upper half of the range of lemon juice values. (Of course this procedure can be iterated in a manner that makes it the most efficient procedure for this sort of search.) Students responded in a positive manner to this proposal: It would support the goal of reconstructing the actual value and it would not be as laborious as the solution Tony originally proposed. In fact, over two thirds of the students ended up voting for this modification of Tony's proposal.

As the group lumbers toward a decision, the different positions have become more clearly articulated: There are competing goals and constraints, some social, some quasiscientific, some based on efficiency considerations of some sort. Each of these reemerges as the discussion nears a close on the second day, with students rapidly cycling through all of them. Sarita reenters the conversation, arguing that "we shouldn't use [Paulina's data point] at all" because, as Lynne discovered in looking ahead in the book, there are no future activities that require Paulina to have a concentrate value, and "it takes too **long** to try and do a **t**est for like **ten** of them . . . it takes . . . the whole **m**ath period . . . but if we don't even **n**eed it, really, why should we **do** it?" Sarita has now argued for the discard option on two bases: (a) because the original value–the true value–is not reconstructable and so the data set will be cleaner without a data point from Paulina, and (b) because it is not needed to ensure Paulina's continued participation. To preserve Paulina's participation, Sarita's notion of a clean data set, and her desire for speediness, Sarita argues that they should just go on without a concentrate value for Paulina.

Jane counters Sarita's opinion, arguing for the higher value of ensuring that Paulina still feels connected, a participant with a token, even if it will have no bearing on the eventual purpose of the data set:

2.102 Jane: well/I think that/if she were going to use it at **all**/
and you **d**on't really need it/you **should** use it/
you would **use**/um/Paulina's concentrate because she's part of the **group**/and
if you **did**n't/it's like/even though we don't **n**eed it/
she **is** still part of the group//

Larry agrees with this. Tony, who originated the labor-intensive strategy aimed at re-creating Paulina's original value, shifts course now and makes another radical suggestion. Maybe the class should just do nothing! If the class does nothing, Paulina will still be a participant in the activities of the group. If at a later time they find that she does need an actual concentrate value, they can decide what to do then.

Larry is stumped. He asks Lynne: How can it be that Paulina could participate without a concentrate value posted on the graph? Sure, she could follow along in the steps the group followed, but what if they did come to some point in the future when Paulina did need a concentrate value? What then? Paulina agrees: What if some unanticipated event gives rise to the need for her to have a concentrate value? Steven announces that he also disagrees with Sarita—he would feel that it was unfair to be left out if it were him. Then Lorna responds to Larry and Tony: "Why should we go back and do it **af**ter when we can do it **now**?"

Finally, to everyone's relief, discussion is cut off and a vote is held. One by one, hands are shown for each of five options: (a) discard the data point, (b) make a new concentrate using the average of 10 and 22 for the lemon juice value, (c) make a completely new concentrate with taste rating, (d) have Paulina test all the possible concentrates to find the original, and (e) test all of the possible concentrates starting with the concentrate in the middle as described earlier, thus narrowing the field of candidates.

Thirteen out of 19 vote for the fifth option, with the other six spread throughout the other options. Lynne makes the observation that "that's the democratic process, where the majority happens to rule. It's not the [name] Program process where we try to do things by consensus. But we don't have time to do it by consensus, so we'll go with this last one." Surprisingly to some, when the experiment was carried out, Paulina actually did experience the recognition phenomenon that Tony's Proustian theory of memory predicted. She recognized the original concentrate she had mixed: 2.5 spoons of sugar and 14 spoons of lemon juice.

DISCUSSION: BALANCING PROBLEMS AND PURPOSES

The flawed data situation, in which a scientist must decide what to do with an observation that does not fit the current experimental specifications, is one of the most obvious sites of simplification within scientific work. The world of physical experience is ill structured, as Star (1983) and others have pointed out. To create a well-structured problem to work on, simplification processes of many kinds are tacitly and explicitly negotiated, both among coworkers and in the discipline as a whole. Star showed that simplification processes, including the editing rules mentioned earlier, are driven by the constant need to reconcile one's larger purposes and theoretical commitments with one's many constraints to accomplish an analysis that will be recognizable and well structured.

In Star's account of the complicated nature of work agreements about flawed data, a solid ground of shared presuppositions is evident. It is clear that to have such work conventions, these workers must share a view of their purposes and commitments and what it will take to create a well-structured data analysis. To freely use the decision rule that Star described ("When in doubt, throw it out"), a member needs to have access to an interpretation of the consequences of particular kinds of error, artifacts, and snags, and their consequences for later outcomes, goals, and actions—all highly context-bound and locally negotiated knowledge. For the scientist, each data point represents an entire chain of conventions, decisions, understandings, and choices. Each data point embodies a piece of that scientist's attempt to construct an inference chain that will be recognized by others in the field.

In the case of our sixth-grade classroom, both teacher and students are engaged in constructing their own editing rule in this particular case. Because there is no standardized set of commitments and understandings to guide their decision, they must jointly find such a set and agree on it to whatever extent possible. Godfrey could easily have made the decision for them. She could have imposed a decision rule like the one Star described: "When in doubt, throw it out." Given the purposes of the graph, of which Godfrey is aware but the students are not (learning about point plotting and exploring relationships between regions of the graph and properties of the concentrates), Paulina's concentrate value was probably not needed. There were plenty of others already entered into the graph. There was no required number of observations—no tight linkage between the number of observations and the inferences to be drawn. On the other hand, Godfrey might simply have decreed that Paulina's personal involvement was paramount. She could suggest that the class accomplish the equivalent of running another subject or redoing the task: Paulina could have been directed to generate an entirely new concentrate ratio, with new values for lemon juice and sugar, or could have been directed to choose another value for the missing lemon juice at random.

The reconstruction of Paulina's original lemon juice value seems the least likely option, given that almost a month had elapsed since Paulina had tasted the concentrate and the lack of a record of the exact value. It is unlikely that Godfrey would have suggested this option. (Notice that in the neuroscience lab described by Star there is no clear analogue to this option. One cannot ask the rat or neuropsychology patient what value they originally yielded or might have yielded.) How did the decision emerge from the group to try and reconstruct the original?

In the process of trying to construct a decision rule, the students were engaged in trying to balance their commitments and resources. To rationally decide what to do about a missing data point, one must review one's larger purposes: Do we need the missing piece? Why or why not? Due to their lack of both pedagogical and disciplinary perspectives, the students have no clear answer to these questions. They search for reasons to choose one alternative over the others and they find reasons that help them narrow the field of alternatives. Some make reference to social norms: Paulina must be included. Some make reference to inchoate scientific norms: The data points that compose a particular object must be generated in the same way. Random or unprincipled substitution of values is not okay. Still others make reference to constraints on resources: What will each of these alternatives cost in terms of time, effort, and messiness, and is it worth it?

The outcome–choice of the streamlined version of Tony's proposal–can be viewed as the students' solution to a set of simultaneous equations of their own: Each of the perceived goals or constraints is satisfied to some extent by the solution they devised. In the absence of a clear metric against which to judge the logical or scientific role of a particular data point, they found it safest to reconstruct the original–Paulina's true concentrate value. This also satisfied the goal of equal participation, valued by at least some of the class. Efficiency gave way to some extent to the preservation of the original. (Tony and Paulina will construct the set of concentrates during recess so as not to take up class time, thus efficiency is not completely ignored.)

The students' response to their dilemma is authentic. There is no predetermined answer to the dilemma, and Godfrey does not give them one. Together they must construct an answer that satisfies them. In doing this, they have had an opportunity to reason at length: a rare activity in many school settings. Moreover, they have had practice in reasoning at length about the relationship between purposes and actions. They were not given a solution–they were forced to construct one.

Fostering Habits of Mind

What is the possible value of this kind of discussion for these students? We would argue that the teacher's discourse practice of negotiating a solution to an unplanned dilemma supports the development of scientific habits of mind in several ways: The student discussions may appear to be quite different from what one finds in a real-world lab, but the students' thinking together actually reflects values that are commonly associated with the ethos of scientific work. Although the topic of this particular dilemma would usually pose no problem in real-world science, the process it represents is a good example of the habits of mind we want to foster. Within a real lab, a dilemma would naturally call forth the kind of response found here: a focused consideration of possible paths of action, a consideration of the consequences that would result, and a reconsideration of the purposes that those actions and consequences would serve. The anchoring of details and subparts to an overarching purpose is an intellectual activity that permeates scientific inquiry of all kinds. This discussion provided students with extensive practice in seeking to clarify purposes and linking competing plans of action to those purposes. Those who view classroom activities as potential sites for socialization into particular intellectual practices might see in this incident a rich opportunity for students to participate in this cognitive activity.

Habits of mind are more than skills and abilities–they also encompass values and inclinations. In addition to developing the critical response skills to engage in this type of reasoning, teachers must help students develop the inclination to engage in it when an appropriate problem arises (American Association for the Advancement of Science, 1993). By allowing the students to take 2 days to attempt a principled solution to the dilemma, Godfrey is letting them know in the strongest way that careful consideration of purposes and consequences is a top-priority, highly valued activity–one for which it is worth postponing the regular lesson.

The specific dilemma that triggered this episode also carries a scientific value: the issue of keeping clear and accurate records and resisting the urge to change them if a problem arises. Instead of simply telling Paulina to choose another value of lemon juice–any value–Godfrey spent two class periods on the issue of what to do. Again the time spent is a direct testament to the value she places on the importance of honoring the documentary record of an inquiry project. Projects like this one "establish realistic contexts in which to emphasize the importance of scientific honesty in describing procedures, recording data, drawing conclusions and reporting conclusions" (American Association for the Advancement of Science, 1993, p. 286).

Solving the Teacher's Simultaneous Equations

How does this discourse practice—negotiating a solution to an unplanned dilemma—work for the teacher in her attempts to solve her own set of simultaneous equations? In each instance of this teaching practice through the 2 years O'Connor observed, Godfrey conducted a discussion for as long as it took to come to some kind of jointly constructed solution, with all of the students participating in one way or another. The various dilemmas that called forth this discourse practice throughout the year were all open ended and had no obvious solution. (Other examples are given in Godfrey & O'Connor, 1995; O'Connor, 1992, 1996.) Like this one, they took place in the midst of the unclear purposes and goals that are a persistent part of science and mathematics inquiry in schools. Lacking both a discipline-based and a pedagogical perspective to organize and motivate their work, students must operate in a twilight of shifting and unclear purposes. Within this milieu, the authenticity problem often arises, even in the best of inquiry classrooms.

In the absence of a disciplinary perspective, the authenticity of an activity has to be secured in some other way. By allowing the students to construct their own reasoning about their group choice of strategy, Godfrey has enlisted them in determining for themselves what purposes and goals the activity entails. Moreover, as evidenced in this discussion, all of the students participate—even those who are not viewed as the most academically able. Thus, this extended negotiation also served to satisfy to some extent the equal access problem. All of the students were engaged in determining the meaning and purpose of their activity. The final solution chosen by the group was originated by a student who regularly attends Chapter One classes and was adopted despite attempts by some of the more privileged students to quash it. Godfrey's orchestration of this type of sustained discussion, the negotiation of a solution to an unplanned dilemma, served as a way to at least partially solve three simultaneous problems.

Learning What a Data Point Can Mean

Beyond the general habits of mind discussed earlier, was there any benefit to this discussion in terms of the mathematical or scientific content of the activity? In our view, there was—it provided students with an opportunity to explore a concept and a related form of representation. In this case, students were considering the nature of the relationship between their own history of actions in the classroom and the nature of a mathematical and scientific representational entity—a data point on a graph. Rarely are such essential linkages pondered at any length: It is difficult to know how one would present the topic—what is the meaning of a data point? The question is less than compelling when considered in the abstract; one expects its answer will always be completely situated within a particular work context. Furthermore, data points and their relation to higher order aggregations and representations are so pervasive in science that many scientifically sophisticated people (including many teachers) would regard the answer as transparent. If we compare what actually is assumed or known about an ordinary data point of any kind in an experimental graph with what these students know or seem to assume, we can see how complex the notion truly is, particularly in the nebulous environment of classroom math and science.

This problem is analogous to that pointed out by a number of constructivist theorists in the area of mathematics learning. They decry the widespread belief among educators that simply presenting students with manipulatives—concrete objects intended to represent various kinds of mathematical entities and relations—will automatically result in students intuiting or constructing the intended understandings of the mathematics; that the manipulatives are (at least partially) transparent. Cobb, Yackel, and Wood (1992) argued that experience contradicts this belief and thus suggested a research strategy:

> The problem of explaining how students make constructions compatible with those that the expert has in mind seems intractable as long as we fail to make our self-evident interpretations of external representations an object of analysis. We experience mathematical relationships as being readily apprehensible in external representations precisely because we assume that our interpretation of the materials is shared with everyone else who knows mathematics. . . . As long as we continue to assume that these interpretations are self-evident, we do not consider the possibility that they might be but one of a variety of alternatives or that students might not see what we see. Further, if we assume without question that the relationships we have in mind are in the students' environment waiting to be perceived, our only recourse when our initial attempts to bring the relationships to their attention are unsuccessful is to be increasingly explicit and spell it out for them. In doing so, we open ourselves to the possibility that the students will take form for substance and merely learn to behave in ways that convince us that they see what we consider self-evident. (p. 9)

To experienced eyes, a data point on a graph may imply a quite transparent relationship between the originator of the data point and the higher purposes of the aggregate representation. It presupposes a generic understanding along the following lines. First we have the scientist, perhaps a lowly assistant, but locally the director of the activity—the actor actually charged with making the observations and recording them. Second we have the experimental subject: the rat, the student, the neurologist's patient. This participant is destined to be erased from the permanent record of the lab activity, at least as a particularistic entity. Third we have the data point, which is a distillation of the contextually important aspects of an experimental/observational history. Each data point has a future history within whatever forms of representation are selected to support inferences and conclusions. Each experimental subject has no role beyond its contribution of a data point.

In one of his social studies of science, Lynch (1985) dramatically described the careful, conventional, contingent processes whereby an animal (or other entity that is a target of observations or treatment) is rendered step by step, by the acting scientist or his assistants, into a set of data points that support discipline-based scientific reasoning. In a study of experimentation involving animals, he observed that

> The graphic display [the aggregate depiction of one aspect of a group of rats' neural architecture] *normalizes* the properties of each animal and each counted [neuron] terminal. The specimen "animal" becomes both more than, and less than, a laboratory rat. It becomes *more than* a nervously staring creature living out its life in a wire cage, since the fine structures of its nervous system revealed through dissection . . . are not at all apparent from the outset. . . . It becomes *less than* the ordinary animal since the original animal is literally thrown away in favour of the residues retained for inspection. . . . Its practical history drops off. . . . The lines on the graph . . . represent measurements performed on methodically processed extracts of the animals' dissected brains. . . . If, in the end, a line on the graph represents a cohort of animals, it acts as a claim about the unremarkable character of the singular histories of each specimen, and of the practical actions and numerous assessments on the adequacy of the actions which accompanied and guided that history. (pp. 57–59)

Thus, the status of the experimental subject in a lab is dictated by the ultimate production of inference chains. The basis for its inclusion in a final account is only what it has to contribute to the conclusions. This contribution is what will determine the lab workers' decision about a particular flawed or missing data point. Whether they decide to discard, reconstruct, or generate a new data point depends on the circumstances. The purpose of the aggregate data representation is relevant: Will the aggregated data be subjected to a statistical analysis in which the lack of a data point might undermine the search for significance? Are the data points already recorded displaying an effect so robust that the missing data point is unlikely to add anything important? The nature of the observation of course is relevant: Is the measured phenomenon something that is relatively stable so that a repeated measure is likely to yield the same kind of usable data? The cost of generating the data point is also considered. How hard is it to get and prepare subjects? Was there anything special and important about this subject? Did it define a limiting case that will be theoretically important?

From the perspective of the students, things are not so clear. The transcripts of the discussion show that the relationship between student and data point is problematic–the dissociation between the experimental subject and the history of the data point that Lynch described does not uniformly hold here. Some students do seem to assume that the subject who originated the data point is irrelevant at this stage. The student who generated the concentrate value can go forward and make inferences about the aggregate set of data points without any tie to the data point she generated. For these students, the experimental subject has been erased.

However, other students seem to have a different sense of the matter. For Tony and some of the other students, the data point on the graph may embody more than just a token of participation. The sum total of their arguments suggests that each data point embodies a self–the thinking, feeling center of experience that continues to play a part in the process of further inference and problem solving. That self, Paulina in this case, is more than just a student who has participation rights and more than just the creator of a chain of inferences. That self has a particular history with the sought-after lemonade concentrate value. That history combines memory, affect, actions, and reasoning of the student and her teammates. In Tony's implied understanding of this classroom math/science activity, the selves and the data points are not separable. It is not sentimentalism that motivates Tony to want to rediscover Paulina's concentrate value: His relationship with her (and with other students) is not particularly close or harmonious. Rather it seems to be a consequence of his view that the linkage between initial observations and interpreted data points should not contain erasures or equivalences; recent histories of selves are what are at stake.

This view of the situation may help explain Steven and Alex's analogy between the loss of a beloved dog and Paulina's loss of her concentrate value. Unlike Tony, both students are among the most able in mathematics and science. Their reminiscences about beloved dogs were puzzling the first time; it was even more puzzling when Steven brought it up again the second day. He was arguing both against giving Paulina a random new concentrate and against using the average of 10 and 22. He recalls the discussion of the previous day: "... It would be like Alex said yesterday: It would be like getting a new dog, knowing that it's not the same dog. I think it's not a good idea to make a new concentrate." Whereas early on Day 1 Steven had asked the question about how close a data point would have to be to count, today he seems opposed to any erasures of the chain of events that started with Paulina's original choice of concentrate value and that ended with the entry of her data point.

After Steven's second mention of the dog analogy, Godfrey appropriates the metaphor and recasts all of the options in its terms. "All of these are getting a new dog though, aren't they?" she asks Steven. He opines that some are, more than others. Lynne agrees that making a new concentrate is "more like if you first owned a dachshund and then your new dog was a great dane, that's like, way new dog, right?" Not everyone shares this perspective. Two of the girls politely but firmly reject this analogy. Molly states that, "I don't think it matters so much cause it's not a big deal . . . it's just a concentrate you know . . . maybe it's not her very very first, but . . . I don't think it matters too much." Hilary repeats her statement of the previous day even more firmly than before: "Well, I think that these concentrates are **not** dogs." Both Molly and Hilary appear to be arguing that the substitution of any value will do—this is a math class, after all, and the linkage between Paulina's original experience and her data point is erasable; it is not the same as one's connection with a deceased dog. The actual concentrate need not be identical with the original to be meaningful in this setting.

For the students, then, it appears that the struggle to decide on a course of action with respect to Paulina's missing data point is really a struggle to come to a group decision about the meaning of that data point within the larger activity. Although they did decide on a course of action, it is clear that they did not converge on one view of the meaning of the data point in all its complexity. Instead, each student grappled with his or her conception of the data point and its relation to the originator and the group. Although this was not a problem with a clear solution, it provided an officially sanctioned opportunity for the students to ponder a knotty and nebulous set of connections among actions, actors, and representations—something they will need to be willing and able to do as they move forward in mathematics and science.

For the teacher, the meaning of each data point is at least as complex as it is for the students, although it presumably exists within a more coherent understanding of the activity. Even so, it is an understanding of the activity that arises out of teaching, and thus again it diverges from the meaning that a lab scientist would assign it. Each data point entered on a graph such as the one described here embodies for the teacher at least an intended instructional history—from generic student's original observation to student's final discovery. This intended instructional history includes what the teacher hopes or expects each student will encounter in the observation phase of the activity and in the transformation of that observation into data within a higher order representation. Thus, each data point is potentially a site for discovery of the relations between the observation phase and the later investigation. Specifically, in this case, the choice of lemon juice and sugar quantity yielded a particular mathematical entity, a ratio, and a physical entity, a concentrate with a particular taste. In the ensuing exploration, each student would notice relationships between both the mathematical entities and the space of the graph, and between physical properties and position on the graph. Of course each data point also embodies a particular student's history with the process and provides the link whereby they will be included in the process of drawing inferences about the graph as a whole. What Godfrey needed to do was ensure that each student would voluntarily maintain engagement with the graph and the inferences made about it. By enlisting them in the discourse practice described here, she refreshed and solidified that engagement for at least many of the students.

In the field of language arts, researchers have struggled for several decades with the issue of how to get students to recognize and enter into the roles involved in real writing. It is hoped that by actually writing texts that are meaningful to them, by writing for real audiences, and by reading extensively, students will develop familiarity with the complex perspectives of author, audience, editor, critic, and even publisher. We suggest that the roles and rights involved in the thinking practices of science and math are at least as complex and inaccessible to students. A better understanding of students' learning to take on these roles will require serious research and theorizing in real classroom settings, with concomitant thinking about what the real practices of science and math are in a far more thorough fashion than we have done here.

It is popular to cite the student's own experience as the basis for construction of understandings in mathematics and science. However, researchers have not sufficiently investigated what is entailed in bringing that experience to bear in classroom science and math activities *qua* activities. Even an activity as humble as deciding what to do about a missing data point takes students and teacher into realms of profound complication. What is the nature of the activity at hand? How is meaning to be negotiated when there are clearly different stances being taken toward the situation? In most people's eyes, the teacher is charged with ensuring a single meaning of that activity to whatever extent possible. In this particular case, the teacher did that by engaging all the students in the process of deciding—not simply deciding what to do, but deciding what the meaning of the decision could be. As the students circled the issues, we venture to guess that they took in each other's perspectives. Some were clearly closer to the target thinking practices of science and math than others, but all provided useful material for reflection and learning. Had Godfrey decided to impose a meaning by imposing a decision, she might have saved 70 minutes, but her students would have lost an opportunity to traverse the complicated landscape of data points and their meanings.

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CHAPTER

5

LEAKS OF EXPERIENCE: THE LINK BETWEEN SCIENCE AND KNOWLEDGE?

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I think there is a challenge and it does not lie in an abstraction called social science, nor in the nature of academic institutions or a male power structure. The central challenge is closer to home. It lies in what each of us chooses to do when we represent our experiences. Whose rules will we follow? Will we make our own? What is the nature of the self, the "I," that so many of our prohibitions bury? How can we unearth some of the inner worlds that we learn so very well to hide? Are we willing to do this within social science? Do we, in fact, have the guts to say, "You may not like it, but here I am."

(Krieger, 1991, p. 244)

Experience thus reaches down into nature; it has depth. It also has breadth and to an indefinitely elastic extent. It stretches. That stretch constitutes inference.

(Dewey, 1929, p. 1)

In speaking of lies, we come inevitably to the subject of the truth. There is nothing simple or easy about this idea. There is no "the truth," "a truth"—truth is not one thing, or even a system. It is an increasing complexity. The pattern of the carpet is a surface. When we look closely, or when we become weavers, we learn of the tiny multiple threads unseen in the overall pattern, the knots on the underside of the carpet.

That is why the effort to speak honestly is so important.

(Rich, 1979, p. 187)

I recently returned from England, where one of my duties was teaching introduction to computing to freshmen in sociology and anthropology. The only available computers were somewhat outdated IBM PC clones. The first day I encountered my first class, I asked who in the class had had some experience with computers. One of the 15 raised her hand. The rest looked apprehensive but polite. "OK," I thought, "we'll start right at the very beginning." I gave a short lecture on software and hardware and gave them each a floppy disk, which they put into the disk drive. "Right," I said confidently, "now please type *a*:." There was a long silence in the room and I could hear no keys clattering away. Finally a boy in the front row raised his hand. "Excuse me," he said, "but how do you get to colon?"

I had not realized that the right question to ask the class was not, "what sort of computing experience have you had?", but rather, "have you ever seen a keyboard?" England is not a typing culture; students right through university customarily write out their papers longhand. The next semester's class included a swift typing lesson.

I use this anecdote to illustrate how membership in a community of practice is not just about apprenticeship and indoctrination, but a matter of linking layers and realms of experience with the initial questions of membership in the community. Lave and Wenger (1991) dubbed the process of acquiring membership in a community of practice one of legitimate peripheral participation (LPP). They equated this with cognition. That is, *knowing itself* is about membership, participation, and entering into a world of skill and shared experience. The concept helps restore both collectivity and praxis to cognitive notions. This chapter adds to this concept the importance of experience and how its problematics link some central questions in science, science education, and sociology of science. In so doing, it raises the possibility of an inverse or complementary concept to LPP: something like illegitimate central marginality (ICM). These are experiences that seem to occur at the center of a community of practice, but that somehow do not fit, which leak out of the community conventions and norms.

Experience is a funny notion. It is real time, it has duration and intensity, it takes place in the present, it is immanent, and, perhaps most of all, it is irreducible. Elaine Scarry (1985), in an extraordinary book on the politics of pain and the body, has a central aphorism concerning pain: "to be in pain is to be certain; to hear of someone else's pain is to be uncertain" (pp. 1–2 and passim). I would like to adapt this aphorism to experience: "to experience, to undergo, is to be certain; to hear of someone else's experience is to be uncertain." Most of the edifice of modern science directly concerns the reduction of that uncertainty through a series of indirect witnessings, on the theory that multiple uncertainties will eventually approximate experience (Haraway, 1997; Shapin & Schaffer, 1986). If we could all simultaneously undergo things, there would be no need for science.

Thus, science education encounters a central paradox: indoctrination of a child/learner into a community of practice via appealing to his or her experience while the central value of that community is learning to distrust experience and systematically distance oneself from it. A similar paradox lies at the heart of recent sociology of science: We are concerned to demonstrate the situated, historicized nature of science, but lack tools with which to do so, which are not betrayals of the very phenomena we are trying to expose. We try to speak of informal knowledge, but have only formal words; we allude to situations and contexts using words inherited from decontextualized and transcendental frameworks. How can we both generalize and be situated? Acknowledge multiple voices and experiences *and* find robustness?

This impasse, among others, has helped create the conditions some academics call *postmodernism*—a sense of contradiction at the core, of splintering, of fragmentation. One response to this is that some of the cutting edge of sociology of science has moved over and become the field of *technoculture*—multimedia, somewhat fractured representations that abandon any referent to a natural world or traditional narrative structure and instead favor nonlinear images in no particular sequence.

Another, related sort of response within sociology of science is what Woolgar (1988) called *the reflexive turn*. This is an examination of the role of the observer within the language of sociology itself—noticing and exploring how one is structuring the narrative, trying to catch oneself taking things for granted and so exposing the situated and contingent nature of all cognition. There is nothing beyond this noticing and textual creation that we can know.

Yet a third response, barely begun in sociology of science but of increasing importance in other parts of sociology, is attempting to incorporate a personal, autobiographical voice in the telling about science. This is direct incorporation of personal experience, often in poetic or prose-poem form, into the doing of the sociology. The tone and framework may be reflexive or postmodern or not. Bruno Latour's recent volume, *Aramis*, tells the story of a massive technological failure to build a new kind of system in Paris; his own voice as observer joins those of the scientists and engineers in a multivocal narrative form (1996). Similar experiments are occurring throughout anthropology (Clifford & Marcus, 1986). Many people in social science today are struggling to write themselves into their science, include themselves and their biographies, and lessen the fictive distance between data and observer. There is always a risk in this: of exposure, of ridicule, of political danger. All of those are present here in the risk I am about to take in writing, as there is in any self-revelation. But I think of this process as a kind of restoration of the original projects of both science and sociology, which began as risky, moral, and radical new ways to order the world. Speaking sociologically, it is interesting that those same moral and spiritual aspects of our work—the sources of passion and mystery—are the things we now whisper about.

Several times in the past years I have had the experience of being seized by words, near-automatic writing that comes out quickly in the form of a poem or a short biographical vignette. It is not a particularly pleasant experience, although it is euphoric in a way. I feel a rush of adrenaline, a cramping, sick feeling in my stomach, and often tremble as I am writing. Afterward I walk around with the pages of writing in my pocket or bag, sometimes for weeks, because I cannot bear to be away from it. Writing like that feels as if something has cracked inside of me and my experience is leaking out. Perhaps this is a cliché with writers because it describes an actual physical event—the muscles of my abdomen and my throat growing tighter and then releasing, then an increased blood flow as something makes sense and I relax. I am certain that everyone who writes creatively knows what I am talking about.

These writings are linked with moments in my biography that take the form of separation, isolation, and a kind of splitting apart, followed not by a prodigal sense of return and unity, but an agreement with myself to continue talking and paying attention to the multiplicity and the splits. The ongoing resolution is a commitment to process and to accept connections despite differences. In this, I find echoes of many of the themes current in postmodern, feminist, and biographical narrative writing. These are themes that have an important place in science education as we strive to link students' situations with membership in a community of practice, without screening out their leaks of experiences.

In the literature on biography, narrative, and postmodernism, splitting, process, and difference are core themes. We are many, not one; fragments, not whole pictures; polyphonic, not univocal; there are just stories, not master narratives, whether it be in writing biography, interpreting the world as scientists, or in popular culture. Much of this writing has opposed post-modernism and modernism by dichotomously categorizing many voices or fragments on the one hand and single voice or monolith on the other. This deletes something crucial about the practice of managing the leaks of experience. As Dewey (1989) put it: "A classified and hierarchically ordered set of pluralities, of variants, has none of the sting of the miscellaneous and uncoordinated plurals of our actual world" (p. 49). At times postmodern writings seem like an almost mindless pluralism, or what common parlance would (mistakenly) call *anarchy*. I do not think the choice now lies between form and formlessness.

I want here to step outside that dichotomy to write about a form of multiplicity that is neither opposed to modernism nor essentially fragmented, but that does not just wind up resolving differences or reducing or categorizing forms. In a sense this means myth-making, as philosophers from Durkheim to Mary Daly, Michel Serres and Donna Haraway have written of it: ideal events at once found in the everyday concrete, containing contradictions but making situated coherence. In another, more sociological sense, this outside place is found in action and in attention to the everyday work that makes and maintains these myths: practices, struggles, communities, aloneness, separateness. This is work that is indeed made invisible through omission from the master narratives of modernism, which describe these processes as only rational, male, European/North American, objective, and reducible to formulae.

However, and perhaps ironically, it is also made invisible by the very postmodernism that criticizes the master narrative—made invisible when it describes these processes as only irrational, fractured, and without coherence. I am a social scientist because I am interested precisely in the nature of the work of articulating the cracks between things or, perhaps to metamorphose a metaphor from Deleuze and Guittari, a rhizomatic work. Social science is a language and place I have found to pay attention and learn about being a human being, to do some of that articulation work. It is also therefore home to a spiritual quest and practices.

We do not have good language for making the kind of multiplicity I describe here visible (Star, 1991a, 1991b). This is because it is about betweenness, not about either unitary thingness or fractured thingness. It is about consequences, not antecedents; multiple interpretations, but multiplicity with structure, location, historicity, and accountability. As Dewey (1989) said:

> Romanticism is an evangel in the garb of metaphysics. It sidesteps the painful, toilsome labor of understanding and of control which change sets us, by glorifying it for its own sake. Flux is made something to revere, something profoundly akin to what is best within ourselves, will and creative energy. It is not, as it is in experience, a call to effort, a challenge to investigation, a potential doom of disaster and death. (p. 51)

When debate in any area of science becomes polarized, as it is now in social science between modernism and postmodernism, it becomes nearly impossible to speak without becoming magnetized toward one pole or another. Nevertheless, I am going to try.

The following piece occurred all through the process of writing my Ph.D. dissertation in sociology of medical science. As I re-read it, I wonder how the story of the science would have been changed had I been able to incorporate this voice simultaneously with the writing and discovery that was part of the thesis. Certainly, had I read someone else's voice with this sort of experience, it would have given me hope and courage in the face of a rather desperate time. I offer it in this context of re-thinking some questions in science education in the hope of continuing a process of validating the primacy of experience in knowing.

MY GENERIC BODY (1986)

(for Laurens White, MD)

> Quantify suffering
> You could rule the world.
>
> They cán rule the world
> While they pretend our pain
> belongs in some order. (Rich, 1978, p. 15)

My former husband used to look at me and say, "You look like the invisible woman."

"What do you mean?"

"Sort of like those models they hand out to you in seventh grade where you put all the pieces together and then you have the Human Body. Like an anatomy book."

"Thanks a lot."

I did feel toward my body like one would toward an anatomy book. It was, well, regular. Absolutely nothing distinguishing about it. I regarded it neutrally—grateful in a way for a lack of deformity. I thought of myself as a "regular" size, a regular shape, a regular health. Kind of generic.

Seven years ago I was in a minor car accident and shortly after that began to experience severe pain in my neck, shoulder, and arms. A long series of doctors and examinations revealed nothing specific; I was variously diagnosed with "whiplash," "chronic muscle pain," and "myofascial syndrome." Over the years the pain worsened and with it I began to lose the use of my left arm. Finally, a year ago, severely disabled, a doctor discovered that I had a condition called *thoracic outlet syndrome*. This is an often-inherited structural condition where the opening formed by the collarbone, upper ribs, and neck is too narrow for the nerves and blocked vessels to pass through smoothly. It's often asymptomatic until a car accident or occupation-related stress adds additional strain to the area. The treatment for the condition is first physical therapy; if that fails, surgery removes the first rib and a muscle in the neck.

I had surgery a year ago. Almost miraculously, feeling and strength returned to my hand and arm and the pain has nearly vanished. Over the last year, after several months of physical therapy and postsurgical headaches, I've regained wellness, although I must still be very careful with lifting, strain, and stress, and have frequent bouts of intense pain.

At first, I thought I would be regaining my same old generic body. Restored. But it's not the same body—for one thing, it's eight years older and wiser. It's also not socially the same body. People don't treat me as a reliable chassis any more–I have become fragile, or for many of them, befriended during disability, always was fragile. Special.

I can tell this story best through a series of vignettes–anything else is too painful yet, raw. They are a set of images burned on my mind. The connecting threads are the lost illusion of genericness; the irony of being a medical sociologist studying chronic illness and living the steps of learning; the tortuous diagnostic path and its organizational roots. These things, and the other parts of my interactions with friends and family, are my body. Just as there is no generic experience, there are no generic bodies. But there is collective experience–the things we have in common, discovered through specific translations.

My Mother

We stand in the surgeon's office the month after surgery. My mother has the same condition as I do; we haven't known before what it was called.

Since I was a teenager, I have had the feeling that my mother and I have exactly the same body size and shape. We could swap shoes and many clothes, have similar posture.

She is dressed in a thin paper gown, sitting on the table where I so recently sat full of dread and hope. I feel our ages, me at 30 and her at 50. I look at her arm, knowing that her pain is as invisible to me as mine was to everyone else, despite its recent rages in my own person. I imagine myself behind her eyes a ghost filling her up and looking out, doctor after doctor and pill after pill.

The nurse comes in to take her vital signs. My mother steps on the scale and I see with some shock that she weighs 40 pounds more than I do. I look down at myself, thin from illness and thinner from a new sense of myself in relation to a fragile world. I look over at a pretty, working class woman inhabiting a world apart from me. She will decide not to have surgery yet, fearing the alien and powerful doctors, preferring the known turf of pain and endurance. I ache to take her fear from her, to assure her that I can fend off the indignities of the hospitalization and the risks of surgery, but I can't.

No pain is shared pain. No pain is generic. But all suffering is joint suffering.

Neurology

Neurology is the last resort of the hopeless, a garbage dump of psychosomatic illness, extremes of pain, uncertainty, and elusive diagnoses. In the middle of the worst of this illness, I am writing my doctoral dissertation about the history and politics of neurological research and I keep getting referred to neurologists.

I am lying on the table in the emergency room, shaking with pain and blacking out with an undiscovered drug reaction to one of the drugs prescribed to help my muscles relax. I am left in the emergency waiting room and I can't move my body at all. I begin to have a seizure that moves from my left leg up my left side, crosses over, dances up to my neck. I try to call out but I can't talk. I concentrate on my breathing, sincerely believing that I am about to die. Suddenly with almost unbearable clarity I understand what it means to be a brain tumor patient in the 19th century, something I have been writing about from the point of view of the doctors researching the subject. Time telescopes and tunnels in around me; I recall poignant photos I encountered in my archival research, pictures of the patients of John Hughlings Jackson, an early and great epilepsy researcher. He was the first to describe the "march" of twitches in an epileptic seizure up and down the body of a patient (Star, 1989).

If I could laugh, I'd laugh. How clearly I can see the legacy of the scientists I am studying, now in my own body—those mysteries of neurology that have never been solved despite a carapace of certainty erected in the name of medicine. I think about my fragile body and its mysteries and try to imagine bringing the order of science to bear on the human body. There is no human body, I say to myself, fighting for consciousness, fighting to be able to call out to a nurse or doctor for help. Hands lift me to a table, push a rubber tube into my arm. Softly, specificity returns to my experience: Leigh, San Francisco, blue jeans, hospital gown, blue sweater, peach colored walls. Later, at home, I look at my body in a mirror. I weigh less than 100 pounds and can barely stand. Survivor, I think. History only counts it when there's a clearly defined experience to be filtered out and labeled. The scientific puzzles like me have no bodies—we are not part of the Human Body that appears in the anatomy book.

Needles

Twice a week for 4 years I have acupuncture treatments to try to control the pain I am in. Because the pain fluctuates in intensity, I am never quite sure if they work and I keep going back.

I lay in the dim, moxa-scented room on a table covered with hand-woven fabric. Peter is a thin, gentle man with a gap-tooth grin. On the wall in front of me is a picture of a naked person, arms spread, with a bright yellow and blue aura surrounding them. The bookcase at the end of the room contains a first aid kit, several physiology and anatomy texts, and a model of a human skull. The house is an old San Francisco Victorian, and the art nouveau light fixtures are lovely 1920s additions.

Peter holds my wrists, feeling for the elusive pulses that separate wood from earth, fire from air, metal from water in the Chinese five-element medical system he follows. I always close my eyes and imagine that we are joined in one big web that trembles with the city rhythms and rumbling California earth. He rests the needles on my skin before pushing them into the pulse points. As I feel the feathery touch on my skin I force myself to relax, breathe deeply. The needles hurt a lot as they are inside me, sometimes like a toothache and sometimes like a sharp pinprick. I try to pay attention to the different feelings because he will ask me about them later, making notes in my fat file about changes, reactions, adjustments, emotions.

The needles make a tickly feeling all over my body, little currents of almost unbearable uneasiness through the muscles. I try to accept all the little funny feelings, experience them as redirecting my tangled up energy flows. Sometimes I feel very silly, as if I belong to a California cult. But like Pascal's deal with God, what do I have to lose? If it works, I win. If it doesn't, all I will have been is silly.

The treatments make me look at my body as a complicated terrain, whose map must be drawn in vivo, like the pulses and flows of the meridians. The needles mark little outposts of the known, pinning down the flows. Like rocks in the current of a stream, something that is me flows over and around them, bubbling up and interrupting the smooth water.

It fills me with happiness to have another body, an old Chinese one with the smells of herb doctors and the weight of an Asian world. My allies are very old in this body, and they are gentle and wise. It is not as important to me to have relief from pain during this time as it is to know that some healer is paying attention to my experience. This is also why I keep going back—to keep knowing that I am not here an unknown, a garbage can category like in Western medicine ("chronic illness"). In acupuncture there are only different configurations, no such categories as chronic or acute, well or ill.

Many times after treatment I have a slight aphasia that lasts for a day or so. I either cannot speak at all or can only find substitute words for the ones I think—they won't come to the surface of my mouth. It is a fitting muteness, I feel, for the experience of my body's fall from the smug fit of genericness into the silence of "pain—origin unknown." As the years go on, I learn to know how hard it is to speak about my body because it means speaking of despair and alliance.

Have You Tried a Heating Pad?

I want to speak of the ethics of the body in the context of this despair. When my pain is public, I become a social object of pity and public dispute. Friends and casual acquaintances offer home remedies and suggest chiropractors, faith healers, diets, exercise. "Have you tried a heating pad?" becomes a joke with me and my friends about the idiocy of casual questioners. One year, just before collapsing and spending days in the hospital in traction, I am sent to (another) orthopedic surgeon. He questions me about my psychological state and "stress." Because nothing has appeared on my X-ray, he suggests wearing a scarf to protect my neck from the cold.

Yes, I've tried a heating pad, just as the woman in the wheelchair next to me has tried prayer and physical therapy. The gentleness of the acupuncturist strikes in sharp contrast with the violence of the neurologists, orthopedic surgeons, and amateur psychiatrists who offer me narcotics and scarves and who inhabit a body world filled with the white ghosts of stress, psychosomatic illness, and malingering patients.

There is no such thing as stress or malingering. There is only the loneliness of pain that has no categories or no allies; there is only suffering that falls mute because it is displaced from the known world. It is immoral to presume that someone in pain does not have the best knowledge of that pain. What is moral is to find the translation key, to listen, recognize, and never to confuse muteness with lack of experience.

Nightmare and Healing

After surgery, the daily pain is gone. The worst horror comes shortly afterward: nightmares in which I wake up in cold sweat screaming that they are coming to get me. I dream of men with knives, of armies at war, strip-mined hillsides, and dismembered bodies. I wake up one morning thinking, "At least when I hurt, I knew where it was."

I feel stalked.

A few weeks after surgery, I start to swim to build up and relax my muscles again. At first, I can only do 5 or 10 minutes, then stop exhausted or hurting. Slowly, the water becomes a familiar environment. I learn to move gracefully and ever more strongly through it. I swim every day, up and down a long pool inhabited mostly by elders—Asian women and White men. They swim slowly, many of them stiffly, and I become one of them. We share a body in this pool, as we fight together to move through the water, through the world. I feel great affection for them.

As I swim, the nightmares recede. Gradually I am able to sleep for longer periods at night and the waking up trembling subsides. I have a sense of moving through the water, pushing against it, as a way of shaping a new body, claiming a new bodily territory.

One day after I am feeling strong and the surgical pain is almost gone, a young man comes up to me as I am resting at the shallow end of the pool.

"Do you come here often?" I grin at the cliché. "Yes, every day."

"You are really in good shape, very slender," he says in a seductive fashion, looking up and down my body. I stare at him in astonishment, aware for the moment only of the scars on my neck and torso that suddenly seem to be huge and livid. "I've been ill," I whisper. The chasm between our knowledges of my body is so large that I have no words. I also know that the body he wants is real, that I am ready to move back into the world. I am an object to him. But I have the power of my body that is the body of the elders in the pool, the body of Chinese medicine, the solved puzzle, the cured case, the 19th-century patients. Most of all, the power of my friends' hands, feeding me, holding me, and affirming my work during the worst of it, has now become part of this body.

I know myself now as an intersection of bodies coinciding at the place called me. The lie of the Human Body, the Invisible Woman, the anatomy book, the chassis—all the lies of normalcy—have been replaced by an understanding of the specificity of healing and the collective nature of suffering. I think I would like to call this learning.

EXPERIENCE AND SCIENCE

> *Writing, a possibility of composing a space in conformity with one's will, was articulated on* the body as on a mobile, opaque, and fleeting page. From this articulation the book became the laboratory experiment, in the field of an exonomic, demographic or pedagogical space. The book is, in the scientific sense of the term, a fiction of the scriptable body; it is a "scenario" constructed by a vision of the future that seeks to *make the body what a society can write*. From that point on, one no longer writes *on* the body. It is the body that must transform itself into writing. This body-book, the relationship of life to what is written, has gradually take on, from demography to biology, a scientific form whose postulate is in every case the struggle against again considered sometimes as an inevitable fate, sometimes as a set of manipulable factors. This science is the body changed into a blank page on which a scriptural operation can produce indefinitely the advancement of a will-to-do, a progress. (de Certeau, 1984, p. 196)

When I wrote the body piece, I was only aware of an urgent need to write, a sensation of cracking, opening up, and an almost unbearable tension between me and the words. Yet in it I also recognize lots of sociology of science and medicine, and thus another way of telling science. As a result of this experience, I also became interested in medical classification and the way that medical organization may structure classification systems—missing certain types of experience. I have gone on to work with computer scientists building electronic libraries and trying to help them incorporate informal and organizational knowledge into the classification schemes. Classically, this would mean that I have let a personal experience motivate an interest in a problem, but I keep wondering if there is not a way to bring it in more directly—a way that would impact science and make it more accessible. Must science, poetry, and biography be separate?

So why poetry? Why represent these experiences as poems, or prose poems, and what does that have to do with social science *qua* science? For years I would have answered, "not very much, unfortunately." Now the combined weight of whispered conversations and many brave assays into print have given me courage to try.

Actually, there are two answers, both methodological. The first answer is that poetry helps me and my audience to do *better* sociology. The second answer is a level of abstraction up from that—such experimental forms of expression are in fact changing sociology as it has been practiced in the past, and so the conventions of expression are changing. Both are important, and I argue here that they are also connected, by presenting several features of this kind of narrative important to sociology.

Stuttering

Tillie Olsen (1978), in her classic essay, "As I Stand Ironing," argued that for many years women wrote poetry—not novels or epics or science—because you could squeeze a line in between feeding a child and doing the ironing; you could hold those lines in your head until there was time to write them down. The existential stuttering that has been part of women's experience, and of our silencing, has often come out in the form of poems because they can fit in between the cracks of a busy, infinitely interruptable schedule. We have not often had the luxury of 500 guineas a year or even a room with a door.

There are many ways to be interrupted in addition to those that come from running a household. Some come from internalized voices. "Why are you writing this? THIS does not fit, it is not *really* _____ [sociology, psychology, scholarship, science] . . . Sounds incoherent. It's not science. Where's the proof? The relevance? The validity?"

Laurel Richardson (1993) wrote of hearing such voices when she presented an interview with a respondent in poetic form at a sociology meeting. These were voices in the audience demanding accountability, feeling rage that she had broken from the canon. There were also her internal voices questioning her experiment. Such voices can fracture a narrative that already has coherence or prevent fragments from coming together into a story that makes sense.

Such fractures are always political and sociological, but difficult to see when they are our own. Stuttering and speaking in short vignettes, such as occur in poems or prose poems like those earlier, are also sociologically structured phenomena. They point to a constriction in our science within which experience will not fit. Instead of trying to return the experience to the canonical form of expression, we should be listening very hard to the fractures and articulation between. The fragments of experience are canaries in the mine of scientific thought. Most physical and natural scientists would be unafraid to speak of intuition and creativity, of unexpected juxtapositions and fragments of insight. Because our subject is organization and relationship, is it not natural that we will be a central source of those intuitions? As Gusfield (1990) wrote in a moving autobiographical essay paraphrasing Alvin Gouldner:

> The perception of sociologists comes from two sources. One is empirical studies and theorizing—the role realities that the sociologist presents to the reader and freely acknowledges. The other, and often the more determinative, is the "personal realities" that the sociologist derives from his or her experiences. These are seldom acknowledged and are often half hidden from the writer as well. (p. 104)

Perhaps we collectively have the courage not to hide them anymore, partially by accepting the fragments as part of our science.

Ambiguity

Not all senses of fracture reflect limits or violations of this sort—limits of time or support. Representing material in a kaleidoscope fashion also *affords* ambiguity in a positive sense. Fracture and vignette allow sorting and resorting. They can help resist ordinality and thus teleology, including Whiggish reconstructions of the past. These virtues are also the features of the postmodern list and why it appears as important in postmodern writing (Bowker & Star, 1994; Goody, 1987). They are also the reason for interest in hypertext and new narrative forms for storytelling—let there be many ways to structure a story, threads that pass through characters or moments or kinds of action (Bolter, 1991; Jones & Spiro, 1995), and simultaneously the way to retrieve pieces of information to have quick access back and forth (this latter a key in practical use and growing past the Faulknerian or Rashomon multiple-storyline format). The argument in favor of such new forms of representation is that they more closely approximate our own lived experience and natural style of learning—one familiar to anyone trying to make sense of a mountain of field notes. Hocks (1994) cautioned against a simplistic version of this lauding of hypertext, nevertheless the openness is important for understanding nonlinear lived experience.

One crucial question here is whether such a list is seen as an interim genre in preparation for an exhaustive ordered narrative. It is in such a guise that it becomes an instrument of social control (Tort, 1989)—the enumeration of events, characters, and other sorts of individuals. It is only as a permanent and open-ended form that it retains openness and accessible, and thus pluralist multivocality.

Irony and Metaphor

> The visible is set in the invisible. (Dewey, 1929, p. 43)

The events I wrote about above have in common many of the ironies in sociology of science and science education: an ironic and paradoxical displacement of self. I have simultaneously the experience of belonging and not belonging (ICM). After surgery, I look healthy, slender, and generic, and, in some sense, I am but also am not. This juxtaposition of contexts becomes ironic, but also funny and sad for this reason: I am forced to stand outside my ongoing experience and look back at it as a stranger, the very essence of irony. (This is the centrally recurring theme in a recent volume of autobiography by 20 American sociologists; Berger, 1990.)

This is the beginning of the sociological imagination, especially as I find out that my experiences are collective ones and there are concepts (upward mobility, passing, pluralistic ignorance, social movements) to help me understand them. From Simmel and Schutz to Trinh Min Ha and Anzaldúa, social theorists have relied on the juxtaposition of contexts for information about each context and about the nature of contexts. It is such a rich and complex source, in fact, that it is difficult to retain within traditional categories. All such rich juxtapositions create important zones of ambiguity, often characterized by a metaphor that satisfies under some circumstances and obscures under others.

Beauty

Several writers in the new sociological and anthropological traditions have written about wanting more beautiful (and less boring) ways to speak of social phenomena; ways of representing people that preserve their voices (for ethical reasons) and their words (so as not to mangle them). Why should we not extend this courtesy to ourselves as respondents in our own science? We are, after all, writing about people when we write about ourselves. By the prior argument, we are also in some sense respondents in our own work. Now that the old subject–object distinctions have been thoroughly flogged to death, why not include our own delicate, lovely thoughts in the writing of our science?

One immediate traditional answer is that beauty will trade off against generalizability. This is instantiated in the old debate about "two cultures," science versus art, which nearly every scientist has come to repudiate in some degree. There is art in science and science in art. Yet there is a fear that if I craft a wholly idiosyncratic production, the knowledge that results may be pretty, but not collective or cumulative. I cannot train students in my own poetry, nor add to a body of knowledge that other sociologists and information scientists can build on. I do not think fears about nongeneralizability in this regard are silly. One of the laudable goals of early science was to correct certain forms of parochialism and make scientific knowledge democratic. Those old goals of making knowledge public and not private for-profit, of having public principles and discoveries instead of patent remedies are under siege, to put it mildly. Because of the failure of the subject–object dichotomy and the attempt to speak in a monolithic voice, people in social science are experiencing an epistemological crisis, even a crumbling of foundations. The ongoing revolution in representation risks begging the question of parochialism—why communicate at all if situated, contextual knowledge is posed as over and against reality?

I am not only interested in producing representations of my own experience, but in understanding collective experience in a way that will go beyond what I could do alone and that will do so with some rigor and precision. I think poetic representation of the kind offered earlier actually enhances such rigor and precision and counteracts parochialism in just the way that significance tests are meant to do. This is somewhat counterintuitive coming from a sociologist. We have always been told that poetry is just the opposite of such restrictions. However, that which makes a poem, or a series of vignettes, *work*, is precisely another way of arriving at the telling example or key concept that lies at the heart of all great social science.

Representativeness is a question for the audience, not the author alone. A good poem is a robust product of a collective experience. It compares, it compresses, it is both parsimonious and generalizable. It is like a good case study, or the kind of truth that comes from long experience; like them, it is not enough if it rambles or speaks only to one kind of experience. In this sense, the poetic vignettes I presented earlier have much in common with Becker's (1970) notes on validity and inference in field work. Having been there and survived to tell the story is not enough to make sociology; but in the context of a listening audience and a collective interested in making social science, it has rigor. Certainly this genre should be of methodological interest to sociologists, especially symbolic interactionists, who for decades have been interested in the subtle forming and interactive reforming of life histories and stories and their relationship with identity (Strauss, 1959; Thomas & Znaniecki, 1927). We are always forming and reforming our stories, often more than one at a time, according to our commitments, audiences, and other circumstances (Becker, 1960). Mead wrote that is was in precisely this sense that the past was formed by the future, in the specious present—finding threads in the form of gestures and symbols, we pull forward a past and only in this sense actually have a present. One of the effects of this is to place social experience in a relativist time frame—relative in the quantum sense, not in the moral/ethical or constructionist sense (Bentley, 1968 [1926]). This has both epistemological and methodological effects, including the ongoing centering of openness to anomalous events in inquiry. Poetry is one of the few tools we have with which to address this complex experience.

Bakhtin (1990) understood this when he wrote in *Art and Answerability* that:

> What guarantees the inner connection of the constituent elements of a person? Only the unity of answerability. I have to answer with my own life for what I have experienced and understood in art, so that everything I have experienced and understood would not remain ineffectual in my life. (p. 1)

John Dewey (1989), again in *Experience and Nature*, echoed the need to see things in context to make experience not alien to our investigations:

> The assumption of "intellectualism" goes contrary to the facts of what is primarily experienced. For things are objects to be treated, used, acted upon and with, enjoyed and endured, even more than things to be known. They are things HAD before they are things cognized . . . the isolation of traits characteristic of objects known, and then defined as the sole ultimate realities, accounts for the denial to nature of the characters which make things lovable and contemptible, beautiful and ugly, adorable and awful. It accounts for the belief that nature is an indifferent, dead mechanism; it explains why characteristics that are the valuable and valued traits of objects in actual experience are thought to creative a fundamentally troublesome philosophical problem. (p. 21)

Nature is not dead or indifferent, and we are part of it. If poetry helps restore us to this insight, then it is essential for going on with sociology of science and science education.

TEACHING AND EXPERIENCE

Experience is real time. It escapes all attempts to represent it. Science is ambivalent toward it, both deifying it in the form of creativity and motivation (and thus ghettoizing it) and fictionalizing it in the form of a subject–object dichotomy (the source of much of Dewey's philosophy and anger). Yet both sociology of science and science education seek to collectivize experience, to link situations with communities of practice, in the name of understanding science. One of the distinguishing things about science education (as I have learned about it at the Institute for Research on Learning, Palo Alto) is struggling to illuminate the ways in which membership may be imposed, and to nurture those insights and methods that grow organically from experience.

The videotape Mike Lynch analyzes (Lynch, chap. 11, this volume) is full of examples of children's experience "leaking out" in the middle of the process of indoctrination, coupled with the teacher's trying to convey information about the de-experiential nature of the community of practice:

> Teacher: "Everything in the world is made up of such small things that you can't even see them with your own eyes."
>
> "Have you ever heard the word *density* before? Now listen carefully—what can you say about the distance between the pumpkin and popcorn seeds? . . . The more scrunched up together all these molecules are the denser."
>
> Kid: . . . "and they are kind of a weird shape."
>
> Teacher (ignores that): "How can you relate this back to molecules?"

In this case, the teacher's program is to teach about density—the weird shape of the popcorn gets lost. There is a contradiction between experience and induction and between correctness and deduction that appears many times. Later in the tape another child makes a joke or observation about learning primary colors:

> "Does that mean they're in the first grade?"
>
> Teacher: "No (laughs), it's just the first step."

But what poetry is lost here! Why not think of primary colors as being "in the first grade"? What we might learn from that analogy about experience and mingling of experiences in the students' own worlds?

Later, the session where the teacher is trying to teach about metaphor, literal and implied meanings, is full of poignant references to experience:

> Teacher: "What would happen if you put the cart in front of the horse?"
>
> Kid: "The horse would go around the cart."
>
> Teacher: "No, you couldn't go anywhere. The cart would be stuck."

Of course, the horse *might* go around the cart. The lesson about metaphor might take a bit longer, but we might also learn about workarounds, rebellion, breaking out of harnesses. . . . The teacher is at pains here to distinguish "what the words tell you" and "what they mean in your head."

In some sense, of course, it is not fair to pull out these examples and tell the teacher what to do, and that is not my point. I am simply pointing to a kind of leak of experience in the short student–teacher dialogues on the tape that could open up new ways of knowing about science, that could make it more contextualized and richer. Thinking collectively about such dialogues means adding the dimension of membership and the rhetoric of a community, and the ways in which such leaks are managed.

SUMMARY

What is the difference between a fracture and a leak? I said earlier that there is no generic experience. The struggle for me in meeting the experiences of my illness has been settling down with the paradoxes and multiplicity (paradoxically); writing was the work of responding to experience. Experience does not come raw, but it comes in real time, in wildness, and not in our control. Responding to experience means letting generalization and specificity be in dialectic in our writings and biographies. This in turn means resistance—to pressures for conformity and toward the uniform voice. The resistance spans a range from craziness and schizophrenia to revolution—the difference between lies in the available technologies and commitments of our communities and audiences. Why risk it? Why say it out loud?

I agree with Dewey and Bentley (1949) that the answer is the same as to the question of why do science at all: to go on. That means reclaiming science from the pollution of rejected experience—a return to a hermetic tradition that makes it a journey, a risk, and a spiritual quest, as well as good science.

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CHAPTER

6

ENTITLED TO KNOW

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The chapters by Cathy O'Connor, Lynne Godfrey, and Bob Moses (chap. 4) and Susan Leigh Star (chap. 5) both emphasize the importance of lived experience to science. They both probe the relationships among legitimacy, science, and identity, each foregrounding a different aspect of the tension between lived experience and the detachment (or detachability) of scientific observation. Star's chapter is an icon, a monument to its content. Jarring in a conference and in a volume on intellectual practices, her very personal account illustrates how carefully the personal has been extracted from scientific discourse. She calls attention to embodied, private, continuous experience: intensely personal and tightly attached to the self, and to the paradox that, in extracting the personal from our scientific practice, we also extract the genius.

Psychoanalyst David Mann once suggested to me that geniuses are people whose work becomes the material of their fantasy lives. Our fantasies are the part of our identities that we keep for ourselves, usually hidden from others. They are a background job available to keep us occupied while we are engaged in meaningless activity, when we are trying to avoid something, or when we simply have the time to lie back and dream. In our fantasies, we create desired situations, forms of participation, relationships, activities, and accomplishments: our ideal trajectory. One might say that the individual's fantasy life is an interior conversation about participation in the world—the internal end of one's social life. Our fantasies are a means by which we continually rework our identities, rethinking old desires to incorporate new developments in our lives. To the extent that science is part of our participation in our most desired communities of practice, it will engage our identities, fantasy lives, and our best intellectual energy.

Between the involvement with which we indulge in our favorite fantasies and the detachment with which we perform unmotivated tasks lies a vast landscape of engagement and disengagement. The challenge for kids, teachers, and researchers in schools is to get curricular activity into the engaged portions of that landscape—to make science, math, language arts, social studies, and the arts all material for kids' external and internal social lives. If scientific discourse is to engage kids' social lives and even their fantasies, it must be fully available to them, offering itself as an extension of what they are already engaged with. The key to extending our engagement to new endeavors is the entitlement to make meaning in that endeavor. As kids approach scientific practice, how can they develop a sense of entitlement? How much of themselves can they legitimately insert into scientific discourse? How much of what they think and do will be scientifically legitimate?

Scientific detachment cannot be slavish. Slavish detachment, like slavish adherence to any set of rules or practice, can come from the sense that one's own knowledge, beliefs, and experience are at odds with, or irrelevant to, the practice of the community. This is not detachment; it is a lockout. A lockout makes it impossible for one to engage the full self in work—to have confidence in one's own knowledge and build on it. Fruitful detachment must be based on the possibility of attachment. The class discussion that Godfrey allows to go on for two periods is about legitimacy. She is encouraging her students to consider what the enterprise is that they are engaged in with their sugar and lemon juice concentrates and ultimately what constitutes and does not constitute legitimate, scientific knowledge. She is inviting students to examine the issue of leakage.

At the request of a sixth-grade teacher in whose class I have been doing ethnographic work for over a year,[1] I recently brought in a bar graph displaying the students' rates of classroom participation in three subject areas (math, social studies, and literature). The graph displayed each student separately, identifying individuals by gender only. The teacher projected the graph on the wall and asked the class what they thought of the patterns it showed. This is a classroom in which discussions of learning styles, megaskills, classroom climate, and so on are daily fare. The overhead engaged the class in a way that many other discussions of this sort had not.

The first question was, perhaps predictably, "Who's that boy on the end?"—a boy with a very high rate of participation. They knew they would not get an answer, but they just had to ask and then they were free to ponder themselves as a community of practice. Ponder they did: Why is it

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[1]This research, entitled "Gender Restructuring in Preadolescence," is funded by the Spencer Foundation.

that the girls who participate reguarly tend to participate in all subject areas, whereas the boys tend to specialize? Why do some people, particularly some boys, not participate at all? How can we make it easier for shy people to participate? Do people who participate in class learn more than those who do not? Is someone who does badly in sixth grade doomed to lifelong academic failure?

Griselda wanted to know how many class sessions the graph represented, pointing out that you could not capture people's classroom participation on the basis of a small number of classes. She speculated about how many classes of each kind would constitute a reliable sample. Griselda hates math and hated the recent unit on statistics, but she cares intensely that she and her class should not be misrepresented. She did not get interested in the statistical issues because the material was relevant, but because it was meaningful. Because she and her classmates clearly owned it: she could see their entitlement to make meaning with and around it.

Griselda understood the graph as a representation of the room she sits in every weekday—a room that is not about math, social studies, or literature, but a room that is about social engagement. When she looks across the classroom, she does not just see fellow learners of math or social studies; she sees old friends, a new kid, a best friend that she's started leaving behind, a new and exciting friend, someone she just had a fight with, a few weird people, a couple of heartthrobs, some smelly people, dodgeball stars, teacher's pets, neighbors, and people who pick their nose. She sees kids with whom she shares history and in relation to whom she constructs her own identity. What they all do on a given day in math or social studies is inseparable from everything else they do inside the classroom and out.

As she ponders the graph, Griselda may be thinking about which data point is her, how she was acting on the days I was collecting those data, how hungry she is, or who she is going to sit with at lunch. Because the real, daily, and familiar are represented abstractly on a graph, the graph ceases to be abstract. The members of the class can point to each set of three bars and say "that's someone in this room." They can speculate about which one is the friend they're angry at or the heartthrob across the table, looking from one set of bars to the next and feeling the relationship between bar length and participation. They can find the connection between this representation and the social configuration that constitutes their class.

As a result, the class knows exactly what the graph is, what it is for, and why they are having this discussion. Indeed, the purpose of the exercise comes to be defined not by me or the teacher, but by the kids whose interest in themselves leads them to ponder their own mutual activity in abstract form. The discussion qualifies as authentic, and not simply because it is about the kids. It is not about what they should do (which is what much of school is about), but what they actually do do; the kids have ownership of the topic from the start and can claim ownership of the activity. Only they can provide explanations for the data, and it is their personal experience that will yield these explanations. This is one of those occasions on which the kids control the curriculum.

Until kids have a way into the material—until they can clearly see themselves as entitled to make meaning with the material—they will not be able to engage with it. The discussion that takes place in Paulina's class is not just about control of the curriculum; it is about community control. It is about the relation between legitimate knowledge and what students and teachers do together in the classroom. In deciding to guarantee her a place on the graph, Paulina's classmates are defining the graph as a representation of the class's joint experience, not just of lemon juice mixtures. They are striving to view the graph in much the same way that Griselda and her class view the graph of their classroom participation. This view of the graph allows the kids in the class to attach themselves to the representation, and embodied in the representation they can in some sense move around in it. Although this may not be the aim of teaching graphing, it is a step toward making graphing meaningful: It is a point from which students can later detach themselves.

The actual making of the solutions was a long and serious endeavor, which, presumably, the students engaged in for its own sake. That activity was about community, as well as about individual students throughout the class making, tasting, getting sticky, and spilling things. Some kids were no doubt clowning while others worked quietly. Some probably took charge and some were watching their heartthrobs or their enemies as they went about (or did not go about) the business of mixing sugar and lemon juice. They probably had to compete for the sugar container and who knows what else. Only the people who were in the class know what went on as they made those mixtures: what the history of each mixture is.

Graphing is designed to extract properties of the product of this activity (the lemon juice mixture), erasing the experience and with it the relation between the mixture and the community that made it. Paulina's classmates resist this erasure. After all, if the graph is not in some way about the activity of mixing the solutions, why did everyone in the class have to make one? Perhaps one person could have done them all or just a few people could have done it. Even the teacher could have brought the solutions premixed. In exercising their concern about keeping experience and representation together, they are also exploring the terms of separation of representation from experience. They are negotiating erasure and, in doing so, learning about what Star coins *Illegitimate Central Marginality* (ICM). They are learning where the boundaries are and what counts as leakage of experience.

Schooling is as much about itself and about kids' behavior as it is about subject matter. Thus, activity, the daily life of the class, social relations, and the subject matter are never quite separate. It makes the elementary school classroom hard for the uninitiated adult to follow, as inquiries about field trips, homework, or whether we are having PE today pop up with all seriousness during question–answer sessions about improper fractions. These inquiries are somewhat legitimate within classroom discourse, along with the observations about kids' behavior that peppers teachers' classroom talk. It is in this context that one student finds an occasion in the discussion of lemon mixtures to mention her expired passport and others find an occasion to bring up stories of their dogs' deaths. As we think about kids' rights to make meaning with science, we need to remember that studenthood is not a generic experience. Some kids' experience gets to leak more than others': The class will not be equally receptive to the details of all kids' lives outside of school, their perceptions, and their concerns. Not everyone's dog will be found worthy of mention. Restricted leakage rights are the ultimate in marginalization, and marginal participation injects marginality into knowledge—not just partial knowledge, but a sense of the marginality of one's understanding. Learning, then, cannot be separated from entitlement, and the educator must be concerned with the entitlement of all kids. We need to think of educational equity, then, not in terms of equal access to learning opportunities, but equal legitimacy—equal access to making meaning. We cannot forget that one needs license to grasp an opportunity. Opportunity does not sit out in space disconnected from all individuals for the more able or eager to grasp; it is more connected to some than to others, itself holding out a hand to those with whom it already has a relationship. Together, these two chapters remind us that only to the extent that learners feel entitled do they have a shot at genius.

Star's own experience has ultimately made its way into scientific discourse—perhaps not medical discourse at the moment, but into scientific discourse nonetheless. It has made it by virtue of Star's courage and creativity, but with the support of her status within the intellectual community. Star's intellectual and professional status allow her to push the envelope in important ways. She takes risks with the hope that her audience will assume from the start that what she is doing makes sense—that they will first question their own understanding if they cannot see where the sense lies. Star's account emphasizes that entitlement is at the heart of intellectual practice—to be shared and used in the interests of intellectual inquiry.

PART

II

Accomplishing Thinking Practices

CHAPTER

7

CULTIVATING CONCEPTUAL CHANGE WITH BENCHMARK LESSONS

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Benchmark lessons are a genre of teacher-instigated full-class discussions aimed at promoting conceptual change in students. Benchmark lessons aim to draw out and engage students' own ideas in a rich context of communal inquiry on a topic of scientific importance. They seek a high level of immediate engagement and extended reflection focused less on scientific facts than on the processes out of which such facts emerge and come to be seen as sensible.

Through the years, one of us (J. M.) has developed a series of such lessons to serve as pivotal components of a high school physics course. However, the assumption here is that these are not idiosyncratic creations, but represent a *natural kind* of instructional technique. That is, we believe we recognize a strong family resemblance among some of the practices of teachers who share a broad view of learning and instruction. We believe that benchmark lessons are essentially "there to be discovered"[1] by teachers who aim at roughly the same goal–deep conceptual change–with roughly the same orientation toward how one teaches. Such teachers, by the natural process of trial and refinement, may independently construct lessons that are like benchmarks in important ways.

We do not directly defend the claim that benchmark lessons are a natural kind. Instead, we characterize benchmarks as we have come to understand

[1]Don't take the *discovery* metaphor too seriously. *Reliably constructed* might be more apt.

them. We try to say how and why they work in such a way as to (a) distinguish benchmarks from other kinds of lessons, (b) characterize their prerequisites and outcomes, and, in suggesting how they work, (c) suggest how one develops benchmarks and how one can improve them.

Our strategy of exposition is as follows. First, we outline some of the background assumptions and orientations that make benchmark lessons sensible. Second, we try to distill the character of benchmarks into a series of maxims that may guide teachers in the practice of creating and conducting benchmark lessons. Finally, we enter a fairly detailed analysis of the knowledge content and activity structural components of a particular classroom lesson. The detailed analysis is intended to support, illustrate, and develop the more general discussion.

This chapter emphasizes the teacher's perspective on benchmarks. Clearly, the student's perspective is as important to develop, and certain aspects of it are so essential to benchmarks that to avoid them would be misleading. However, for the sake of simplicity and depth, when there appears a choice, we speak about teacher issues.

FOUNDATIONS

What sort of teacher might invent something like a benchmark lesson? Describing commitments and orientations behind such a lesson is an excellent place to start. The learning sciences are in the midst of, if they have not completed, what we take to be a Copernican Revolution concerning core assumptions about knowledge and learning. There was a time when one could speak unself-consciously about learning as a transmission of knowledge from knowers to learners. Even if the metaphor had some rough edges, it was taken to be a serviceable first approximation.

This is no longer the case. At least some of the things that are learned in school touch deeply on students' prior knowledge, understanding, and intellectual world view. In these cases, the transmission model is clearly too crude to endure. Prior student conceptual resources and beliefs have a deep effect on the dynamic of instruction, either beneath the surface or quite prominently and visibly. We believe many sensitive teachers are aware of the influence of students' own ideas and seek actively to understand and engage these. This is the first pillar of benchmark lessons.

One visible version of the influence of students' prior ideas is the familiar phenomenon of *misconceptions*. Many studies apparently show that students frequently have deep and resilient ideas about school subject matter. Measured by a repertoire of simple, qualitative problems—which nonetheless get to the heart of instructed scientific views—many students, in some cases the majority, come out of instruction essentially as they went in.

In our view, characterizing prior ideas as misconceptions overestimates the individual robustness of these ideas and greatly underestimates the richness, generativity, and possibility of productive engagement of naive knowledge. Nonetheless, misconceptions research constitutes a valuable reference that establishes the importance of prior ideas in conceptual change.

In contrast to a misconceptions orientation, benchmark lessons count heavily on the productive contributions of a student's ideas. Old ideas serve to scaffold and provide reference markers in the process of learning science. Much of our own prior empirical and theoretical work has been to substantiate and elaborate this claim (diSessa, 1993; Minstrell, 1989; Minstrell & diSessa, 1992; Smith, diSessa, & Roschelle, 1993). The process of ferreting out pieces of prior conceptualizations and framing them in discussions to be maximally helpful in learning is at the core of preparing and running benchmark lessons.

A most devastating scenario for the role of prior conceptions in schooled learning occurs when they are not directly engaged at all. If teachers do not cultivate in students any view of their own prior conceptions and their roles in learning, students may decide school ideas make no sense because they do not jibe with their own versions of these ideas. Alternatively, students may decide their own ideas must simply be abandoned, thus forsaking one of the most important resources for learning.

Beyond this first pillar, seeking to build on a continuity of ideas, our benchmark orientation involves a second dimension of continuity. We believe conceptual change entails a continuity in sense-making activities. Knowledge, as conventionally conceived, does not adequately convey the nature of important parts of the mind's life. People have interests, habits, and patterns of engagement, not just instrumental *know how* or *know that*. Students should be understood as committed doers, not just knowers. The educational task should be conceived as providing students better scientifically adapted ways of being and doing, not just knowledge and concepts in a narrow sense. If a student winds up being able to solve a problem with a scientific concept, but feels no inclination to pursue his or her own version of a scientific view of events outside the classroom—or feels completely at a loss without an authoritative presence that specifies what constitutes a scientific view—this is not a science instruction toward which we can feel much commitment.

A scientist's ways of thinking are strongly situated in his or her personal sense of identity and worth. They are situated socially, in community interchange and membership, as well as privately. For the purposes of this discussion, we take as axiomatic that this broader personal and social context for knowledge must be engaged and developed in classes, as well as the narrower concept- or knowledge-oriented views of students.

Sense-making activities makes a good slogan for this orientation. In the first instance, focusing on patterns of activity undermines sometimes inappropriate assumptions about the locus of knowing. *Sense-making* has a congenial double meaning. Most obviously, the active search for sense is a wonderful bridge between the fabric of everyday life, of a child's world, and a scientist's world. Einstein said, "Science is nothing more than a refinement of everyday thinking." Thinking of classroom discussions as activities in the pursuit of sense—inquiries—does justice both to the core properties of science and also to the restless, organizing nature of human action in any context. Scientific inquiry is not the same thing as what we all do in our daily lives, but one can be seen as a species of the other. Instructionally, students can be moved gradually and with care from one to the other.

There is also a more straightforward interpretation to sense-making. Educational activities must simply make sense in the most direct way to students who engage in them. This interpretation reminds us that learning science fundamentally changes what things people view as sensible to do or think. We cannot jump too quickly to activities patterned after professional science, leaving students in an uncomprehending wake. Students have their own personal and social worlds to hold onto. Instruction must respect that. The currently popular adjective *authentic*, used to describe good activities, should point in the direction of respecting students' judgments of sensible in what they are asked to do.

MAXIMS FOR BENCHMARKS

How are benchmarks different from other lessons?

Benchmarks Are Memorable

In common English, benchmarks are easily accessible standards against which other things may be measured. In surveying, bench marks are permanent indicators (e.g., of altitude) that serve as reference points in further charting the unknown. Similarly, benchmark lessons are intended to be memorable reference points in learning. In our experience, students consider them the highlights of a course even many years later.

Benchmarks Have Content, Epistemological, and Social/Activity Goals. They Build on Prior Ideas and Competencies

Content Goals. Of course we want our students to learn subject matter—in our case, physics. Benchmark lessons help students come to a more scientific interpretation of natural phenomena. We view this not as eradicating misconceptions, but rather as fostering a reconstruction of understanding from pieces, many of which students bring to class. Indeed, most of these initial ideas are not so much wrong as they are incomplete or perhaps inappropriately applied by scientific standards.

The quality of understanding that we aim for is important as well. We want to help students construct flexible, powerful, and felt-to-be sensible conceptions that can be appropriately applied or accurately seen as irrelevant in a wide range of contexts.

Epistemological Goals. Building a new conceptual framework from older ideas is a slow process. This is an important epistemological point for us to make about benchmarks, but also for students to experience and think about within them. Benchmarks are intended to be reference experiences for students' understanding of the nature of learning and physics broadly. We want them to come to understand physics as a process of inquiry and a frame for judging results of inquiry, not just results per se. Benchmarks engage students in generating a fabric of understanding by weaving evidence from and rational argument about the natural world.

Social/Activity Goals. The communal aspects of benchmarks are also important. Benchmarks are a scaffolded introduction to participation in a knowledge-building community wherein knowledge products are created in collaboration and collectively validated with reference to reason, experience, and scientific aesthetics.

Benchmarks Are the Beginning of an Extended Process

We (J. M.) use benchmarks near the beginning of a unit. This sets a high standard of engagement; it raises to consciousness many ideas and relevant experiences, and it focuses attention on critical issues that need to be resolved. However, benchmarks do not do the work of conceptual change alone. Although it may be a critical learning experience, a benchmark lesson must be set in the context of other learning experiences that, explicitly or implicitly, relate to it. Revisiting partly and newly formed ideas and arguments can emphasize the importance of a benchmark and its products. Revisiting also elaborates the ideas and their relations to diverse contexts. Making the ideas work in problem solving or projects can help students enhance their understanding as well as their perception of the power of an idea. Thus, benchmark lessons are not only global reference points for learning physics, but they also frequently serve in important ways to focus and organize subsequent learning specifically on the topic they introduce.

Benchmark Lessons Are About Important Issues. They May Help Students Re-Experience Their Familiar World

Benchmark lessons take a lot of time and care to develop. It behooves us to choose events or situations that involve ideas critical to the discipline. It is also critically important that the situation to be discussed evokes a rich set of ideas from students. Indeed, it is frequently tactically useful to channel the diverse ways of thinking about the situation into a discussion or debate about some relatively small number of alternatives, each of which supports a range of argumentation, both pro and con. However, it is seldom the point of the benchmark directly to decide which is the appropriate view. Experiments are not intended to settle matters. Instead, they reflect back on the reasons for expecting one result or another. Rather than "things weigh less in water," a preferred form might be "buoyancy would explain why this object weighs less."

A challenging measure of the success of benchmark lessons and attendant learning activities is the degree to which students come to re-experience familiar phenomena in a new way. If the world looks and feels different, and especially if students are aware of the shift and of the broader new context for their experience, genuine conceptual change has occurred (diSessa, 1986). "I used to think the ground just supported me; now I can feel it pushing up on my feet." Part of the memorability of benchmarks comes from being conscious of this transition.

Fostering Progress Along the Multiple Dimensions (Content, Epistemological, Activity/Social) Without Wresting Control From Students Requires Flexible Use of Many General and Specific Strategies on the Part of the Teacher

Fostering conceptual change involves teaching strategies that encourage students along two lines that may seem contradictory: to be both critical of ideas but supportive of free expression. Many students need assistance in formulating and representing their ideas. To encourage expression of tentative ideas, it is sometimes less threatening for students to formulate their ideas individually or in small groups before asking them to share ideas with the larger class. In small groups, fellow students can help reluctant students articulate their ideas. However, we want students to promote investigations that scientifically test ideas. We want students to criticize ideas actively on the basis of experiences and rational argument. In the long run, we want learners who are willing to make and correct errors rather than avoid and deny them (Papert, 1980; Resnick, 1987).

Listening and questioning techniques are especially important in fostering and guiding conceptual change. Some questioning can promote thinking within the discipline. "What would happen if . . . ?" "How do you decide . . . ?" "What actually did happen?" "How would you interpret or explain that result?" The teacher can also foster thinking about the students' own learning. "Is what happened consistent with what you expected?" "Is resolution of the inconsistencies worth doing?" "What would be the value?"

In the discussion, the teacher can guide the class by focusing on leads initiated by students, gently providing context for them. "Is that the same as X said?" "Y's idea seems different." "What's the key part of that contention?" This helps to honor the free expression of ideas and prepares the students to do their own thinking independent of authority. Even such simple strategies as waiting after asking questions and after students answer can foster deeper, more complete thinking. Students can and do reformulate their responses given time to do so (Rowe, 1974).

Shifting responsibility for questioning and answering to the students can foster preparation for lifelong inquiry and conceptual change. Acknowledging a question by a student, but reflecting it back to that student or to other students, can prepare students to use their peers for learning and to be less dependent on an authority. "Well, what do *you* think about that?"

To monitor the conversation, the teacher needs to know a lot about the students' initial ideas—how to draw them out, clarify them, and organize them unobtrusively to make productive contributions. Listening carefully and critically and asking questions to clarify what students are saying help students feel that their ideas and their thinking are important. In this way, a teacher can model the important process of being appropriately attentive to how one says something and finding out how seriously and literally a colleague intended an expression to be taken.

Allowing the conversation to move in the directions students lead focuses the effort on the organic development of students' ideas rather than on the "right answer." In a class situation with several students suggesting different avenues of thought, the teacher has the important but difficult-to-manage opportunity to lead by selecting focus.

Benchmark Lessons Assume Unusual Skills and Attitudes on the Part of Students as Well as Teachers

Teaching in these ways assumes some characteristics of the participants. Mutual respect is necessary between teacher and student and between student and student. The environment must support people who are willing to take the risk of being wrong. The learner must be willing to put forward a rough idea, explain and defend it reasonably, and have the idea tested by experiment and by others testing the idea against their experience. Students have to be willing to refine, revise, or even reject their ideas. They must be willing to share with and borrow from others. Teachers and students need to value inquiry as much or more than right answers. Most classrooms, we believe, teach the opposite of this.

Benchmark Lessons Are Difficult to Run and Learn to Run, but the Rewards Can Be Impressive

It takes time to develop the skills and confidence as a teacher to organize benchmark lessons. It takes effort and reflection to build any particular benchmark. Students usually do not begin by being prepared to work effectively in benchmarks. Sometimes a well-prepared teacher, class, and lesson fail for having made unhelpful choices during the running of the lesson, or just because students and teacher cannot get in synch. Yet these lessons can be exhilarating and deeply rewarding when it is evident students have taken them as the landmarks in learning they are intended to be.

A CASE STUDY OF A BENCHMARK IN THE MAKING

To exemplify the previous principles, bring out some of the richness and complexity of benchmark lessons, and raise some more detailed issues concerning them, we present here a case study of a benchmark in the making. That is, although what we describe was a completely spontaneous happening, it shows for us all the essential earmarks of a benchmark lesson. It is about a familiar physical event and evidently provokes a rich set of ideas from the students. There is a furious engagement on the part of the students, and we argue that this discussion is about important physics. What is perhaps most critical is that the teacher's stance and set of strategies are very much in the line of benchmark lessons, although this teacher had not heard the term. It is a slight disadvantage that this lesson is not a mature benchmark. However, this affords the opportunity to show from what experiences benchmarks emerge. It also lets us display heuristics for developing benchmarks.

The lesson at issue occurred in a sixth-grade classroom in a school in Oakland, California, about 2 months into a full-year course on physics developed by the Berkeley Boxer Group. It followed 4 days of intensive collaborative work by the students and teacher, which were separately analyzed (diSessa et al., 1991). There were four boys and four girls in the course. The students are bright and the school is scholastically oriented. However, we caution against dismissing the occurrence as exceptional. First, we remind the reader that these are sixth-grade students dealing with material that is more characteristic of high school or even college science. Second, the logic and arguments are drawn mainly from everyday experience and seem typical of the intuitive knowledge that we have become convinced is generally accessible to all students in many areas of science. Finally, this class is not typical of the school in which it took place. The teacher has already had to work very hard to undermine the teacher-oriented, correct answer-focused ethic that pervades most schools, this one included. Cultivating benchmark lessons is not especially easy just because students may be bright.

The lesson concerned a seemingly simple and innocuous question. Does an object engaged in a reversing motion stop between its forward and reverse motions? For example, does a ball rolled up a hill stop at its highest point before rolling back down?

Reviewing the video, we find it easy to imagine painting this discussion in a bad light. First of all, the teacher completely abandoned her own well-rationalized and well-prepared agenda to pursue a discussion about which she had no clear idea where it would go. Second, the discussion was chaotic and seemed nearly out of control several times. If the principal had looked in at those moments, we can imagine a rather negative evaluation. Even when the conversation was orderly, many students' contributions seem muddled to us, even after many viewings of the video tape, and they may have seemed so to other students. To make matters worse, the teacher did not always seem on top of the conversation. She might have even been uncertain of the correct answer. The talk led to no resolution. Although the *stop-during-reverse?* issue has an easy answer for physicists (of course it stops![2]), that answer was probably never the majority belief by the students even at the end.

However, both we and the teacher thought this was an exceptional learning episode. In the first instance, its very occurrence shows the teacher's dedication to student ideas and initiative. That openness allowed for a good discussion and created the possibility of locating a basis for—and beginning to develop—a full-fledged benchmark. The occasional lack of clarity and closure on the right answer are typical of benchmarks, and they are an excellent trade for the personal engagement they allow.

We first give a sketch of the trajectory of the conversation to orient readers. Then we dig into some details, organized by the two key issues: understanding what sort of ideas students brought to this discussion and looking at some of the strategies the teacher used to cultivate the discussion. Finally, we look at revising and improving the lesson toward the goal of a more fully prepared benchmark. The appendix contains transcriptions of some important sections of the lesson. A quick scan of the appendix

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[2]We use the term *stop* essentially as these students did—to refer to zero speed. For some purposes (but not ours), it is sometimes appropriate to use the term in a more restricted sense, requiring higher order derivatives to be zero as well. Also to clarify terminology, we use *velocity* and *speed* interchangeably, whereas in some usage speed is the magnitude of (signed or vector) velocity.

would serve readers well at this point. Looking back for details is especially valuable later to check our interpretations. In the text, we reference relevant quotations by segment number in brackets (e.g., [1]).

ORIENTING NARRATIVE

Review and Introducing the Task for the Day

The day began with the teacher drawing from the students a review of what happened the day before, ostensibly with the goal of bringing an absent student up to date. She soon turned to her agenda for the day, which was to exercise students' skills at depicting various motions within a number of different representational schemes that the students had developed during the prior 3 days of work. Among the representations was a standard one physicists might use–graphing speed versus time. The motion to be represented was described as what happened when someone tried to ride a bicycle up a hill but, being too weak to succeed, "ran out of steam" and (with great skill) reversed direction and rode backward down the hill [1]. Indeed, the specific curricular goal for the task was to get negative velocities into play.

Negative Distance?

Students selected or negotiated with the teacher the representation they would use and then went to the board. One of the students, S., who selected graphing speed (vertical) versus distance (horizontal), appropriately had the graph double back horizontally. As a result, it seemed the issue of negative velocity was going to be joined. Even before the class reconvened to discuss its representations, a side discussion developed about the reversing distance graph. A student, C., protested, "You can't go negative distance." Another student, Sh., added that any motion creates a positive distance. The creator of the graph defended it, stating that it depends on where you measure from. Apparently his claim was that if you have a reference position in mind, taking back distance (*negative velocity* in more technical terms) is quite sensible. [Segment 2 contains part of this discussion.]

The Core Dispute

One student, J., was selected to explain her representation, which was, in fact, a graph of velocity versus time. J.'s graph doubled back vertically; it swooped down almost to zero speed and then back up. Evidently, she did not think to show negative speed. The dispute broke out when another student suggested the graph should get to zero [4]. The students quickly took sides. S. and C. strongly (and unwaveringly) defended the claim that there is a point of zero speed. S. described the turnaround as "teeter-tottering" for a moment. A. was perhaps the most vocal advocate of nonzero turnaround. C., countering the fact that stop did not seem to be evident to some students, introduced the notion that the stop was very, very short—a millisecond. The teacher polled the students [end of 4]. They were roughly equally split, although some students were reluctant to take a stand.

Machines Versus People

C. introduced an analogy where he considered that the stopped state would be evident—a giant pendulum amusement park ride. A. protested that machines are different from people. You could not hold yourself still on a steep hill, but the machine operator can make the pendulum stop. Among the considerations that followed were that a bicycle is indeed a machine and that the amusement ride operator does not—*could not*—reliably cause the ride to stop at exactly the correct point. The discussion was continuing at a furious pace.

A Simulation

The teacher suggested a simulation. She asked A. to walk in slow motion to show what the bicycle would do. No clarification arose. At the point of turnaround, advocates of stop claimed to see it; opponents said it was not there. A counter to A.'s "no stop" claim came from a waffling student. M. said she might be moving her body (e.g., moving it around) yet not be going anywhere. Apparently the claim was that you could be moving in place so this should count as stop.[3] A revised simulation—rolling a cylinder up and down an incline—appeared to have some greater effect. A. watched intently and redid the motion several times. Responding to a claim of stop, she said, "Oh, you mean right there."

Omnipresent, Instantaneous Stops

Sh. introduced a consideration she would repeat later. She maintained that every motion involves stopping after every tiny movement [6]. It would be nonsensical to show these. The instantaneous stop of the bicycle rider on the hill, presumably, is as nonsensical. We interpret this argument later.

[3]It is interesting that Aristotle also discussed this point. He decided that it is nonsensical to speak of an object being at rest and moving at the same time.

Representation Versus Reality

The conversation took a new turn. Is it reasonable to depict invisible or nearly invisible things [7]? Among the variations on this: If the stop is "tiny, tiny," wouldn't it be misleading to show the graph touch the zero line, especially with (thick) chalk? On the other side, why would one bother showing the speed coming down to some tiny (nonzero) speed when, from a distance, everyone would read it as zero? The teacher introduced the notion of blowing up the graph and tried to focus on the issue of "what happens," not how to depict it.

How Slow Is Slow?

The following issue arose twice: If the speed never reaches zero, how small *does* it go? Suggestions were "1.2" and ".5," "Between moving and not moving." The teacher took another poll. There was no resolution, although in the process some students had wavered back and forth. Generally, the "no stop" side seemed to be retreating. With time running out, the teacher tried to close down the discussion, introducing the class activity for the following week. As the bell rang, a student reopened the stop discussion and students continued animatedly as they walked out of the door.

We now begin a more detailed review of this classroom conversation. Our discussion is somewhat complex because we have three goals: (a) illustrate general characteristics of a benchmark lesson in a particular case, (b) illustrate strategies of evaluation and improving benchmarks, and (c) develop some detail relating to this particular topic as we believe it may evolve into a superior mature benchmark. The review has two parts. First, we consider subject matter. Second, we turn our attention to social/interactional issues.

REVIEW OF CONTENT LEARNING

Benchmark lessons entail a central commitment to students learning important subject matter as a natural continuation of their own ideas and sense-making capabilities. Many researchers contend or imply that some profitable forms of learning activity (e.g., "small-group discussions") may be designed and evaluated independent of the subject matter involved and independent of knowing about the particular conceptual resources students bring to bear. This is not the case for benchmark lessons. This section focuses particularly on (a) defending that there is good physics in this discussion, and (b) drawing out some of the naive ideas involved and their lines of development toward expertise.

There is some face value to the focus of this discussion. This lesson started and ended with issues concerning graphing a continuously changing quantity–velocity. Negative speed was the sanctioned topic of the lesson, although unannounced, and there are indications that idea could have been effectively engaged in early side arguments about the meaning of S.'s reversing distance graph [2]. (We argue later that a revised lesson should reintroduce negative speed because it relates to one important class of arguments about stopped objects.) The main focus of discussion concerns an interesting kinematics question and, thereby, various conceptual models of stop. In particular, seeing a stop at the point of turnaround more or less implies a sophisticated notion of instantaneous speed that is difficult even for high school and college students. We continue along the following lines.

- There are timeless issues here. Aristotle debated with his contemporaries about this very question.
- There is evidence in the misconceptions literature that some standard instructional problems arise around this issue.
- Research on intuitive conceptions suggests that many of the ideas the children brought out are typical resources, not surprising aberrations.

Aristotle Visits a Sixth-Grade Class

In his *Physics*, Aristotle devoted an extended discussion to the question of zero speed, in particular, in a reversal.[4] His position was that a reversal does entail stop. He also believed it was stop for an extended period–not instantaneous. He made the following points:

1. The stopped state is evident empirically. One may simply observe it to happen.
2. Stop is necessary theoretically for a number of reasons.
3. The stopped state is for a finite duration. Instantaneous stop is an incoherent model of reality.
4. Aristotle introduces Zeno's paradox of the arrow–that because a moving arrow occupies a given space at an instant, one must conclude that it is at rest. He asserts this is counter to common sense and that it violates certain theoretical principles, such as assuming (nonexistent) time atoms (instants) and treating essentially continuous time as a mere sequence.

These students did not exactly come to the same conclusions as Aristotle, but the overlap in the set of issues and even in arguments is significant.

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[4]The relevant sections are Book VI, Chapter 7; Book VII; and Book VIII, Chapters 1–9. See Aristotle (1941), pp. 333–390.

1. Some students contended stop is visually evident in reversal. Others rejected this. The conditions are set for at least some students to re-experience a familiar event.

2. A wide variety of arguments was brought to bear on both sides (although only a few resemble Aristotle's). In this, two other preconditions of a good benchmark are met. A rich set of students' ideas is engaged by the discussion. Although the debate is channeled into a small set of alternatives, student arguments separated out and tracked the reasons for belief in one alternative or the other.

3. The dominant model of stop exhibited by these children entails a finite duration. Like Aristotle, they have sensible beliefs about the world. Like Aristotle, they have not yet accepted the sensibility of another model of stop that is now conventional in the scientific community.

4. Sh.'s argument [6] is remarkably similar to Zeno's argument. She argued that if one describes reversal as containing an instantaneous stop, any motion may be (absurdly) depicted as stopped at any time. She apparently accepts the plausibility of Zeno's model—that, at each instant, an object might legitimately be considered at rest. She also accepts Aristotle's commonsense argument that there is evidently motion, and she concludes it is simply nonsensical to depict instantaneous stop.

In drawing these parallels with Aristotle's *Physics*, our position is not that student conceptions may parallel positions held at various stages in the history of science in any detail (e.g., McCloskey, 1983). Rather, it is that the intuitive resources that even young students bring to bear are surprisingly similar to those scientists can bring to bear, especially at historically early stages of an inquiry (see also Clement, 1983). In this way, we argue that it is generally plausible to engage students in serious discussions of (some) serious scientific issues. We can expect arguments and conclusions to vary, but scientists and naive students can occupy a common intellectual terrain.

Conceptual Difficulties

One relatively well-documented novice misconception is that, at the peak of a toss, there is no acceleration (Clement, 1983; Reif, 1987). A plausible interpretation of these results is that students model the stopped state, which they have been instructed exists at the peak, as an extended stop (diSessa, 1993). Within an extended stop, there can be no acceleration.

The duration of stop was the crux of many arguments in our student discussion and it is arguably the central conceptual issue behind the whole discussion. The notion of instantaneous stop was maintained by no student, even those who maintained there was a stop. At best, the students assigned an extremely small time duration to the stop. Even this was usually contested as nonsensical or undepictable. In this regard, it is intriguing to note the sequence of durations ascribed to the stop by these students. In order, one finds:

- for a very short time
- like for a second
- a millisecond
- a tiny, tiny, little, tiny, tiny, miniature, miniature second
- a really short time
- point zero, zero, zero, zero, zero, zero, one
- there's never gonna be an end to blowing it up and finding the exact, it's so little

It appears that the force of argument is pressing these students into a limiting process. The progression seems in any case to be progress. However, we would be reluctant to think of this progress as achieving the full-fledged concept of limit, which makes instantaneous stop sensible to a physicist.

At the same time that we use misconceptions research as a guide to difficulties in conceptual development, we do not regard this misconception–that stop implies an interval of stop–as a critical barrier for students coming to a Newtonian view. Rather, we see engaging it as an opportunity to refine intuitive conceptions in a way that highlights for the participants the subtlety of scientific ideas. That is, our epistemological goals are as important as our conceptual ones. For these, all we need is that students get a good enough sense of the Newtonian view in this context so that the conceptual development they undergo could serve as an object lesson: Understanding science may involve subtle but comprehensible shifts in our naive ideas.

Other Intuitive Threads

Many of the arguments advanced by students seem to represent common intuitive ideas. For example, S. several times advanced the claim that the rider stops in a teeter-tottering at his reversal. This implicates seeing the situation in terms of balancing. Indeed, balancing is a central conception in naive physics (diSessa, 1993). It may even be surprising that S. is the only person in this conversation to voice balancing as a major consideration. This relative nonsalience of balancing is consistent with a claim we (A. diS.) have made in other circumstances–that instruction in physics actually encourages the *duration of rest* misconception by encouraging students to look at the situation as one of competing forces that happen to balance at the moment of reverse (diSessa, 1993).

The argument over the distinction between machines and people reinforces this interpretation—that students sometimes believe stop can happen only in a situation of balance. The argument seems to be that, with machines, sufficient force can be brought to bear to hold (which we interpret as a form of balance) an otherwise moving object at rest. If our bicycle rider is not strong enough to make the hill, presumably he is not strong enough to balance the force of gravity and hold himself at rest. A. said, "Your feet cannot hold you on a hill!"

Some perhaps surprising data from earlier in this physics course suggest yet more reasons that students do not see the stopped state as salient or necessary. One of the first activities with students was to ask them to develop a simulation of what happens to an object when it is simply dropped from rest. Only one of the groups of students who worked on a simulation bothered to show gradual speedup.[5] Instead, the other students seemed content with a motion that jumped from rest to a (constant) falling speed. If continuity in speed is not salient, it is much easier to imagine an object that simply travels upward, then reverses (without stopping) to travel downward. The stopped state only happens, presumably, when an object is held in place.

Calibrating students' knowledge is an important part of our review of content. Calibrating our own, and thereby establishing goals for instruction, is another. Many technically sophisticated individuals may judge that it is obvious, or at least necessary, that a reversal entails stopping. However, in the first instance, this judgment involves more than just reversal. In a world that contains infinitely rigid objects, which research indicates most physics-naive people accept (diSessa, 1993), a simple bounce must involve discontinuous velocities. Otherwise, objects will interpenetrate.

More profoundly, let us consider the integrity of Sh.'s model of motion. She envisages (or, at least, could envisage, we claim) a world of time atoms, where movement is always discontinuous. An object hops in each "tiny, tiny, teeny" step from one place to another. There is in the world, as scientists best understand it, extremely important subperceptual and even, in principle, unobservable phenomena. We do not believe there is any inconsistency or even implausibility that the world might be discrete in time below our threshold of perception. To be sure, a continuous view of the universe won out in Newton's mechanics and successors. This involves the distributed mathematical and physical success of the whole paradigm, which cannot be reviewed in any reasonable sense in a classroom.

The importance of this observation is the following. What is obvious, or even plausible, is an extremely subtle issue. Instructors much too often

[5]The students used an unconventional method of depicting speeding up. They drew an increasing spatial density of dots. However, their explanation of what they showed was unambiguous.

assume that the correct view is much more compelling than it is to students, even more compelling than it should be. They feel justified in presenting and nudging students toward what is right. This is even more a problem in classrooms that seek to engage students' own judgments—an engagement that we see as critical. If we understand that the correct view is not necessary (nor even plausible) to students, and that, on the basis of the demonstrations and arguments we can present in classes, it may not be made necessary on any grounds, a recalibration of educational success must be in order. The best outcome may not be that students articulate an allegiance to the instructed view, but may simply articulate that view along with others. Espousing a view without understanding its limitations and the strengths of competing views is by no means an unqualified positive.

In our own work, we had to confront that students knew the correct view, could use it effectively, and could even articulate the standard arguments for it. However, they simply did not believe it. We have wrestled with this and have come to the conclusion that this is a state that would not be allowed in many classrooms; it represents a respectable and possibly optimal outcome. Although we can easily imagine that this debate, as good as it is, could run an even better course, it is not at all obvious that such a course would include an agreement that reversal entails a stop.

"THE DANCE OF OWNERSHIP": SOCIAL INTERACTIONAL REVIEW

The Constructivist Dilemma

A constructivist approach to teaching seems inevitably to entail a dilemma. On the one hand, constructivism is a commitment toward students' own constructive power in learning. To many this means essentially, "Leave them alone!" On the other hand, as teachers we are committed to doing our best to help students learn. Genuinely to leave them alone violates that commitment. Of course, the dilemma is not an unresolvable paradox, but it does reflect the rich question of when and how to intervene, support, and suggest, and which work is desirable or necessary to leave to students.

Although the social interactional patterns we saw in this discussion are far too complex and subtle for any approximately complete exposition here, a particular version of the constructivist dilemma provides a view that brings a surprising amount of order from apparent chaos. We call this the *dance of ownership*. We metaphorically view students and teachers working together in a joint production—a dance—in which each lead and follow, in subtle and obvious ways, and in intricate combination. Sometimes the teacher leads with moves obviously intended to direct, and students may acquiesce. Sometimes students do not accept the teacher's move. They may just resist, offer alternatives in one way or another, or perhaps simply not see how to respond. In this conversation, it is clear that students were not only responders; they initiated lines to which the teacher needed to respond.[6]

The rhythm of the dance is also important. Sometimes it clunks along—move, countermove, acknowledge, acquiesce. Sometimes the interaction is so fine grained and well coordinated that *leader* and *follower* make little sense. For our purposes, it is critical to unpack ownership and leadership. There is no single global sense of ownership, say, the right to speak or set the terms of the conversation. Instead, we see three relatively distinct dimensions of ownership that relate directly to the goals our teacher had for this discussion.

First, student interactions have a natural spontaneity and flow that needs to be respected. Clarity, orderliness, and scientific or rational well formedness of presentation trade off against the natural dynamic. To pick one example, student ideas do not *keep* well. Intuitions need to be spoken quickly or they can easily die. Requirements to allow other students or, indeed, the teacher to finish their turn and that follow-up comments be on topic and in the logical order of argument must be balanced against conflicting requirements for spontaneity.

Second, this teacher acted as if (and we agree) it is critical that students are the primary contributors of substantial ideas to the discussion. However, provided this condition is satisfied, the discussion can be made better if the teacher adds ideas in the spirit of the discussion, ideas that students might have introduced under other circumstances, or at least ideas that can be quickly grabbed into the discussion. The teacher is a participant in the dance; it is unnatural and unnecessary for the teacher to refrain from being a contributor to the substance of the discussion. In our experience, students in one class might make critical contributions to one such discussion that in other editions simply do not arise. In those cases, the teacher can be a surrogate student, advancing arguments and ideas that might have been made by students under other circumstances. This is one of the critical cumulative effects of experiencing multiple occurrences of a benchmark. The teacher gets better at simulating students, knowing what kinds of ideas can be added to the discussion (often by watching them be introduced by students), and with what effect.

The third species of ownership is the most subtle. Making judgments of adequacy of arguments and bottom-line conclusions is a critical part of a

[6]It is interesting to contrast this analysis with other, more conventional analyses of classroom interaction. Typically, contributions are analyzed into stereotypical sequences of contribution types, such as "question, response, evaluation."

discussion. Indeed, one might cogently argue that it is the central thing learned in a discussion like this—not conclusions, but bases for judgment. On the one hand, a teacher obviously should point out strengths and weaknesses as she sees them, at least on some occasions. The teacher can sometimes productively stand in for the wisdom of the institution of science. On the other hand, judgment even more than facts cannot be communicated to students simply by asserting it. It needs to be developed in more gradual ways. Thus, it is easy to take the ownership away from students; in contrast, simply holding back is frequently the best strategy.

Each of these three dimensions—(a) pragmatics of the discussion, turn taking, tone, and logic of the discourse; (b) the ideas and conceptual basis of the discussion; and (c) the bases of and rights to judgment—set the territory for components of the dance of ownership. In black and white, the teacher must decide when and how he or she wants the conversation to be: slow, methodical, and rational, or (possibly) ebullient but chaotic; dominated by scientific concepts and judgments, or intuitive, with student ideas setting the grounds for discussion and bottom-line decisions. In more realistic gray tones, each dimension calls for judgments by the teacher on how far students have been stretched from their home ground, how far they should be stretched at which times in the discussion, and what strategies are most promising given the state of the conversation and possibilities it affords.

This analysis sets the ground for a rich and multifaced expertise by benchmark teachers. It undoubtedly includes an abundance of strategies, articulable or not, reactions and *knee jerks* in the flow of such conversations. It includes values and the ability to judge and reflect on many layers of classroom interaction, at least the three dimensions of ownership listed. It includes the resources to revise, redesign, and profit from the past.

The analysis of our case study with respect to social and interactional structure has two parts. First, we argue briefly and globally that these students did, in a real sense, own important parts of the discussion. Then we look specifically at teacher strategies.

Student Ownership

There were many indicators that the students owned and felt they owned many aspects of this discussion. In the first instance, the topic—stop or no stop—was not in the agenda of the teacher. Although she rejected earlier suggestions that students made about what should be done during this class, she entirely abandoned her own plan to pursue this debate when it started. The reason seems plain enough. The students were enthusiastic and involved instantly and almost continuously through the discussion. Indeed, that very enthusiasm and the extended, varied, and cogent nature of the interaction support in a general way one of the central presumptions behind benchmark discussions—that children possess substantial conceptual resources for undertaking discussion such as this. Even the most reticent students in the class made substantial contributions. Given a little help from the teacher in getting air time (which they received in this case), one might be hard pressed to determine from this particular discussion which students were generally outspoken and which were shy and retiring. Initiative was much more evenly spread compared with other discussions. Recall also that students resumed the discussion spontaneously at the end of class and continued into recess.

Interest and enthusiasm aside, there is a face value to the intellectual focus of the discussion, to which the teacher undoubtedly reacted. It is a debate about the subject matter in question. The students introduced many or most of the lines of argumentation, from the debate about controlled (machines) versus natural motion, to Sh.'s version of Zeno's paradox, to the reintroduction of representational issues late in the discussion.

Ownership is not something that can be handed to students. It is a stance by students that can be cultivated or repressed. We argued in our analysis of the four preceding days of discussion that these students possessed some important skills and orientations that made such a discussion possible (diSessa, Hammer, Sherin, & Kolpakowski, 1991). In particular, the teacher had worked hard—not only in this class, but in other classes in which she had these students—to get them to listen to each other and to value, speak for, and defend their ideas. Hence, their ability to engage in a lively but intellectually cogent discussion is neither magical nor unanticipated.

Teacher Strategies of Intervention

We now turn to teacher strategies for managing and nurturing a productive benchmark discussion. Rather than trying to sort out the complexities of context specific judgments by the teacher, we point out systematically that she frequently made polar-opposite moves along the dimensions of concern—for example, sometimes strongly taking over directorship of who speaks, at other times simply letting things run. In doing so, we intend to implicate another level embedded in the teacher's artful decisions about when to do what and about how to adapt general strategies to the quickly moving discussion. We make only the barest suggestions here about that level of detail.

The Teacher Frequently Let Things Run. The lesson we analyze was only 30 minutes long. The core debate was only about 16 minutes in duration. Yet there were several reasonably long periods when the teacher did not intervene at all. While the students first put their representations on the board, there is a stretch of almost 3 minutes where the teacher's voice is not heard. During this time, there are several contentful discussions among the students, including the substantial little debate about whether you can go negative distance or not [Segment 2]. In the heat of the dispute about the amusement park ride, whether machines are essentially different from this human situation, there is a stretch of more than a minute and a half when the teacher says nothing. During this time, we would surmise she is both trying to understand where this discussion is going and where it might go. She intervenes at a critical time when it seems the discussion is not progressing well. Indeed, one student, A., is heard to complain she does not understand why they are being allowed to continue when, she believes, the teacher knows the answer and could simply provide it [Segment 5].

The Teacher Intervenes at Critical Times to Explain Her Own Perspective and Strategy. A.'s complaint that the discussion is pointless—the teacher knows the answer and can just provide it [5]—is a critical event. First, it highlights one of the dimensions of preparation the teacher has attempted to provide these students. The standard mode of operation in classrooms emphasizes right answers and the teacher's authority in these so much that student discussion is implausible, especially to students. Despite that the teacher here diligently reinforces students' rights and abilities to think for themselves, still A.'s courage and willingness to participate seriously in this debate is an issue.

Although A.'s complaint is barely audible in the discussion, the teacher quickly took control and explained her perspective. She insisted that she believed the students could come to a good conclusion if they would think about it. She also explained that she was not even sure there was a *right* answer to the question. [Again, consult Segment 5.] Although unusually close to the epistemological heart of a benchmark discussion, this intervention was not unusual in that this teacher frequently explained what she was about and more times asked students to reflect on why the class was doing what it was doing.

The Teacher Made Many Strong Organizational Moves in the Conversation. In contrast to the segments where she let things run, sometimes the teacher simply took control of the conversation, although she did this almost exclusively for organizational purposes. "B. has something to say."

One of this teacher's habitual strategies for clarifying the state of the discussion was to poll the students as to their belief at the moment. Polling also allows students to step back from the flow of the discussion to reflect on their overall judgment, which we take to be a critical focus of development in benchmarks. The move seems well adapted to bringing logic and order to the discussion without interrupting flow; one can wait for an open space to take a poll.

Here are some examples of teacher's polling: "So, raise your hands if you think it should go to zero." [See the end of Segment 4.] "Does it stop or not? J." Sometimes students would demur, and the teacher pressed, "You've got to have an opinion!"

The Teacher Sometimes Let Her Own Moves Be Ignored. Students' responses to the teacher's organizational interventions were usually, but not always, yielding. They also were taking responsibility for deciding whether logical organization or flow deserved higher priority from one moment to the next. For example, at one point, the teacher tried to break into a heated exchange on whether this bicyclist could in principle hold himself at rest on the hill to restate the issue: "There's a question whether (continued raucous discussion)—Okay, there's a question about whether her. . . ." The move was ignored or rebuffed, and the teacher simply retreated for a while [Segment 4].

The Teacher Introduced Modes of Inquiry. Teachers, of course, suggest activities such as conversations, board presentations, and so on. In this discussion, the teacher made at least two strong moves to refocus the mode of inquiry. First, she took control of the conversation to ask a student to simulate, in slow motion, the bicycle going up and down the hill. Although a student had suggested getting another student to try the task, it was the teacher who took this seriously and made it happen. Thus, this is one of many cases where the teacher guided by selecting from student initiatives. Presumably the teacher had reason to believe that this empirical mode might have an effect, for example, that students might see the stop. In general, such moves implicate further expertise about productive modes of inquiry and are a further locus where experience with multiple editions of a discussion can accumulate in skill in conducting it.

When the simulation appeared to fail on the grounds that a person is too unlike a bicycle, the teacher did not insist or declare. Instead, she introduced another experiment—rolling a cylinder forward and back in slow motion. That is, she let the judgment of the group speak, not her own.

The Teacher Sometimes Organized Observations at a Very Fine-Grain Scale. During these simulations, this teacher provided an overlay of focus leading up to the point of reversal. "Okay . . . okay . . . okay . . . STOP!" Presumably her intent was to point out verbally the place where stop might be observed. (It is not clear from the tape whether this was needed or successful.) van Zee (1990) also pointed out that seeing is a complex act; helping to focus students' perceptions can make the difference between success and failure of an experiment.

The Teacher Sometimes Introduced Ideas and Arguments. Subject to the constraints of ownership, as we pointed out, it makes little sense for a teacher to abstain completely from the discussion. This teacher introduced several ideas and arguments with significant strength and intent. For example, she introduced and pushed hard the following question: If the bicycle does not stop, what is its slowest speed? We take this to be a fine move and one that seemed to have some positive effect. (M., in particular, seemed pressed toward zero by this, although he was generally in the nonzero camp.) In fact, it may be a little surprising that the move was not more effective. Evidently, students did not feel as much arbitrariness in pronouncements of 1.2 or .5 ("between moving and not moving") as we might hope they would eventually.

On another occasion, the teacher made a surprisingly strong move directed squarely at one student. This was in response to Sh.'s "it's unreasonable to show stop because, after all, we could imagine a stop after each instant's movement in *any* motion." The teacher said: "Sh., you're made of molecules, and we can't see 'em. Does that mean you're not there?" [Segment 6]. A bit later, however, she rephrased the criticism as a question: "Are we concerned about what it looks like, or are we concerned about what's actually happening?" Notice the epistemological nuance involved in raising this issue.

We think the teacher is misinterpreting Sh. in this situation,[7] or at least missing an opportunity for an important exploration, to which we return later. Regardless of whether this is a misinterpretation, there are two important points about this interaction. First, it is an opportunity to think about the possibility of reacting differently in a future version of the lesson. We argue later that there is much to be gained by tentatively agreeing with Sh.'s point and pursuing it. Second, even if the teacher is mistakenly too aggressive in this interaction, the overall trust and group dynamic survive nicely. Sh. laughed at the teacher's joke and showed no signs of being cowed by it.

The Teacher Monitored Her Moves and "Took Them Back" if They Did Not Work Well. At one point in the discussion, the teacher strongly pushes J.—who had drawn both a velocity versus time graph and a picture of the hill—to erase her hill [3]. We believe her motivation was to concentrate clearly on the scientific representation and suppress picture drawing. In fact, the teacher tried to draw on the authority of the rest of the class to sanction this move, taking a quick poll about whether the hill was necessary.

[7]The teacher seems to think Sh.'s argument is that things that cannot be seen should not be depicted. Sh.'s case is both more particular and has more support. It deals with instantaneous stops and recognizes that, even if these exist in constant motion, we simply do not display them in graphs.

T: OK. Raise your hand if you think the [hill] helps to explain that? OK (to J.), for you, it did, but it seems like we didn't need it. . . .
Sh: That's cause we already know the story of what's happening.
T: OK, that's true.
Sh: I mean, if you had whispered in our ear, it might be different.
T: OK, you're right.

Once again, we see a high degree of fine structure in the decision making. Strong moves are possible. Students do not need to run the show. However, weak moves and even nonparticipation, or taking back strong moves, are also appropriate under some circumstances.

The Teacher Was Explicit, But Also Used Subtle Cues About What She Took to Be Important. Several times in the discussion, the teacher simply announced what she took to be the important point. On other occasions, she used less obtrusive cues. For example, in the retelling of what happened the previous day, she commented on the recounting of the process of naming representations, "dah, da, dah, da, dah . . . ," seeming to say, "OK, let's get on to more important things."

The Teacher Took Responsibility as Curator of Decisions and Conclusions to Which the Group Had Come. The recounting of the previous day's work, in fact, showed an important class of responsibilities the teacher took on. In the first instance, the point of these recountings is to keep the history of the group process alive—to help students feel the coherence in their work. You cannot own what you cannot hold onto. A second point on which this teacher explicitly remarked to us is that recounting gives students further practice explaining and justifying to other students. In this particular retelling, however, it was clear this teacher had some focal conceptual and group process points she wanted to get to. She wanted to reinforce that the group had rejected some representations as too complicated, and she wanted to review that the group had decided against graphing speed versus distance. Not only did she force this second issue into the open by prompting until it arose, but she tried to review the rationale for it as well. "Why did we decide that?" In this case, the review of the rationale was not very successful, but the teacher chose not to stall the class to force a clear review. We now list our final few strategies with abbreviated discussion and support.

The Teacher Prompted for Reasoning. Decisions and judgments are much easier to pronounce than reasons or rationale. Yet reasoning, not right answers, is at the core of benchmark lessons. In major and minor ways, the responsibility this teacher felt to draw these out was evident dozens of times in the discussion. "What was wrong with that?" On other occasions: "Why didn't we like Volcano (one of the rejected representations)?" " 'Cause why?"

The Teacher Took the Time to Repeat and Rephrase Student Contributions. "All right, so you think it shouldn't touch the zero line. . . ."

The Teacher Monitored the Discussion and "Snapped up" Useful Contributions That Might Have Been Missed by Some of the Students. This was evident in, for example, her response to A.'s complaint about "the teacher knows the answer" [Segment 5], in her stopping the conversation to pick out Sh.'s remark about invisible stops and confront it [Segment 6], and in her taking over a half-serious suggestion that a student should be made to simulate the bicycle rider into a full-fledged, organized activity. Again, the teacher guides many times by selecting and may even be a surrogate student by introducing student ideas herself (e.g., in future versions of this lesson).

The Teacher Summarized the State of the Discussion. "Okay, are you ready? This is what I'm gathering from this. Some people think that her graph should go to zero, and some people think that it shouldn't." [Segment 4]

The Teacher Questioned Students About Their State of Comprehension. "You see that, M.?" On another occasion: "Did you get that?"

HOW TO MAKE A GOOD THING BETTER

Spontaneity, online skills, and strategies are always a vital part of fostering excellent discussions. Yet benchmarks are also long-term cumulative constructions in several senses. The values, stance, skills, strategies, and interactional patterns of both teachers and students grow gradually. In this section, we emphasize cumulativity in terms of a teacher's knowing both the intuitive ideas children may bring to bear in a discussion on this topic and also the lines of development it is possible to foster. The intention is to use what we have seen here as a teacher might—to prepare for a better benchmark.

Our review of content anticipated two substantial suggestions. First, we noted that a world that is discrete in time (time atoms beneath our perceptual limits of resolution) is a real alternative to conventional scientific conceptions of motion. We believe the teacher might, in some future version of this discussion, really open up this topic. Could we, in fact, know with certainty that the world is not discrete in time or space? Rather than challenging Sh. on the fact that we all know atoms exist independent of our ability to see them directly, we suggest it would be more productive to consider whether anyone historically could have ruled out atoms of matter before they were in any sense observed.

If time were discrete, what should the meaning of zero speed be? In this case, Sh. is surely correct. Saying that at each instant things are not in motion merely restates the presumed fact that time consists of a sequence of separate moments. As such, it is not worthy of notice. Instead, being stopped should mean something more—something that is not always true. It should mean that an object does not move for several moments—that is, for an extended duration.

It is perhaps controversial to teach nonstandard views of the world. However, we believe the value sometimes outweighs the risks. As we pointed out, it does no one good if students slavishly insist that textbook science is right without understanding that there might be alternatives—that simple observation and reason are not sufficient to settle even some apparently simple questions. Appreciating unusual but defensible views of the world builds *epistemic humility* and sophistication.

In other contexts in this course, these students were presented with multiple models of motion. One of the best developed class of models, computer simulations of motion, is, in fact, most suggestive of Sh.'s model. Objects move on the screen by hopping from place to place. Although the continuous model of space and time is intuitively powerful enough that students generally interpret "hopping" as an artifact of the computer world, it is probably a positive move to raise the issue explicitly.

We also mentioned in our review of content that temporal continuity is an important line of conceptual development to shepherd.[8] In this context, these students do not seem to find continuity as powerful and salient as might be. It is acceptable to them that an object may suddenly reverse its motion without slowing and stopping in between. Our guess is that the original topic of the lesson—negative velocity—is an important stepping stone that will add credibility to the case for a stop. If we develop a secure sense of negative velocity, the graph of speed versus time for this motion will not double back on itself, but will continue below zero. In that case, it would seem much less plausible that it somehow skips zero. Recall that one of the two staunch defenders of *stop* was the only child who demonstrated a belief in the possibility of negative speed.

One technique we already mentioned is to conclude a benchmark lesson with a laboratory demonstration. In this case, a simple electronic distance-

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[8]Indeed, we are suggesting that both continuous and discontinuous models of motion are important to consider. It is not incidental that Galileo extensively discusses continuity arguments in his treatment of a reversing motion.

sensing device (sonar) could be set up to watch an object moving up and down an incline. The graph of velocity (or simply differences of position from one reading to the next) would show a straight line of constant slope passing from positive to negative at the reversal. Of course, a student might well argue that the device is doing the wrong calculation. However, a simple, consistent, analytic form for velocity is, in fact, one of the good reasons to take negative velocity as meaningful. The demonstration would add an important additional perspective on the debate.[9]

We leave a final issue unresolved. Is it possible to provide students with a cogent, articulable model that would be an excellent "thing to think with" in pursuing a more conventional view of stop? Perhaps within a discrete-time model, stop might mean that an object remains at the same place for exactly two instants.

CONCLUSION

Benchmark lessons are complex and cumulative constructions (but also always spontaneous and improvised ones) that implicate a range of values, including: (a) a particular view of what deep understanding means, centered on explanation; (b) a commitment to the richness and value of students' ideas; and (c) a commitment to giving students a broader understanding of what science is based on community exchange and reflection on the learning process.

Our content analysis of one lesson aimed to show how much knowledge students have that can enter into excellent conversations like this one. Not any topic could possibly bring out such expertise on the part of children. Knowing where we can build is a major part of the enterprise of designing good benchmarks. Learning about student ideas is also a significant focus of developing a teacher's expertise. Being prepared for what students might say—and being able to trace more easily their judgments and follow their unusual but often cogent lines of argument—is important for the leader of a benchmark lesson. In turn, selectively following their ideas gives the teacher leverage in positioning those ideas so as to be maximally productive in the discussion.

As far as the outcomes of learning, our analysis suggests that getting the right answer is too much favored over understanding competing points of view, their strengths and weaknesses. Developing a student's ability to make judgments and scientific sense should be a major goal. Giving them the responsibility to do this is a strong commitment that sometimes might not admit of finding out the right answer as a feasible goal in a lesson.

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[9] This and similar classes we have given were computer based and in some instances students essentially did this experiment.

As for the form of the conversations, our analysis demonstrated an array of strategies that go into the dance of ownership, which might well be regarded as dazzling. We have argued that a central organizing principle behind a teacher's running of a benchmark lesson is to preserve students' sense of ownership over the form of the conversation and the ideas and judgments contained in it while advancing students' competence in each of these dimensions. At almost every turn of the conversation, a teacher has opportunities for moves ranging from doing nothing, to strongly organizing the turn taking, from rephrasing and summarizing, to making an argument either for herself or as a surrogate student, from following the flow, to introducing a completely different mode for the activity (like the simulation of a reversing object by a student or the reflection on the role of teachers in benchmark lessons in reaction to A.'s expressed frustration in not being given the answer). The fact that these strategies often line up as polar opposites—do nothing or organize; pick up a student idea or refute it—suggests that the analysis at the level of strategy repertoire is incomplete. We have barely scratched the surface of understanding how teachers do (and should) select from the repertoire according to circumstances and how they can fit general strategies to the particulars of the given conversation.

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APPENDIX

Segment 1: The teacher introduces the task to make depictions of a motion in various representational formats that were invented by the students. She describes the motion.

Teacher: Steve's riding his bike up the hill, right, but he—he's not really good at riding his bike up the hill so he almost gets to the top—he almost gets to the top, right, and you know what happens? He runs out of energy and he fall *[abrubt cut]*—he just rides—he's really good at riding backwards and he goes, phzuuuu, backwards all the way down the hill.

Segment 2: S.'s graph doubles back on itself, implying taking back distance (negative speed). Other students dispute the possibility of this, maintaining that distance must always increase.

B: S., is that yours?

S: Yeah. That's volcano. *[Volcano is the name of one of the representations. It is basically graphing speed versus distance.]*

B: Volcano—

S: Distance, distance

C: You can't go negative distance.

S: He's going backwards.

C: Yeah, but still. . . .
[Some unintelligible discussion.]

Sh: You're going distance, you're just not facing the way you're going.

C: Right. You're going distance. . . .

Sh: S., look, S., would you say I'm going distance right now? Yeah, I moved from there to there, I'm just not facing the way I'm going.

S: *[He is at the board writing.]* There. He goes 10 kilometers and then he goes back 10 kilometers.

B: You're going distance, but you're retracing your—

S: It's measuring—okay. But if you're measuring from your feet then you're not going anywhere. If you're measuring from there you're going someplace. But then if you go back, you're not going anywhere. You're going back.

A: Can I say something about mine?

S: . . . you're going backwards. Where are you measuring from C.? *[A. tries to get people's attention at the board to no avail. S. is talking at the same time. J. is still working on her drawing at the board.]*

Sh: Look here's my foot. Then I move this. Here's distance. . . .

C: *[Continuing and supporting Sh.'s thought.]* You're just not facing the way you're going so. . . .

S: You're measuring from here . . . you go like this.

Segment 3: In the midst of responding to criticisms, J. is about to erase an extra portion of her drawing that shows the hill, not the motion. The teacher intervenes to find out what the hill picture is for and tries to marshal support from the students behind her own opinion—that it is not necessary. One student protests. The teacher retreats from her move and then restarts the process of fixing J.'s graph.

T: Wait, wait, wait. Let her explain 'cause I want to see—what is this thing? It says distance covered.

J: OK, this part inside the box is the stuff that he actually got to. This is the top of the hill, and he never got to that. Okay. So when you—This *[hill picture]* is to help explain this *[graph]*.

T: Okay, raise your hand if you think the blue thing *[hill picture]* helps to explain that? Okay, for you it did but it seems like we didn't need it so—*[J. starts to erase the hill.]*

Sh: That's cause we already know the story of what's happening.

T: Oh, that's true.

Sh: I mean, if you had whispered it in our ear, it might be different.

T: Okay, you're right. But now we're giving them more room to fix it. Why do we need it fixed?

Segment 4: A furious debate ensues over whether there is a stop as motion reverses. The teacher tries to enter the discussion, fails, and retries three times before getting back in on her fourth attempt. She then summarizes the state of the discussion and takes a poll.

[J. is revising her graph.]

C or S: ... be at zero?

J: No, he never actually hits zero!

S: He stops.

J: I know.

S: Well, if he stops, then he's not going zero miles per hour when he stops.

A: Wait a second. No, he couldn't stop. If he's going up, he wouldn't stop—

Sh: He wouldn't stop—

M: Yeah ... he'd just take a quick ... *[Others are talking simultaneously.]*

S: ... teeter-totter ...

M: Haven't you ever rode a bike up a hill, you just put your feet on the ground and the bike doesn't go anywhere.
[Heated yelling from several students.]

T: So, basically....
[More yelling.]

T: *[She waits then tries to get in.]* There's a question whether—Okay, there's a question about whether her—
[More arguing while T. talks.]

B: You go up—M., M. You go up and then you like slow down, and then you start coming down. You never actually stop.

S: ... you teeter-totter. *[He holds his hand up flat and rocks it.]*

T: Okay, wait—

Sh: He went up and he—

A: Let's get a hill, put S. on it, and see what he does.

T: Okay, are you ready? *[Finally, there is relative quiet.]* This is what I'm gathering from this. Some people think that her graph should go to zero and some people think that it shouldn't.

M: Yeah, it should go to zero.

T: So raise your hand if you think it should go to zero.

Segment 5: A., barely audible, complains that the teacher should just provide the answer. The teacher picks this up, questions their perception of her role, and tries to deflect focus from both her own judgment and the right answer.

A: I wish Ms. T. would give us the answer instead of making us do this.

Sh: It's what we said.

S: She said it stops!

T: Is that what I'm for?

A: Yes.

S: You said it stops and then it comes back.

B: Let's like attack each other . . .

T: Okay. The point is this. I know that you can come up with the answer if you could just think about it. And I don't even know if there is a right answer, but the point is you need to discuss what you think about this.

B: Okay, well I think that–

T: Some people still think that he doesn't stop. Some people think he does–And now there's this question of whether the bicycle is like the *[amusement park ride (machine)].*

Segment 6: In the midst of the continuing debate, Sh. introduces a version of Zeno's paradox of the arrow. The teacher, sensing this is important, makes space for Sh.'s idea, but she does not get the point well enough to make good use of it.

Sh: . . . whenever you're doing something, you're stopping every single, tiny, little, tiny, tiny, miniature, miniature, miniature, little second.

A: We're talking about stopping.

T: *[To Sh.]* Wait, what? *[T. leans over, puts her hand out as if to focus the class's attention on Sh.]*

Sh: You can't always see it goes down to zero.

T: Wait, wait. Say that again.

Sh: Every time you do any tiny little tiny tiny thing, it stops for a tiny tiny bit, but *you can't always see it go down to zero and stop. [The last part is strongly emphasized.]*

T: Wait. We're not saying if we can see it or not; we're saying does it ever stop.

Later, Sh. continues the same point. The teacher puts her down, but with a joking comment at which all laugh. The teacher restates what she takes to be the current main issue.

Sh: You can't see my hand going like this *[stopping?]*. So in a motion, you might not be able to see it. And we're supposedly drawing the

motion. If you can't see the stop, then why put it on just because you know it's there?
[General talking.]

T: Sh., you're made of molecules, and we can't see 'em. Does that mean you're not there?
[Sh. laughs and nods yes.]

A: No, that means the molecules aren't there.

T: Okay. Are we concerned about what it looks like or are we concerned about what's actually happening? *[Students are talking on the side.]*

?: What's actually happening.

?: No, no, what you can see.

Segment 7: The students reenter the topic of representational adequacy. The issue becomes, regardless of whether there is a stop, will the representation be informative or misleading?

A: I don't think there is a big enough stop to put it on the graph.

M: Yeah.

A: Cause it would just confuse the person that's watching it.

T: M. Sh! *[Calls for quiet.]* M., M.

M: I think that there actually is a stop but it's like point zero, zero, zero, zero, zero, zero, one, and it's so tiny that I don't even see the point of putting it on the—I mean you could make it so that the graph is like the size of like planet Jupiter or something and then it. Then it would be sensible to make it touch the line.

Later:

S: It looks like it's touching, but it's not.

M: —I'm saying that there's a difference between this and this—

C: If it's gonna look like it's touching—

M: It's almost invisible but still, there's still a difference.

C: M., but if I'm seeing from here, I can't see that almost invisible difference. So, why even make it not touch?

M: That's what I'm saying.

C: Why go through the effort of making it just barely touch it if it looks from back here like it is touching?

M: No, that's what we're all saying. We're saying that there's no point in making it touch, but there's also no point in not making it touch.

C: Right.

CHAPTER

8

. . . THERE'S FIVE LITTLE NOTCHES IN HERE: DILEMMAS IN TEACHING AND LEARNING THE CONVENTIONAL STRUCTURE OF RATE

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INTRODUCTION

This chapter explores teaching and learning mathematics. Both are complex in many dimensions, as shown by recent research that uses teaching interviews to study conceptual change (Nemirovsky, Tierney, & Ogonowski, 1993; Steffe & Cobb, 1988; Thompson, 1994) or that follows conceptual change during classroom instruction (Cobb, Wood, Yackel, & McNeal, 1992; diSessa, Hammer, Sherin, & Kolpakowski, 1991; Lampert, 1986, 1991). As we move away from theorizing about teaching and learning as the transmission of information—teachers pouring knowledge into the receptive (or not so receptive) heads of students—we need a new language to explore what teachers and learners do in interaction (Bruner, 1986; Greeno, Collins, & Resnick, 1996). This edited volume proposes thinking practices as a different kind of language for describing teaching and learning. Our contribution elaborates this language in an exploration of teaching and learning in a particular elementary school mathematics classroom.

We have multiple goals in writing this chapter. First, we have used this project to continue a three-way conversation, including Magdalene Lampert, that started in meetings leading up to the conference on which this book is based. In those conversations, we kept returning to questions about what kind of mathematics we value, how classrooms could be organized to facilitate this kind of mathematics, and how to convince others that it was valuable.

A second goal for this chapter is to look deeply into how rate—what we take to be a central concept in the mathematics of change—develops in a classroom environment where learners are expected to experiment with and communicate about their own thinking. In this light, our job is both to explore the social organization of mathematical activity in a classroom and to follow specific aspects of a complex concept through that organization.

This leads to our third goal, that of unpacking the structure of how teachers and learners participate in a thinking practice in a classroom. As an analytic category, *practice* is often described as the dispositions that people acquire while participating in shared activity, but it is difficult to describe how their participation is organized or how these dispositions develop (Lave & Wenger, 1991). We need detailed descriptions of how mathematical practices are structured for learning, particularly in classroom settings. We hope to contribute to a growing body of research on how practices of mathematical reasoning develop (see Saxe & Guberman, chap. 9, this volume; O'Connor, Godfrey, & Moses, chap. 4, this volume) without losing track of individuals and their activities as participants.

Our final goal in writing this chapter has been to explore what is possible in working with an archive of innovative classroom teaching. Lampert's material provides us with a model of such an archive—it is a detailed and carefully indexed record of a sustained teaching intervention that can support multiple lines of analysis. Our analysis, carried out according to our own interests and largely independent of Lampert's accounts of her teaching, is a limited experiment with trying to use an archival collection of mathematics teaching and learning. This chapter puts some of our work into a form that is accessible to others in the research community. Hopefully, our three-way conversation and studies that spin out from it will continue.

Reciprocal Dilemmas of Teaching and Learning

Constructing stable ways of doing mathematics is difficult for students and teachers alike. Students come to the classroom with prior understandings, teachers often try to build on these understandings when presenting new material, and students then must figure out how new and often challenging concepts are related to their own experience. Making sense of mathematics creates reciprocal dilemmas for teachers and learners around issues of how (or whether) problem contexts can engage prior experience, how different forms of representation can be about the same mathematical concept, and how (or whether) to work toward a shared understanding. Cuban (1970) describes dilemmas from a teacher's perspective:

> Dilemmas are conflict-filled situations that require choices because competing, highly prized values cannot be fully satisfied. . . . Teaching requires making concrete choices among competing values for vulnerable others who lack the teacher's knowledge and skills, who are dependent upon the teacher for access to both, and who will be changed by what the teacher teaches, how it is taught, and who that teacher is. (pp. 6, 12)

Teachers must balance multiple values and make a series of rapid choices with important consequences in their work. The more complex and overarching a teacher's set of values or principles, the more difficult this balancing act becomes. How does a general principle translate into action? Can it be different with individual students? Does any principle always hold? What about principles that contradict one another? For example, a teacher might want students to explain their ideas or problem solutions to one another using whatever forms of representation they find helpful. But just how *does* a teacher get 29 students to explain mathematical ideas to one another? What if some students appear to understand a concept quickly and are not interested in explaining it to others? What if some of the explanations mislead other students?

Learners face complementary dilemmas as they try to get their school assignments done and, in the course of doing that work, present themselves as capable participants to others in the class. How can they make sense of the problems they are asked to solve, different representational systems that are used in the classroom, and persistent requests to demonstrate that they understand what they are being taught? We assume that producing and interpreting representations of quantity are central for developing mathematical competence in school. However, this assumption does not describe how students actually find problem situations (as distinct from the problems they are given), how they produce coherent mathematical representations of these situations, or how they communicate with others about possible solutions (see Newman, Griffith, & Cole, 1989, on the problem of creating and analyzing whole tasks in classrooms).

Students' dilemmas in learning mathematics parallel those we all face in everyday life. In exploring the role of representations in the organization of social action, Becker (1986) recommends that we:

> . . . deliberately avoid[ed] judgments about the adequacy of any mode of representation, not taking any of them as the yardstick against which other methods should be judged. [. . .] It seems more useful, more likely to lead to new understanding, to think of every way of representing social reality as *perfect*—for something. The question is *what* it is good for. The answer to that is organizational. (p. 125; italics original)

Becker's advice foregrounds what is usually left out in discussions of representation: Not only is a representation about and for something, but it is made and used by people. For Becker, the distinction between making and using representations appears in the red, huffing faces of pedestrian tourists, who struggle over San Francisco's hills to and from Fisherman's Wharf. They clutch perfectly explicit street maps in their hands, but these maps are made by automobile associations for drivers and show nothing about local elevation that might help someone on foot to choose a comfortable route through the city.

By analogy, we can imagine red-faced elementary mathematics students clutching the "frozen remains" (Becker, 1986, p. 123) of a textbook diagram or worked example, wondering how in the world its maker (we know them as curriculum writers) could have overlooked their problem of not knowing how to partition a line drawn on paper so that calculations work out just right, or how to choose among many possible operations in the next step of a symbolic derivation. These splits between making and using representations appear in and out of mathematics classrooms.

The dilemmas faced by teachers and learners in a classroom constantly shape each other. When a teacher asks one student in a group to explain something to their peers, she creates dilemmas for learners. Likewise, when students adopt or construct some form of representation to make sense of a problem for themselves and others, they create dilemmas for their teacher. Understanding teaching and learning in the classroom—how stable ways of doing mathematics develop—requires careful attention to shared dilemmas of context, representation, and sense making.

A Case Study of Teaching and Learning About Rate

This chapter is organized as a case study of teaching and learning the conventional structure of rate in an elementary mathematics classroom. We work with records provided by Magdalene Lampert of her own teaching. Our analysis follows a group of students through several days of work with problems on the relationships among time, speed, and distance. First we outline an approach to mapping the structure of participation in Lampert's classroom. Then we present a detailed analysis of how Lampert and several of her students work through the conventional structure of rate on a particularly challenging problem. We end with a discussion of how learners take up particular mathematical practices and how we might approach the problem of replicating aspects of thinking practices we value across different institutional settings.

A PARTICIPATION STRUCTURE FOR LEARNING MATHEMATICS

We have two reasons for looking so closely at a relatively small slice of a year-long record of elementary school mathematics teaching. First, we still have much to discover about how students learn to do quantitative reasoning: finding problems and quantitative relations within these problems, constructing and interpreting representations of these relations, and using these representations to organize meaningful calculation and communicate with others about the results of their work. Second, Lampert teaches as part of a clinical academic appointment, and so brings a unique set of personal and institutional resources to the classroom (see Lampert, chap. 2, this volume). As such, these data provide a window into what might develop if the work of teaching were reorganized, as it is in some other countries, to give teachers more time to reflect on their own practices and the needs of their students (Stevenson & Stigler, 1992). If we take the question of how to teach and learn the mathematical structure of rate as a serious research problem, Lampert's materials provide a valuable opportunity to examine this question in detail.

Background to the Study

We started the analysis reported in this chapter independently, and our selections from a sizable body of material turned out to overlap in surprising ways. Data sources included parallel video records (i.e., two camera perspectives on the classroom), transcripts of talk from these records, and daily journal entries both from Lampert and her students. These and other types of data (e.g., interviews and examinations) made up a collection documenting a full year of Lampert's fifth-grade mathematics teaching in a school affiliated with Michigan State University. Our analysis focused on several days drawn from a 6-week unit on the mathematical relationships among time, speed, and distance (see the appendix for an overview of the unit and list of materials provided to us by Lampert). Our selection and analysis did not attempt a complete account of the unit, much less a year of Lampert's teaching. Instead, this chapter reports our exploration of how the work of teaching and learning mathematics was undertaken in a complex classroom environment.

An Organization for "Authentic" Mathematical Work. In this classroom, Lampert taught 29 fifth graders (10- and 11-year-olds) during the hour following their lunch and recess period. Students worked in groups of four to six at clusters of tables around the room. Lampert started each class by writing a "problem of the day" at the chalkboard. Students were expected to copy that problem into a personal, bound notebook. Students worked in "small group time" for approximately the first half of the class, followed by "whole group discussion" for the remainder of the class. Lampert collected, read, and annotated students' notebooks every other week. Her written comments to students provided the basis for summary reports used in conferences with parents.

In notes that introduced materials used in our analysis (see appendix), Lampert reports that, from the start of school until early October, classwork focused on "learning ways to approach doing mathematics in school."[1] One of her goals was to introduce students to an "authentic form" of mathematical activity that resembles historical and contemporary accounts of how mathematicians work. This includes the notion that answers can "follow reasonably from" assumptions (we see this as developing a sense of mathematical necessity), learning that different assumptions about "conditions" on a problem can lead to different but plausible conclusions, and expecting that a challenge to a conclusion can be grounds for revising one's thinking. Lampert made these expectations explicit by asking that students record specific activities in their journal entries.

Finally, for the unit we examine in this chapter, Lampert had students watch *The Voyage of the Mimi* (Bank Street, 1985; Lampert, 1985), a videotape about a fictional research voyage aboard a sailing ship. She intended to use this as an anchoring context for discussions about situations involving rate (Lampert, 1985). Just before our selections, students watched the first two episodes of this videotape series, and their classroom problems were mostly variations on finding a single unknown in the time–speed–distance relationship. Lampert planned to have students work on a problem from the third video episode, in which the ship loses electrical power. As a way of measuring their speed, the *Mimi*'s crew dropped a piece of bread overboard at the bow and then recorded how long it took the bread to clear the stern. As a result of this anchoring context, most classroom discussions about "problems of the day," the structure of rate, and alternative strategies for finding unknown values involved a general context of travel.

Our Selections From Lampert's Material. After independently reviewing the case materials Lampert provided, we made a series of further selections (see Fig. 8.1). Events presented for detailed analysis in this chapter were chosen to illustrate aspects of teaching and learning that each of us felt were important for characterizing Lampert's classroom as a developing mathematical thinking practice. Naturally, these progressive levels of selection reflect our interests, and our analysis cannot determine either the prevalence of these events or the collective quality of their outcomes. We believe the events we have chosen are typical of Lampert's teaching and the experience of many of her students, but our real aim is to focus on how teaching and learning are actually accomplished in the ongoing work of this classroom.

Because the case materials Lampert provided for this chapter spanned late October through the middle of November, we began our analysis well

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[1]Unless otherwise indicated, quoted terms are taken directly from Lampert's journal writing. In our work with classroom recordings, we find she uses parts of this vocabulary consistently with students, particularly during whole-class discussion.

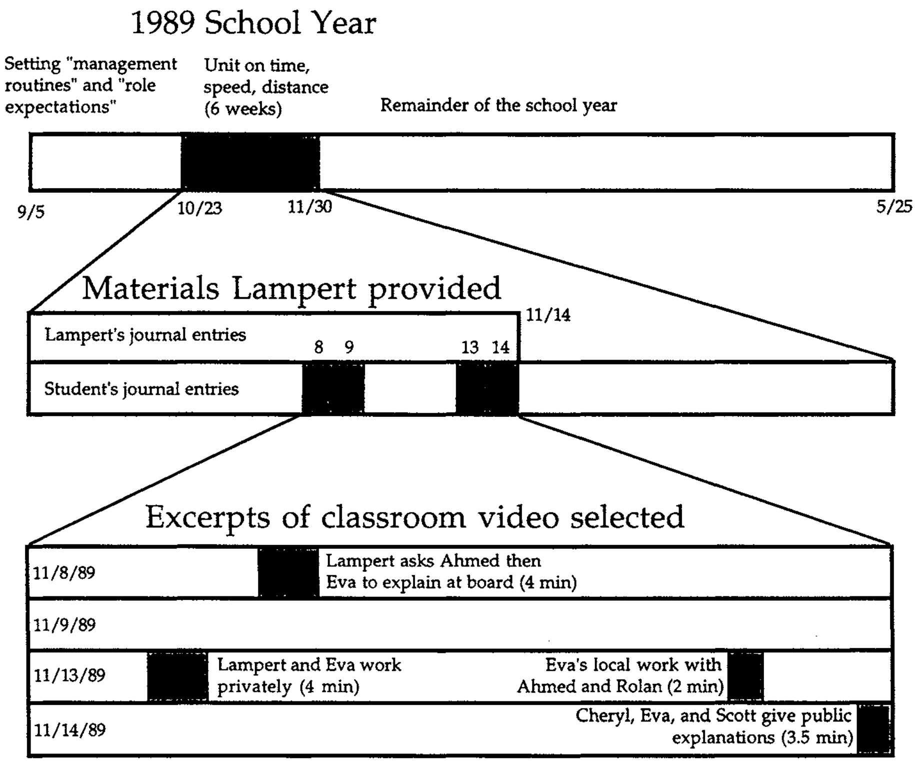

FIG. 8.1. Our selections from Lampert's time–speed–distance unit.

into the school year for this classroom. As a result, conventions for talking, broad patterns of classroom organization, and responsibility for documents were already well in place. These conventions required some effort to develop and were recognizable once established, as evident in a journal entry Lampert wrote after returning from a short vacation:

> It was *great* to be back! I feel very relaxed about having a sort of messy beginning of class—although it was far from being chaotic. So many routines are in place, the kids & I "understand" each other, there is a culture of sense making and mostly meaningful activity. (Lampert's journal,[2] 10/23/89, p. 98; italics original)

The Structure of Classroom Participation. We think about this set of conventions for talk, activity, and work with documentary materials as a

[2]We cite entries from Lampert's journal, her students' journals, and video records of classroom events (time, camera, and date) using specific indexes into this corpus of classroom data so that others working with these materials can examine and build on our account.

participation structure (Erickson & Schultz, 1977; Philips, 1972), which Lampert also describes as "routines" to engage students in "sense making" that resembles authentic mathematical work (Lampert, 1991; Lampert's journal, 11/4/89, p. 133). Of course, students come to the classroom with varied expectations about how to participate in mathematics. The kinds of talk, activity, and documentary work that are already familiar to students in school (e.g., Lemke, 1990; Mehan, 1985) or outside of school (Dyson, 1993; Eckert, 1989; Erickson & Mohatt, 1982; Heath & McLaughlin, 1994) may or may not be compatible with the structure that Lampert is attempting to build.

The match (or lack of it) between students' existing ways of doing mathematics and the kind of participation structure Lampert hopes to establish is part of what leads to specific dilemmas for teaching and learning in this classroom. Some of these are beyond the scope of materials selected for this case analysis (e.g., What are students' entering mathematical practices like? When and how do they challenge or argue about ideas outside this classroom?). Other classroom dilemmas, like proposing different forms of representation or deferring evaluation of errorful but potentially interesting student contributions, are more accessible within this corpus of classroom data.

As a way to focus our analysis of the participation structure in Lampert's classroom, we combine three analytic categories: (a) a set of marked[3] activities for doing mathematics, (b) linked classroom settings in which these activities appear, and (c) particular forms of representation used by Lampert and her students.[4] We use these categories to create a map that will help us look for how students enter the participation structure that Lampert is attempting to create. The first two categories—activity structures and settings—are discussed next. Later, we examine a particular representational form within the details of case materials.

An Activity Structure for Mathematical Work

Because Lampert's classroom, and any place where teachers and students work, is complex, we need some framework for organizing an analysis of mathematical practices. The framework should both help select material from the data corpus as a way of managing the analysis and foreground issues we think are important for learning mathematics. Figure 8.2 shows a map for this case analysis organized around the three analytic categories mentioned earlier.

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[3]Activities are marked in the sense that Lampert and her students make explicit references to named activities in their interaction, and these activities are explicitly recorded (with varying detail) in students' journal entries.

[4]See Saxe (1991, chaps. 3 & 15, this volume) for a related description of practice participation in and out of school.

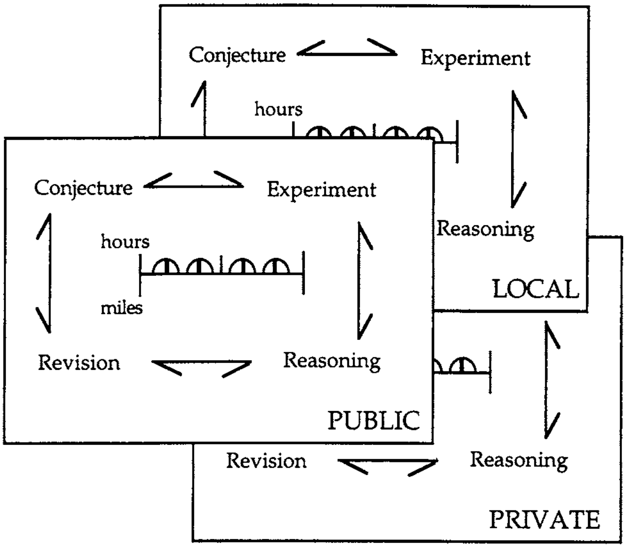

FIG. 8.2. Map for exploring a participation structure in classroom mathematics: Particular forms of representation (center of each plane) support mathematical activity (periphery of each plane) that moves across settings (overlapping planes).

To describe the structure of mathematical activity in this classroom, we borrow terms directly from Lampert and (sometimes) her students. As a way of doing, talking, and writing about mathematics, Lampert consistently asks her students to make "conjectures" about relations between quantities and their values, to carry out "experiments" (usually involving calculation) that bear on these conjectures, to "reason" about the results of these experiments, and then to "revise" their conjectures accordingly. Activities marked by participants as conjecture, experiment, reasoning, and revision sometimes make up composite episodes that Lampert and her students call "explaining," "agreeing," or "challenging" during classroom discussion. These mathematical exchanges, of course, appear within broader patterns of life as a fifth grader in Lampert's classroom: Each class meeting focuses on a "problem of the day," there are regular cycles of assessment and grade reporting, and these all fit within the progression of an elementary school year.

Settings for Teaching, Learning, and Doing Mathematics

Students conduct these (and other) activities in different settings within the classroom (separate planes in Fig. 8.2): working in private on the problem of the day (e.g., in their journal), making and revising conjectures in the local work of a group (e.g., leaning into the space of another student and pointing to their writing or drawings), or asking and sometimes being required to conduct these activities in the public setting of a whole-class discussion (e.g., demonstrating one's approach at the chalkboard). By using the term *setting*, we are trying to describe a student's "personally edited" version (Lave, 1988) of classroom contexts like seat work, group work, or whole-class discussion. This approach to context attends both to constraints provided by classroom routines and to participants' flexible reproduction of these routines in interaction.[5] As the teacher in this classroom, Lampert can appear in any of these settings; because video records used in this case follow Lampert, the settings we describe usually (but not always) include her presence. Moving from private to local to public, settings successively expand the social availability of students' activities and so create broader opportunities for evaluating a student's position, finding or comparing alternative approaches to a problem, or even proposing new problems. Settings are the second analytic axis for the map we are using to organize this case analysis (Fig. 8.2), with activity structures and representational forms providing the other two.

Although each setting provides opportunities for learning, the participation structure that Lampert creates encourages movement of mathematical activity across these settings. Reasoning about mathematical conjectures does occur in private (e.g., when a student works in her journal or confers with Lampert at her seat), but within local or public settings these activities take on more of the composite character of a mathematical "challenge" or "explanation." Participation in these discursive patterns leads to the center (Lave & Wenger, 1991) of a thinking practice that Lampert is trying to build—the "culture of sense making" and "meaningful activity" she writes about in her journal.

By following this analytic map, we are setting off to explore teaching and learning mathematics in a particular way. Within this map, when students begin to reproduce the discursive patterns that Lampert hopes to teach (e.g., giving an "explanation" for a "conjecture"), and they do so across settings, we would take this as evidence that they are learning a specific way of doing mathematics. As marked activities are taken up across settings in Lampert's classroom, students appear to go beyond calculation or recall of problem-solving strategies to engage practices that compare alternative notational forms, recognize and find mathematical necessity, explore new mathematical objects, and communicate with others about the results of

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[5]What we call an *explanation* in a *public setting* does not guarantee the attention of all members of the classroom (e.g., what Stigler, 1996, records as the perspective of an "ideal student"). Rather, the setting is public for its immediate participants (i.e., the potential audience is large) and may be carried out simultaneously with many other contexts. This distinction is immediately obvious when watching and listening to a local group of students during what would otherwise be called a whole-class discussion (Hall, Knudsen, & Greeno, in press).

this work. Learning this kind of mathematics in the fifth grade may *require* that students enter a new participation structure–one that Lampert works hard to provide and that some students eventually take responsibility for reproducing on their own. For the purposes of this edited volume, we call this circulation of activity and forms across settings (i.e., the intended participation structure in Lampert's classroom) a *mathematical thinking practice*.

WORKING ON THE STRUCTURE OF RATE

Entering a new participation structure for doing mathematics is one way to describe learning in Lampert's classroom. If we are right about the importance of moving specific mathematical activities across private, local, and public settings, we should be able to illustrate this movement (and the progressively more sophisticated character of students' mathematical work) within our selection of materials. As it stands, our analytic map tracks mathematical activity across settings, but it is still empty of any particular mathematical content. We have yet to add an analysis of particular representational forms that circulate through settings, change in transit, and provide structuring resources (Lave, 1988) for "experimenting" with a "conjecture" or the composite character of "explaining" or "challenging" a mathematical idea.

A Representational Form for Rate

From a cognitive perspective, rate is a conceptual entity (Greeno, 1983) that is central for quantitative understanding of domains as different as movement, commercial exchange, and biological growth. As a measurable aspect of a situation (Thompson, 1994), rate is an intensive quantity (Greeno, 1987; Hall, Kibler, Wenger, & Truxaw, 1989; Quintero & Schwartz, 1981) that specifies how two other quantities are related. For example, if a car travels for 3½ hours at 40 miles per hour, three quantities are placed in relation: an intensive quantity for the rate (40 miles per hour), an extensive quantity for time (3½ hours), and another extensive quantity for distance (140 miles, by multiplicative composition). As a relation between two other quantities (time and distance), rate has a dimensional structure that is useful across a variety of domains: Given the value of any two quantities in this triad, the third can always be found (Hutchins, 1995).

From an instructional perspective, students bring a long history of experience with rates to the classroom, but they may not be aware that rate is a structural relation between other quantities or be able to use this relation across a wide variety of situations. Thus, it is a central conceptual problem for many students to distinguish between different types of quantity (i.e., extensives and intensives) and to find strategies that can generate one of these quantities from another two. Students are expected to learn this as a stable set of relationships, not only for making estimates about ship or car travel, but for a broad class of situations involving rates. Framed in this way, Lampert's pedagogical problems are getting students to develop representations for working out these relationships in specific situations and helping them to realize that the same kind of representation can structure other specific situations (i.e., to develop a general understanding of rate).

In this section, we first describe the classroom development of a representational form used by Lampert and her students to work with the dimensional structure of rate. We then present an analysis of the representation as a structured drawing that can support some aspects of inference and calculation but not others. Finally, we compare student-generated versions of the representation in response to different problems of the day.

From Drawing to Diagram. The day after returning from her short vacation, Lampert records "a diagram of the journey" in her journal (10/24/89, p. 104) showing two snapshots from a drawing that she constructed in layers on the chalkboard (see Fig. 8.3). The drawing shows an approach to the

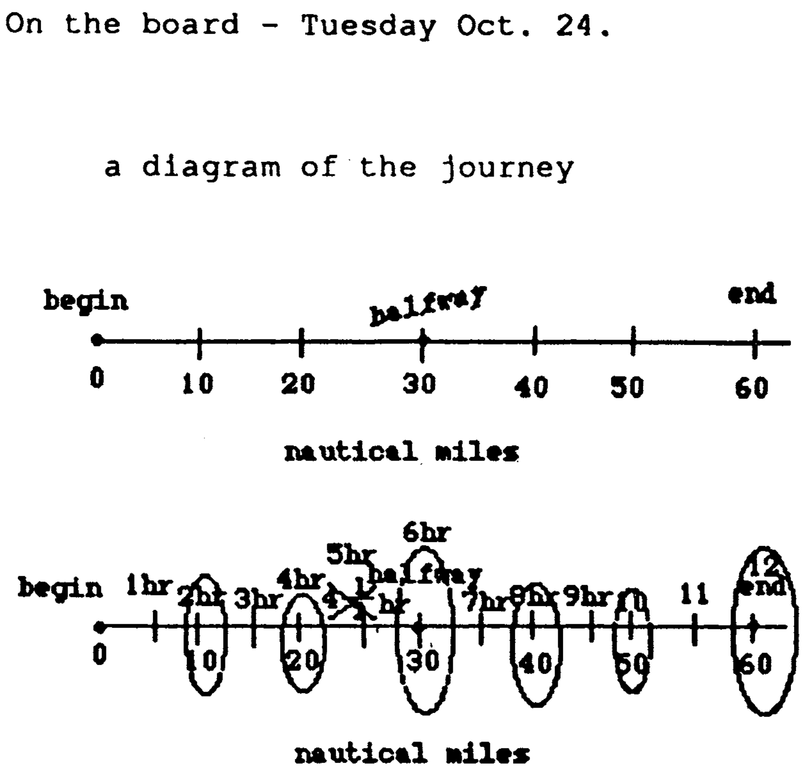

FIG. 8.3. A diagram of the journey that fuses number lines for time and distance (Lampert's journal, 10/24/89, p. 104).

problem of the day: If the *Mimi* travels 60 kilometers at a speed of 5 knots, how long will the journey take? We call this drawing a *journey line* to capture the joined sense of depicting the journey given in the problem narrative and surrounding instruction (e.g., the *Voyage of the Mimi*, students' talk about driving, etc.) with the conventional notational structure of a number line (i.e., a horizontal line, places for values shown with vertical cuts at regular intervals, and various labeling conventions). The journey line depicts the intensive structure of rate with upper and lower dimensions that fuse number lines for time and distance. What results is a single left-to-right display. In this display, partitions and labels above (time) and below (distance) are physically joined as a single inscribed line. As an integrated drawing of a constant speed, the journey line offers a set of representational conventions for coordinating quantities across dimensions (i.e., time and distance).

In the materials provided for this analysis, we cannot tell how Lampert actually developed the fused dimensionality of the journey line in the classroom. From successive snapshots in her journal (above, then below in Fig. 8.3), we see that a narrative description of travel (i.e., begin, halfway, and end) is layered over with unit times (e.g., 1 hr, 6 hr, 12), that Lampert's drawing visually foregrounds vertical alignment as a coordination scheme for quantities across dimensions (e.g., ellipses drawn around vertical cuts every 10 nautical miles), that an error appears and is corrected along the time dimension (e.g., 4½ hours), and that specific pairs of ascending values are produced as the journey progresses from left to right.

In notes written the day before, Lampert considers constructing a Cartesian display by "crossing" number lines:

> The work of *graphing* will be new to them (I think), and I don't want to spend a lot of time on it—2 crossing number lines, the numbers on the *lines*, not in the spaces, and they cross at zero. The question of *scale* will also come up if they want to do *big* numbers. There's a lot of good work possible here, and for today I think I need to play it by ear to see where they are and what's possible. (Lampert's journal, 10/23/89, p. 97; italics original)

Lampert hopes that moving from number lines to graphing will help students explore the relationships among time, speed, and distance. She has no way of knowing in advance how students will take up the journey line as a system for representing motion. This is an instance of a teaching dilemma driven by interacting principles or goals: Lampert wants to build on a mathematical context that is already familiar to students (the number line) to develop a representation that is "new to them" (a graph composed of two number lines that cross at zero). However, students might invent uses for the system that Lampert will find difficult to understand in the moment, or this system could be counterproductive for a broader conceptual understanding of intensive quantity that she describes as "going from additive to multiplicative structures" (Lampert's journal, 10/26/89, p. 110; Vergnaud, 1982, 1983).

Two further observations about the journey line are important. First, this representational form is not idiosyncratic to Lampert's teaching, but resembles drawings made by people from varied backgrounds as they try to solve problems that involve rated motion or production (Hall, 1990; Hall, Kibler, Wenger, & Truxaw, 1989). Second, this representation of a story about motion does not spring, fully developed, into a stable diagrammatic display. Instead, as Lampert and her students' journal entries show, what they call a *diagram* is incrementally constructed, students participate in this construction, and then they reconstruct similar drawings in private, local, and public settings. Unlike static textbook diagrams, *drawings in use* have an inspectable history of production—they, along with other representational forms, travel through activities and settings in our map of a participation structure for this classroom (i.e., a journey line is at the center of each vertical plane in Fig. 8.2). As a central finding in our analysis, these forms provide media for communicating about and working on conjectures, experiments, reasoning, and revision. In use, they are the stuff that anchors talk about explaining, challenging, or agreeing with mathematical ideas.

Being explicit about how the journey line is produced helps us to see that it is a central achievement, progressively developed over several weeks in Lampert's classroom as her students begin to understand the structure of rate as an intensive quantity. It also supports students' work on relations of proportion and the symmetrical structure of multiplication and division. There are reciprocal dilemmas for learners, however. For someone new to the mathematics of rate in school, how can a blank surface (i.e., a journal page or the chalkboard) be organized to show regular motion, particular beginnings and endings (i.e., places along the journey line), and precise values (i.e., labels along the line) for different events that share the same regular motion? These and other dilemmas for learners will surface as our presentation of the case continues.

Conventional Resources for Drawing Rate. The journey line, at least as we read it and watch its use in classroom conversations, is based on a set of common conventions that are important resources for understanding rate. In a journal entry written after the class, Lampert notes student contributions to the activity that resulted in the journey line of Fig. 8.3:

How represent:
  Dorota → a line, marked off every ten mile.
  Catherine said "20 is four fives" so that's how you know its four hours.
Multiple strategies for getting 12 hrs:
  Connie & Yasu: halfway is 6 so whole way is 12

?	count up from 8 by 5's to 60 (we already had figured out 8 hrs = 40 miles)
Tyron & Eddie:	each "half space" is worth 10 miles, 2 hrs.
Richard → purple:	double the 6, you get 12 (he doesn't use the word pattern)
Sharoukh [only][last]:	Just divide 60 by 5 & you get twelve (Lampert's journal, 10/24/89, p. 104)

The journey line is a representation that mixes iconic[6] and symbolic elements: a bounded segment, optional labels on measured dimensions, place markers that systematically subdivide the segment, and values written at specific places. When given a coordinated arrangement on the page or chalkboard, these elements may help makers, users, and readers of a drawing to share a relatively stable set of meanings about the structure of rate. Illustrated with Fig. 8.3 and Lampert's notes about student contributions, we can summarize these potential senses of rate as follows:

1. *Within each dimension*, linear extent shows events and relations between events in the problem situation. This depends on shared conventions for: (a) partitioning a bounded extent into collections of intervals with equal extent, (b) annotating components (i.e., labels for places, intervals, or entire dimensions), and (c) narrating descriptions of what is shown, referenced either/both by talking about the display as a sort of number line (e.g., Catherine says "20 is four fives") or as an actual journey (e.g., Catherine continues "so that's how you know its four hours").

2. *Across dimensions*, vertical alignment between upper and lower regions of the drawing provides a way of associating related quantities (e.g., 30 nautical miles, 6 hr) around particular places within the narrative structure of the journey (e.g., halfway).

3. Given a way of coordinating inferences about extensive[7] quantities within dimensions and intensive quantities across dimensions, the journey

[6]Marks in the journey line are iconic to the extent that they can be read as a visual or pictorial representation of something. For example, the partitioned line can be read simultaneously as a path coordinated with the passage of time, or specific marks along the path can be read as "places" in a trip. Iconic representations may be more effective than symbolic representations for supporting some kinds of inferences about relations between quantities (e.g., that the *Mimi* will travel 10 nautical miles every 2 hr, as visually foregrounded with ellipses in Fig. 8.3). For arguments related to the relative efficiency of different types of representations see Hall (1990, 1996), Larkin and Simon (1987), and Sherin (1996).

[7]The fused structure of a journey line can support inferences about other types of quantities like differences or factors and relations between them (Greeno, 1987), but it is limited as a representation for problem situations that involve different rates (e.g., one boat overtaking another) or nonlinear rates (e.g., a boat that accelerates). The journey line is limited in different ways as a representation of motion, as in cases where changes in direction would be relevant.

line provides *a physical calculus*[9] *for rate*. That is, a user can produce ordered values along each dimension (e.g., an unknown student contributes "count up from 8 by 5's") or find an unknown value in one dimension, given a specific value in the other (e.g., "count up from 8 by 5's *to 60*", italics added).

4. As a supporting medium for inference and calculation, the journey line provides a *shared form* for students' explanations about choices among alternative answers (e.g., Lampert writes, "Catherine said '20 is four fives' so that's how you know its four hours") or justifications for carrying out particular calculations (e.g., Connie and Yasu argue "halfway is six so whole way is 12").

In summary, the first two senses of rate provide resources for making inferences about relations between quantities (i.e., within and across dimensions), while the third sense of rate (i.e., a calculus) is sometimes used to produce "answers" and at other times organizes numerical calculation using different representations (e.g., numbers are pulled out of the drawing for columnar multiplication or long division). The fourth sense of rate (i.e., a shared form) carries a tension between "showing" and "telling" one's reasoning about rates, evident in the way written explanations in students' journals refer to elements of these drawings, or the way drawings are sometimes offered as self-contained explanations. For example, a new student in Lampert's classroom writes in his journal, "the diagram EXPLAINS MY ANSWER" (Sam's journal, 11/8/89, p. 7). The conventional details of a mundane drawing are complex, but few of them are optional. Students have to manage this complexity when using the journey line to do an "experiment" to show their "reasoning," or to follow another's "explanation."

Students' Production of Drawings Over Time. Before considering the work of one group from Lampert's classroom in detail, we juxtapose our analysis of the conventional structure of the journey line with a representative series of these forms in actual use. Table 8.1 shows problems of the day, journey line drawings, and student or teacher annotations to these drawings in a chronological sequence for two table mates, Karim and Ellie. Both are central participants in the detailed analyses that follow. One striking difference between Karim and Ellie's drawings is the relative stability of conventions evident in each series. For Ellie, equal interval scaling stabilizes over time, dimensional separation increases (e.g., value labels are clearly separated above and below the line), labels begin to include dimensional

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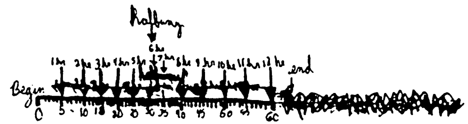
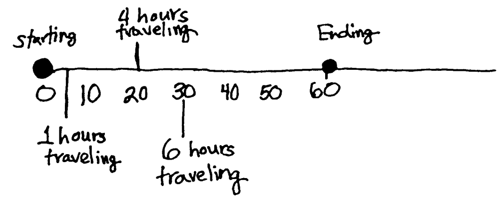
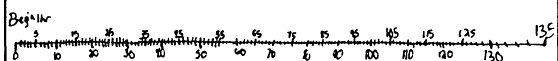
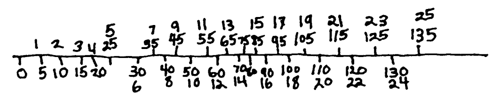
[8]By *physical calculus* we mean a type of representation (here the journey line) and specific ways of using that representation to perform calculation. We are not referring to the broader historical meaning of calculus as taught in secondary and undergraduate mathematics courses, though the same characterization would apply (i.e., types of representation with specific uses).

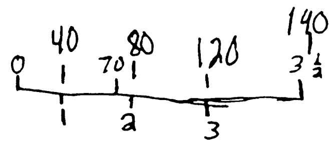
Table 8.1. A Chronological Series of Problems and Journey Lines From Two Students' Journals (10/24/89 through 11/14/89).

Problem of the Day	Selections From Karim's Drawings	Selections From Ellie's Drawings
10/24/89: 1. If the Mimi travels 60 nautical miles at a speed of 5 nautical miles per hour, how long will the journey take? 2. If its speed increases to 8 nautical miles per hour, will the time be longer or shorter?		
10/25/89: Make a diagram like we did yesterday to figure out how long it would take for Mimi to go 135 nautical miles at 5 knots.		 Lampert: Please <u>label</u>: which is miles and which is minutes?

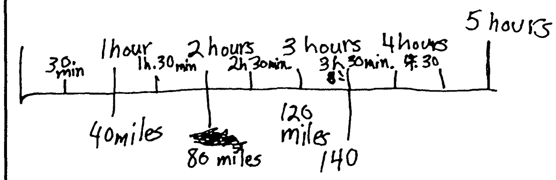
11/8/89:
A car is going 40 mph

1. how far will it go in 3 1/2 hr?

2. how long will it take to go 70 miles?



Lampert: But <u>why</u> do you multiply by 3? And <u>why</u> do you add 20?

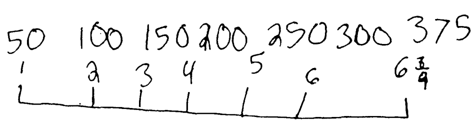


11/9/89:
If a car is going 50 mph

1. How far will it go in 2 1/4 hr?

2. How long will it take to go 375 miles?

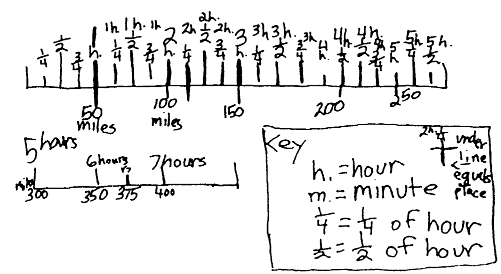
3. How far will it go in 10 min?

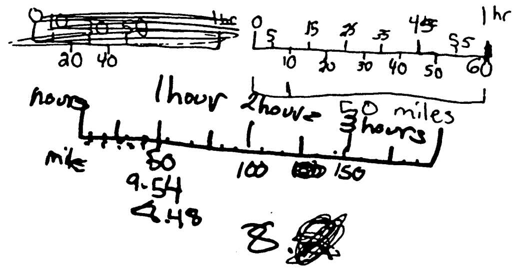
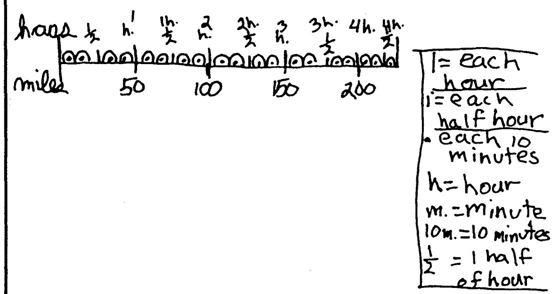
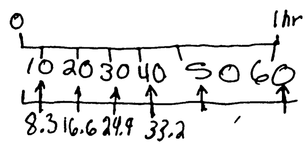
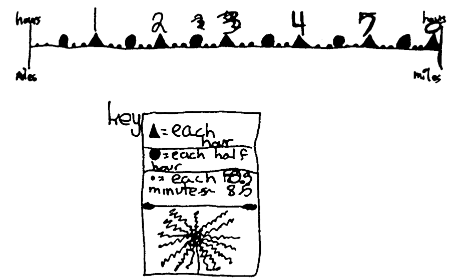


Nov. 12, 1989

Your diagrams will be more accurate if you use the boxes on the page to make the spaces even.

Dr. Lampert



11/13/89: 1. If a car goes 50 m.p.h., how far will it go in 10 minutes? Make a diagram to explain your thinking. 2. If a car goes 5 miles in 10 minutes, what is its speed in miles per hour?		
11/14/89: I think ___ is the most sensible conjecture because ___ . You may use a diagram to explain.		

units, and interval partitioning is increasingly differentiated (including iconic keys late in the unit). By comparison, Karim's drawings show value labels that continue to mix dimensions above and below the line (even splitting into multiple lines), dimensional units are only occasionally present, and spatial intervals along the line show no fixed scale. It may be that Ellie's adoption and coordinated use of conventions for producing journey lines becomes more systematic over time, while Karim's production remains relatively unconventional.

A second interesting contrast is the way that Karim's drawings shift in response to a more challenging problem of the day (see Table 8.1, 11/13/89): "If a car travels 50 mph, how far will it go in 10 minutes?" Karim constructs three quite different journey lines for this problem, the first and second showing progressively finer partitions of 1 hour into minutes (i.e., by units of 10 minutes, crossed out, then by 5 minutes). In both of these drawings, minutes are shown as place labels that alternate above and below the line. On his second attempt, Karim includes an enclosing label for 50 miles with a vertical cut aligned at 10 minutes. For reasons not apparent in his journal, Karim's third drawing segregates quantities for time and distance, respectively, above and below the journey line. We return to Karim's work on this problem later, but a plausible interpretation of this drawing sequence is that he successively approximates a journey line that will allow a coordinated, simultaneous reading of time and distance units (i.e., by vertical alignment).

Of course, our selections give little information about the actual production of any particular drawing, and variation may be high across students in drawing skill, the style of their notebook entries, or the amount of material they produce. For example, over the course of 6 weeks that students worked on time–speed–distance problems, the five students for whom we received journal selections varied considerably in their output: Karim wrote approximately 740 words[10] and made 25 drawings (16 journal pages), Ellie wrote 250 words and made 34 drawings (30 pages), Sam wrote 1,500 words and made 28 drawings (20 pages), and Charlotte wrote 3,500 words and made 40 drawings (42 pages). By comparison, Lampert wrote approximately 14,300 words (62 journal pages) during the first 4 weeks of this unit, although her journal reflects a very different perspective on classroom events than that of her students. Clearly there is variety in how students use their journals and in the material that they choose to include.

We cannot make inferences about the nature of Karim or Ellie's understanding solely on the basis of how well their drawings show a particular structure over time. For example, the variety in Karim's drawings is puzzling but may reflect an effective approach to distinguishing between different

[9]Word totals were calculated by counting lines of writing on each journal page and multiplying by an estimate of the number of words per line.

quantitative dimensions when working with a rate. However, exploring how particular drawings are produced should uncover a diverse set of competencies, both for their makers and users. The next three sections use our map for the structure of classroom participation (Fig. 8.2) to follow the journey line as it is used in different mathematical activities across settings in Lampert's classroom.

Drawing, Explaining, and Knowing (Local to Public)

Approximately 2 weeks after Lampert introduced the journey line, she wrote in her journal about following up on a complaint by Ellie that no one would help her understand how far a car traveling 40 mph would go in 3½ hours. Lampert asked Karim, in the *local setting* of table work with Ellie, to explain why he chose to multiply by three when solving this problem of the day.

> So I said → but *your job* is to explain *why* you multiply. He thought for a minute and put head to notebook and started *to draw* saying to himself "this is how I'll explain it." At first I thought he was not cooperating with my scheme, but then I was just bowled over by the idea that he had figured out that the diagram would be the way to show why it was 40 + 40 + 40 + 20 or 3 × 40. (Lampert's journal, 11/8/89, p. 144; italics original)

During whole-class discussion later that day, Lampert asked Karim to show his explanation to the class, asked Ellie to review his explanation, and finally asked for students to suggest ways in which Karim's drawing could be improved. In the transcript of this *public setting* that follows,[11] Karim's drawing at the chalkboard (Fig. 8.4) is nearly identical to what appears in his journal (Table 8.1, 11/8/89, Selections from Karim's drawings).

01:30:24 to 01:34:40 (11/8/89 B)

Lampert: Now one of the things that I saw as I was walking around was something that I'd like to see a lot more of. I gave Karim a very special challenge. One member of his group said, "I really don't understand these kinds of problems AT all." And I went over there and I said, "Karim, can you help this person explain? Can you explain? Help this person understand?" And he said, "Oh yeh, it's just three times, you know, three times ah forty, that's all." I said, "But what if the person doesn't know

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[10]Transcript conventions include: EMPHATIC talk is in uppercase; onset of overlapping talk is shown by matching open brackets [across turns at talk; stretched enunciation of syllables is shown with colons :::, descriptions of action are italicized and placed in parens; elapsed time or uncertain passages of transcription are shown in parens without italics; and number words are spelled out when transcribing the utterance.

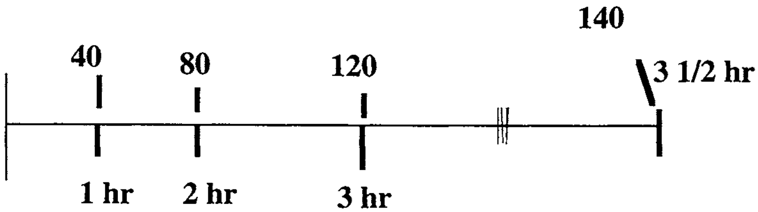

FIG. 8.4. Lampert (light lines), Karim (bold lines), and Ellie's (smeared line) drawing at the chalkboard to show "WH::Y you multiply."

	why you're supposed to times? How could you explain that?" And do you know what he did? He said, "I know how I can explain that." And he (*draws line at the board; vertical cut bounds left end*) drew a line in his notebook and he explained it, using that line. Karim, do you think you could come up here and show the whole class what you did?
Karim:	(*stands, slaps down pens*)
Ellie:	(*smiles, inaudible talk*)
Lampert:	(10 sec) This is a picture of WHY:: you multiply to solve this problem. Ok?

Showing "A Picture of WHY:: You Multiply." As Karim approaches the board, Lampert has done several things that follow our map of a participation structure in this classroom. Earlier in the day, she moved a private conversation (Ellie's original complaint) into a local "challenge" of explaining why multiplication makes sense in this problem. Now she brings the results of this teaching intervention into a public discussion about explaining why mathematical operations work to solve problems. Lampert starts the drawing as a line segment that is bounded to the left, open to the right, and otherwise undifferentiated (light lines in Fig. 8.4). She also explicitly frames Karim's activity as a "picture of WHY:: you multiply."

Karim:	(*draws vertical place at right boundary*) I drew a diagram (*draws vertical cuts down; labels places 1hr, 2hr, 3hr; labels 3½ hr above vertical cut at right boundary; 24 sec elapsed*) and alls I (*draws vertical cut up; labels place 40*) did was put forty miles for each hour.
Student:	Where?
Karim:	(*steps back, looks at class*) . . . and I kept on addin', by forties. (*continues with 80, 120; draws vertical cut up and left from right boundary; labels place 140; snaps chalk into tray; 17 sec elapsed*)
Lampert:	And (3 sec) how does that explain how you're supposed to multiply three times forty?

Karim: Well, like, every hour, you're going, every hour you're going forty miles and so I just added, um, I got three hours and then I added forty, three times, and then it gave me one hundred twenty, then I had to, um, take a . . . I had to divide forty in two, in half, and that gave me twenty, so I added twenty cause a half an hour is half of, like, an hour.

With his completed drawing in view, Lampert presses Karim for an account of why multiplication helps solve this problem. Karim briefly narrates rate as a relation between units of time (i.e., "every hour") and distance (i.e., "you're going 40 miles") and then summarizes a strategy of repeated addition and halving to find the distance remaining beyond 3 hours. As drawn, the intervals between successive hours grow larger as the journey line moves to the right, although neither he nor Lampert mention this as a potential problem.

Lampert: And did everybody in your group understand what you did there, do you think?
Karim: Well, I think.
Lampert: Well, I know I only asked one person to really try and understand what you were working on, because I think your group is just beginning to figure out how to work together, okay? Can somebody else in Karim's group explain this drawing?
Ellie: (*raises hand*)
Lampert: Ellie? Thank you Karim.
Ellie: You want me to come up there?
Lampert: Yeh.
Ellie: Um, its a good strategy because . . . it says miles per hour and (*L hand points to 1 hr as lower place label, then to 40 as upper place label)* one hour for each one and its really, its (3 sec) When you get up to one twenty, which is four, which is three, fours, you, uh, put a *(R finger erases/smears vertical cut at center of rightmost interval on board*) half in there because it says three and a half hours, so you put a half right in there. And, uh, since half of forty is twenty, you add another twenty on and it's one forty.

Ellie, the original recipient of Karim's explanation for why multiplying 3 and 40 would work, gives a slightly different public account of the solution. She also mentions the two-dimensional structure of rate (i.e., points to lower then upper place labels), but then gives a narrative summary of calculation that is closer to multiplication. In addition, by tracing out a new place on the journey line at 3½ hours (i.e., erases/smears vertical cut), she partly repairs Karim's expanding scale for successive intervals.

Developing an Explicit Explanation Across Turns at Talk. What is the character of these attempts at explanation, both for Lampert and her students? Although the details are complicated, we find three public turns at explanation—two for Karim and one for Ellie—that appear to replay and elaborate something these students have done in a prior local setting. Under Lampert's questioning, these turns become increasingly explicit about rate as a relation across drawn dimensions and multiplication as a summary of repeated addition.

Lampert starts this public account by asking Karim to "show" what he "did" and then previews his work at the board as a "picture of WHY::" multiplication can be used to solve the problem. This is in sharp contrast to what Lampert recounts as Karim's original response (i.e., "it's *just* three times [. . .] forty, *that's all*"; italics added), both in the form of representation used (i.e., drawing vs. verbal utterance) and in what is being represented (i.e., a journey versus an arithmetic operation). During his first turn at a public explanation, Karim indeed *shows* how he made the drawing: He inscribes values for time without speaking, recounts/previews rate as a first-person iterated action of labeling (i.e., "alls *I did was put* forty miles *for each* hour"), writes paired values for distance while giving a narrative summary of addition (i.e., "and *I kept on addin'*, by forties"), and finally writes a correct answer without describing how he managed the final half hour.

After an evaluative question from Lampert (i.e., "And (3 sec) how does that explain . . . ?"), Karim's second turn is more explicit: He gives a second-person version of rate (i.e., "every hour *you're going* forty miles"; italics added), collapses his earlier iterated addition into a narrative summary (i.e., "I added forty, *three times*"), and then gives an explicit account of division and addition to manage the proportional relation between remaining time and distance (i.e., "I had to *divide forty in two*, in half . . .").

While our analysis is speculative, the differences between Karim's first and second turn at explanation are interesting: (a) showing becomes telling, both in response to Lampert's question and indexed to a finished drawing at the board; (b) explicit description of rate as a relation shifts from the action of a first-person agent ("alls *I* did was put") to that of a second-person agent ("every hour *you're* going") and so presumably inserts the hearer within the explanation,[12] (c) a description of iterated addition goes through a narrative transformation into something closer to a description of multi-

[11]Coordinated changes in voice (e.g., from "I" to "you," "we," or "it") and gestural depiction are important in mathematical conversations for several reasons: (a) they may reflect different perspectives taken by the speaker on what is being discussed (Church & Goldin-Meadow, 1986; Crowder & Newman, 1993; Hall, 1996; McNeill, 1992; Ochs, Gonzales, & Jacoby, in press), (b) they may position or direct the attention of other participants in the conversation in particular ways (Goodwin, 1990; Roschelle, 1992), and (c) they may delegate authority for what is being said to other, more powerful agents (Latour, 1988; Pimm, 1978).

plication ("forty, three times"), and (d) Karim's elaborated second turn briefly narrates proportion as coordinated actions across dimensions of the journey line ("I *added twenty* cause a *half an hour* . . ."; italics added).

By the time Ellie comes forward for the third public turn, the makings of a reasonable explanation for multiplication are available in a whole-class discussion. The developing explanation is anchored by talk and action on a drawn representational form—the journey line—that can be given a (mostly) shared reading by participating students. Ellie replays the major elements of Karim's elaborated second turn, gives a similar narrative summary of multiplication from a second-person perspective ("*you get up to* one twenty . . . which is *three, fours*"; italics added), and partly repairs the uneven scaling that appears to be a recurrent feature of Karim's journey lines (see Table 8.1).

These turns at explanation in a public setting not only illustrate Lampert's emphasis on explanation, but also her preference that students explain to each other, across settings, before coming to her for help. For example, writing in her journal about a similar public setting several days later, Lampert notes:

> Sharoukh had arrived at the very precise "answer" of 8⅓ miles. . . . When I asked how many people agreed with 8⅓, several raised their hands (maybe 10). When I asked who could explain to the whole class why it makes sense everyone but Sharoukh put his or her hand down. Enough. Nothing needed to be said here. (Lampert's journal, 11/13/89, p. 153)

Explanation, as a relation between people, is prominent in Lampert's classroom. From a disciplinary perspective, valuing explanations in classroom interaction models for students some version of what practicing mathematicians (presumably) do. From a cognitive perspective, explanation may lead to greater understanding on the part of the explainer (Chi, Lewis, Reimann, & Glaser, 1989) and, under some conditions, on the part of a recipient. But there are still significant dilemmas for Lampert in making decisions about moments of classroom interaction and for her students as they try to follow her requests. Certainly it is not always possible to rely on the explanations of students: Their understanding may be fragile or incomplete, the narrative structure of their explanations may not express necessary relations clearly, or they may not be willing to work with students who might learn from their explanations. We explore these reciprocal dilemmas more fully in the next section.

The Dimensions of a Conjecture (Private to Local)

Lampert and her students make frequent transitions among private, local, and public settings. We now turn to an extended example illustrating the movement of a single discursive pattern—explaining why conjectures about the distance traveled by a car over a short interval of time are more or less reasonable—across private, local, and public settings. In this extended example, Ellie first consults with Lampert during her private work (11/13/89), then she appropriates parts of Lampert's approach to help other members of her local group, including Karim, find a defensible conjecture for the problem of the day (also on 11/13/89). Our example concludes as the whole class settles on the most plausible conjecture for this extended problem of the day (11/14/89; see Fig. 8.1), including a public account given by Ellie, who appears to have appropriated parts of her private interaction with Lampert. The analysis has strong limits set by the difficulty of collecting film records of private or local interaction. In many cases, because the details of journal work are not visible in the video record, we have no way of knowing how transcribed talk and written or drawn material are coordinated. Still, we can find clues for how journals act as displays in students' explanations or challenges and how explanations constructed in one setting are used in other settings.

We open with Lampert helping Ellie find a reasonable answer to the first part of the problem of the day (see Fig. 8.5, top of right facing page). Determining how far a car traveling at 50 miles per hour will go in 10 minutes is a difficult problem for several reasons: The units for time are mixed (hours must be coordinated with minutes), the number set involves a division (50 ÷ 6) with a noninteger solution, and the concrete event in question transpires inside the unit of time used to express the rate (i.e., 10 minutes vs. 1 hr). This is the third of 4 days during which students work on this problem (11/2, 11/9, 11/13, and 11/14). At the end of the prior day (11/9/89), students proposed two public conjectures about how far the car would go in 10 minutes: 5 miles and 7 miles. In her journal entry from that day ("Reasoning #3" in Fig. 8.5), Ellie wrote "I think my answer is right because 50 ÷ 10 = 5 which is the answer. I checked my answer with this" and drew an arrow to two, scratched-out drawings for different decompositions of 1 hr time intervals.

Private Work on a Dimensional Drawing. Ellie's journal entry on 11/13/89 (Fig. 8.5) shows both parts of the problem of the day copied from the board, a heavy horizontal line, then a drawing in an area labeled an "Experiment." With (we assume) a partially completed version of this drawing in view, Ellie and Lampert start a conversation:

1:20:19 to 1:21:40 (11/13/89 A)

Lampert:	(*moves to Ellie, whose hand is raised, after finishing a comment to Karim about getting back to work*)
Ellie:	Dr. Lampert?
Lampert:	Um hm. (*leans over Ellie's R shoulder to look at her journal, blocking camera*)

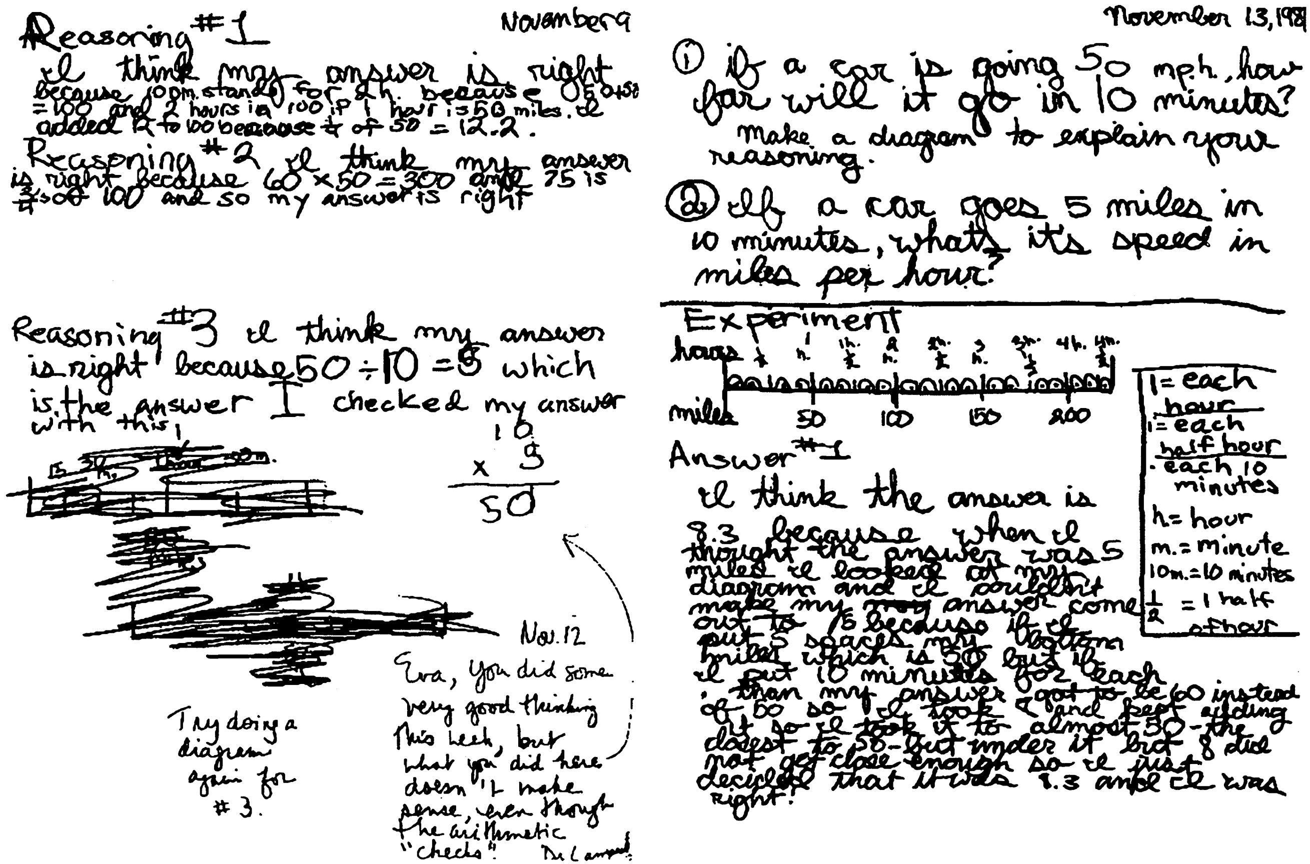

FIG. 8.5. Facing pages of Ellie's journal for 11/9/89 and 11/13/89.

Ellie: If, um . . . If this was ten minutes, would there be um, if there's . . . (3 sec) if each of these were ten minutes?

Lampert: Um hm.

Ellie: Could this be fifty?

Lampert: What do you think?

Ellie: I don't think so because there's five little notches in here, and each, um, notch stands for ten minutes, and um, and . . . since there, right here there's six patches, then ten times six equals sixty.

Lampert: Hmm. (*nods head*, 3 sec) Now . . . (*R hand up, leans further in*) I think you're onto something here? (*both laugh*) And you know what I think you need to do? If you want to find out (*R hand to journal surface*) what each of these notches is . . .

Ellie: They're ten minutes.

Lampert: Well, but if, (*R hand back to journal*) you just said, if each one was ten minutes it wouldn't go to fifty, it would go to sixty.

Ellie: That's true.

Lampert: So ten minutes (*shaking head*) is too much.

Ellie: (4 sec) I know, but it says right here, how far would it go in ten minutes.

Lampert: I know.

Ellie: (6 sec) And, and this, I couldn't put like one in here and three in here, I mean one in here and two in here, could I?

Lampert: Nope. (*shaking head*)

This is a complicated beginning. Without access to Ellie's journal page at the time of this conversation, we cannot be sure what she or Lampert are leaning over and talking about. One possibility is that Ellie is pointing to some unlabeled place in her journey line where the first hour will end and the car should have traveled 50 miles. She (and/or Lampert) may be switching the diectic referent of Ellie's "Could *this* be fifty?" (italics added) among several alternatives: units of time (i.e., 1 hour or 60 minutes, along the top of the journey line), units of distance (e.g., 50 miles, along the bottom), or the value of a derived quantity with undetermined units (e.g., 50 or 60 of something). As shown in Fig. 8.6, Ellie's "five little notches in here" refers to five place markers (i.e., from left to right in Fig. 8.6a: two circled dots, a light vertical line, then two more circled dots; also see Ellie's boxed "key" showing the meaning of these icons at the right in Fig. 8.5). These place markers cut out what Ellie calls "patches" along the journey line (i.e., the segments between circled dots and vertical lines). Assigning a given value of 10 minutes to each patch yields a combined value of 60, which Ellie apparently finds incompatible with the given value of 50. After Lampert apparently agrees (i.e., "it would go to sixty"), Ellie proposes a change in conventions

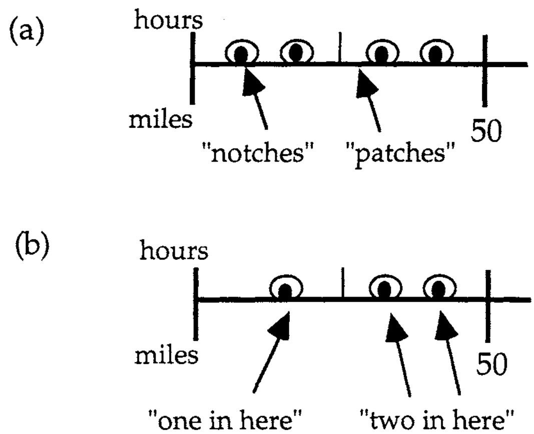

FIG. 8.6. A graphical interpretation of Ellie's question about (a) the number of notches and patches in her existing journey line, and (b) a proposed change to the conventions for making the journey line.

for making the journey line by placing one notch to the left of the midpoint and two notches to the right (see Fig. 8.6b).

We (and they) must simply move on without settling the issue for now. However, two observations are important for our argument that representational forms circulate and are transformed in student activities. First, regardless of whether Lampert and Ellie understand each other, their conversation is immediately about conventions for drawing a rate (i.e., notches, patches, their arithmetic entailments, and a proposal for placing notches differently). In terms of our map of a participation structure, a student's question about the plausibility of a conjecture in a private setting also becomes a conversation about how a particular form (i.e., Ellie's rendering of the journey line) represents the structure of rate (e.g., "each, um, notch *stands for* ten minutes"; italics added) and how this form can be used in an "Experiment" to evaluate a conjecture. These kinds of conversations make up the mathematical activities (e.g., experiments or reasoning) that Lampert hopes will lead to discursive patterns of explanation in the classroom. As a result, shared ways of holding talk accountable to representational forms is part of what needs to develop in this mathematical thinking practice.

Second, reciprocal dilemmas around making and using representations operate in the moment-to-moment activities of a teacher and a learner. What can Lampert do to recover the sense of Ellie's apparent cross-dimensional talk (e.g., does Ellie's "Could this be fifty" refer to a time, distance, or rate)? At the same time, how can Ellie work on the inconsistency she thinks she has found in her earlier conjecture while still preserving the integrity of her experiment in the face of alternative readings of a seemingly simple drawing?

These are problems that Lampert and Ellie have in making sense out of one another's mathematical reasoning, and they have yet to be resolved in this conversation. More generally, this is the interactional work (e.g., achieving common conventions, making sense of technical talk, and pursuing the dimensional structure of rate) that fills out the activities of our map of a participation structure. Lampert can anticipate this work and we can hope to analyze it, but these activities must be brought to life in the practical experience of students in this classroom. Dilemmas in hand, we return to their conversation.

01:21:40 to 01:22:48 (11/15/89 A)

Lampert: You know what? (*shifts further over table surface*) Your diagram is really helping you to figure out why the answer to this is not five.

Ellie: (inaudible)

Lampert: I know that . . . (*R hand to journal surface*) that's what you did over here, just fifty divided by ten is five, right? (*R hand to journal surface*) And you checked your answer. But, if it, if fifty . . . if it was five, then each one of these things would have to be . . . (*bobbing head*) ten, ten . . . you'd have to have FIVE spaces! But you have to have six spaces. . . . So, if you have to have six spaces . . . can you figure out ABOUT what each space should be?

Ellie: (7 sec) Seven?

Lampert: Okay, (*R hand to journal surface*) if it was seven, then this one would be . . . fourteen.

Ellie: Fourteen.

Lampert: This one would be . . .

Ellie: Um . . . twen, twenty one.

Lampert: And this one would be?

Ellie: Twenty eight.

Lampert: This one would be?

Ellie: Um . . . seven times five? Thirty five . . . and forty two.

Lampert: Not enough is it? (*pulls back*, 3 sec) It was supposed to come out to fifty.

After a quick evaluation of Ellie's progress (i.e., "You know what? Your diagram is *really helping you* to figure out why the answer to this is not five"; italics added), Lampert attempts to reframe the conversation in several ways:

1. She brings the prior history of Ellie's experiment into the conversation from the facing page of her notebook and then evaluates Ellie's earlier reasoning (i.e., "what you did over here, *just* divided") by comparison with her current experiment.

2. From Lampert's perspective (as we imagine it), Ellie's diagram could help to reconcile earlier arithmetic calculations with a new sense of the

problem. Her earlier reasoning divides 50 by 10, apparently without considering the dimensional structure of either quantity, to produce a result that Ellie records as "5 miles." In the drawn structure of her current experiment, however, six intervals (or patches) cut out between the beginning and the first hour will each require a pair of typed quantities (a distance and a time). If Ellie can manage a conventional reading of the drawing that locates quantities within specific dimensions, she may be able both to reject her earlier conjecture (i.e., 5 miles in 10 minutes, 10 miles in 20 minutes, etc.) and find an arithmetic approach to a new one.

3. When asked what value each "space" should have, Ellie supplies a new conjecture—apparently about what distance the car will travel in 10 minutes. Lampert then uses the drawing to start a series of oral calculations that accumulate 7-mile increments at successive places indexed by talk and gesture along the journey line (i.e., "*this one* would be fourteen, *this one* would be . . ."). Ellie takes over these calculations at the third place (i.e., "Twenty one.") and continues through the sixth place to find a value that is below what the given rate requires (i.e., Lampert says, "It was *supposed* to come out to fifty.").

Drawings as Experimental Devices. Following Ellie's explicit account of this activity as an "Experiment," we might think of the journey line as an instrument for testing a variety of conjectures, each constrained by the (as yet) implicit logic of preserving a constant proportional relation between pairs of quantities at vertically drawn places along the line. What started as a conversation about how to partition the journey line has now produced a way of using the line to test different conjectures. Ellie quickly produces a new conjecture:

01:22:48 to 1:24:10 (11/13/89 A)

Ellie:	Eight.
Lampert:	(*R hand to journal surface*) Well, let's try eight. Eight . . .
Ellie:	Sixteen . . . twenty four . . . thirty two . . . (5 sec) forty . . . two, [five
Lampert:	[Forty.
Ellie:	Forty, then forty eight.
Lampert:	That's pretty close, isn't it?
Ellie:	Yeah.
Lampert:	(*leans further over table*) Well, you want to try nine?
Ellie:	(*on edge of her seat*) Okay. Nine . . . eighteen . . . twenty seven . . . thirty six, um, forty . . . five, fifty four. (*looks up*) That's too much.
Lampert:	That's too much. Which one came the closest?
Ellie:	Eighty. (*shakes head*) Eight.
Lampert:	Okay, [so . . .

Ellie: [So . . . eight point . . . (*sits back, looks up*) Should I eight point?
Lampert: Say, how about if you just put (*points to journal*) a little bit more than eight? (3 sec) Eight point something or a little bit more than eight.
Ellie: Kay. Eight point . . . (*looks left and up*) six? Or something?
Lampert: Eight point six is quite a lot. That's almost nine.
Ellie: Maybe . . . (*looks left and up*) eight point, uh . . . (*L hand beats*) three.
Lampert: Okay, could you (*R hand to journal*) write down I think it's eight point three and tell me how you figured that out?
Ellie: Okay.

Lampert fades out of the narrated stream of calculations, pausing in her talk to create openings in which Ellie can take broader control over testing conjectures of 7, 8, and 9. Ellie independently recognizes that 9 overshoots the desired value of 50. When Lampert summarizes Ellie's work by asking which conjecture "came the closest," Ellie correctly chooses 8 and then independently suggests choosing noninteger values in the interval between 8 and 9 (i.e., "Should I eight point?"). Lampert evaluates one of Ellie's choices directly (i.e., "Eight point six is *quite a lot*. That's almost nine.") and then asks Ellie to write an explanation for her reasoning in her journal (i.e., "tell me how you figured it out").

Within the span of less than 4 minutes, Lampert and Ellie manage to explore (a) what conventions govern use of a representational form that has been circulating through this classroom for several weeks, (b) how starting assumptions necessarily lead to conclusions that may or may not be compatible with conjectures about an answer (i.e., a kind of proof by contradiction), and (c) how to coordinate calculation within and across the dimensional structure of rate to arrive at a plausible answer. These all appear within the competing pressures that comprise Lampert's work as a teacher: visiting multiple individuals or groups in a limited period of time, relating students' current conjectures and experiments to evaluations of their earlier work on this problem, and pursuing teaching principles that foster particular ways of doing and talking about mathematics.

It is difficult to tell what sort of common understanding this exploration provides for Ellie, despite her taking over parts of a process for testing and revising conjectures about possible answers. Ellie's journal entry for "Answer #1," apparently written in response to Lampert's request that she describe how she "figured it out," still shows evidence of trying to coordinate uses of notches, patches, and something she here calls "spaces" as distinguished parts of the journey line:

> I think the answer is 8.3 because when I thought the answer was 5 miles I looked at my diagram and I couldn't make my answer come out to 5 because

> if I put 5 spaces my bottom miles which is 50 but if I put 10 minutes for each . [*Ellie's single dot in this "answer" is shown by her legend to represent 10 minutes*] than [*then*] my answer got to be 60 instead of 50 so I took 8 and kept adding it so I took it to almost 50—the closest to 50—but under it but 8 did not get close enough so I just decided that it was 8.3 and I was right! (Ellie's journal, 11/13/89; see Fig. 8.5; italicized comments in brackets are added)

As she finishes her journal entry for the day, Ellie decides to attach values for time and miles to iconic markers for 10-minute increments (i.e., "if I put 10 minutes for each"), and she uses this convention as part of a physical calculus (e.g., "I took 8 and kept adding") to evaluate different conjectures about the solution. We leave Ellie just as Lampert must, uncertain about what she understands after this private consultation.

Moving Mathematical Activity Across Settings. We return to the local setting of Ellie's group, approximately 12 minutes after Lampert asks Ellie to write about her revised conjecture. A conversation starts between three members of the group: Ellie, Karim, and Ivan. Because the camera is focused on Lampert's interaction with another nearby student, the three-way conversation is only partly audible, and we can only occasionally see these students leaning over a shared table to work on their notebooks. The transcript that follows is our best effort to extract a conversation out of the periphery of the primary audio and video record. We are presenting, then, not only an illustration of how activities like making and testing conjectures move between private and local settings, but also an illustration of how a line in our analysis can move into one of many classroom settings that even a careful videography cannot sample.

01:36:31 to 01:38:01 (11/13/89 A)

Ellie??:	Eight . . . sixteen . . . twenty four . . . thirty two . . .
(?):	forty eight . . . fifty six
(inaudible)	
(Karim):	This is thirty two . . . forty?
(?):	What's thirty two plus eight?
Ellie:	Right! So this is thirty two, so this has to be forty. Forty, forty eight. It doesn't actually come out to fifty, so . . .
Karim:	Forty times . . . point two . . .
Ellie:	No.
(Karim):	Eight point two, eight point two, eight point two!
Ellie:	So, now let's try nine. Nine?
Karim:	Eighteen, twenty seven . . .
Ellie:	Forty five, then fifty four!
(inaudible)	

Ellie:	Okay, if it's fifty four, then that goes too far. Which one came the closest?
(Karim):	Eight.
Ivan:	(No, nine) came the closest.
Ellie:	Nine came to fifty four, and eight came to forty eight. Which came, which one the closest?
Karim:	Eight.
Ellie:	Eight? Okay. So um, but ... if you do just plain eight, that doesn't work. KARIM, wake up! Eight point, what'd you (do), two?
(?):	(That's it!)

Under Ellie's apparent direction, these students narrate a series of calculations that test 8 as a conjectured answer for this problem. As Ellie evaluates the result (i.e., "doesn't actually come out to fifty, so . . ."), Karim proposes 8.2 as another conjecture. Reproducing Lampert's private conversation with her, Ellie presses on with the next whole number as a conjecture, which she and Karim subject to the same stream of narrated calculations. Regardless of whether they use the ordered spatial structure of a journey line (we occasionally see Ivan lean over and touch the surface of the table), these calculations have an identical iterative character, continuing until the desired value is met or exceeded.

Finding that 9 miles in 10 minutes yields 54 miles in an hour, Ellie exactly reproduces Lampert's request for a comparison (i.e., "Which one came the closest?"), and Karim eventually answers correctly. When Ellie asks about his earlier proposal (i.e., "Eight point, what'd you (do), two?"), he or Ivan agree with some apparent exasperation. Although we do not know what prompts this conversation, it is clear that Ellie is reproducing the gist of Lampert's private consultation and that at least Karim is willing to follow out her approach to bounding a plausible conjecture from above and below. We resume as Ellie emphatically asks Karim for his reasoning about the new conjecture:

01:38:01 to 01:38:55 (11/13/89 A)

Ellie:	No, YOU have to think of reasoning, why do you think it's eight point two?
Ivan:	(inaudible, *pointing*)
Ellie:	I didn't tell him. He thought of it.
Ivan:	Yeah, you did.
Ellie:	No, I didn't. You weren't listening.
Ivan:	I was listening. That's why I'm COPYING! (*starts writing*)
Ellie:	Well, I'm the one talking.
(?):	I know.

(Ellie): Come on.
(inaudible, 10 sec)
Karim: Don't rush me...
(?): Don't rush him.
Karim: Don't rush me!
(inaudible)

Ellie also reproduces Lampert's interest in reasoning and explanation as the grounds for choosing among answers. She attempts to block Karim's or Ivan's direct acceptance of 8.2 as a satisfactory conjecture, admonishing them to take this conjecture through the same cycle of experimentation and revision as their earlier conjectures (i.e., "YOU have to think of reasoning, why do you think it's eight point two?"). Exasperation in what may have been Ivan's voice now becomes explicit in an accusation that Ellie has simply told Karim a new conjecture on this problem. As Ellie protests that Ivan hasn't been listening, he begins "COPYING" her account with emphatic irony. The conversation trails off, literally out of our hearing range and, in tone, away from any semblance of collaborative work (i.e., Karim's repeated complaint, "Don't rush me!"). However, even in this local encounter between three table mates, several observations are important for our broader argument about moving mathematical activities across settings.

1. These students are not only talking about the particular mathematics of this problem, but also about how to talk about and work on their conjectures (Cobb et al., 1992). When Ellie insists on testing whole number conjectures sequentially (i.e., like an "Experiment" in her journal) and on finding reasons for adopting noninteger conjectures, she explicitly challenges her peers' way of solving the problem of the day as being at odds with the participation structure that Lampert is trying to promote.

2. This excerpt makes it clear that forms of participation across students are variable, ranging from quite specific reproductions of the way Lampert models preferred activities (e.g., Ellie's persistent interaction with Karim) to abbreviations of these activities (e.g., Karim's quick acceptance of a new conjecture) or overt trivializations (e.g., copying another student's argument).

3. Ellie's conversation with Karim and Ivan is different, in important ways, from Lampert's conversation with her. When Karim offers 8.2 as an answer, Ellie does not acknowledge the conjecture—not even to insist on an explanation—but continues with the next iteration of her experiment with whole numbers. In other places, she fills in the next step of an argument herself, without checking whether Karim (or Ivan) are following. Unlike Lampert, Ellie appears to have little sense of *explanatory empathy*: the ability to structure an explanation so it actively involves the recipient and supports their growing understanding. Explaining with empathy is not the same as telling;

rather, it is an interactive process that requires being able to explain while monitoring the other person's understanding.

Explanatory empathy is something that good teachers do well, even if with great difficulty. It is not surprising that a fifth grader just learning mathematics might not be skilled in this type of interaction. Here again we find a reciprocal dilemma of making sense: If Lampert distributes the work of explanation to her students, neither she nor they can be sure of the results. Given that fifth graders may not be empathetic explainers, how does a teacher trade the value of their explanations to fellow students against the confusion that might result?

From Conjectures to Certainty (Private to Public)

We close this detailed examination of private and local work on the dimensional structure of rate in much the same way that Lampert does—looking for public accounts of why a single conjecture is more plausible than its many competitors over 4 days of work on a difficult problem. In a whole-class discussion with a carefully drawn journey line on the board (Fig. 8.7), Lampert moves along successive places of the line, narrating calculations that involve fractions of an hour. As the excerpt starts, she has already tested and rejected conjectures of 5 and 10 miles, and she starts to consider 8.3.

01:46:17 to 01:48:38 (11/14/89 B)

Lampert: OK, every time I (*draws arc below journey line from 10 to 20 minutes*) go ten minutes, I have to (*points to addition of frac-*

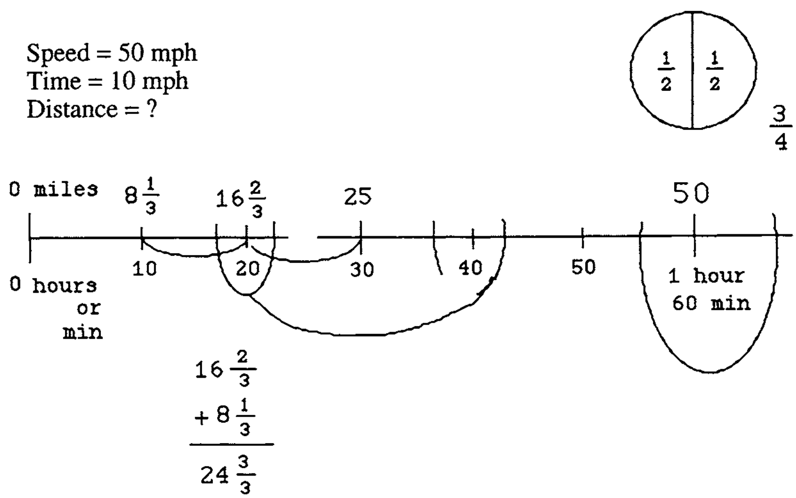

FIG. 8.7. Lampert's final journey line for choosing among students' conjectures.

tions) add another eight and one third. . . . OK, what do you think? (11 sec) If I add eight and one third to eight and one third (*sweeps from $8\frac{1}{3}$ to $16\frac{2}{3}$ on journey line*). I get sixteen and two thirds. If I add another eight and one third, I get up (*sweeps to 25*) to twenty five. Charlotte?

Charlotte: I think that's correct.

Lampert: What do you mean?

Charlotte: I think that twenty five is the right answer for goin' with thirty. Even like, it doesn't have to have a third with it just, just because the other numbers have a third with it. Because it, it adds up equally three thirds which you can also put as . . . um, twenty five. And so, and so the next time you'll add eight and one third, and if you, you'll get thirds, then you'll get thirds on fifty, and on sixty you won't get any thirds because you'll have one third . . . with forty, and what are the other numbers? Two thirds with fifty, and you'll get three thirds every third number.

Lampert: OK, that's good reasoning. Ellie, what do you think?

Ellie: Um, I think it's right because um, when it says fifty miles per hour, um sixty, sixty um, well thirty is half of sixty, and twenty five is half of fifty. And fifty should be where sixty is because sixty minutes is one hour, and if um . . . they're going fifty miles per hour, then um, the fifty would be at sixty minutes.

Lampert: Good reasoning! So, we have two ways now of thinking that that number down there is gonna wind up to be fifty. Dorota, what do you think? [. . . Dorota's response inaudible]

Unlike Lampert's earlier conversation with Ellie, where the dimensional status of different numbers (e.g., 10, 50, or 5) shifted across different readings of how to partition the journey line, Lampert's public calculation is clearly indexed to specific, measured dimensions in both her talk (e.g., "every time I go ten *minutes*") and action (e.g., draws arc below journey line from 10 to 20 minutes). In addition, calculations with whole and fractional numbers that students found difficult in their work on this problem are carefully displayed.

Charlotte's public turn is part of a routine structure in Lampert's whole-class discussions: an exposition by Lampert, usually appropriating parts of a students' approach to a problem, leading to a question that students either volunteer or are called on to answer. In this case, Charlotte volunteers a public account of why Lampert's narrated calculations are correct, pointing out and then progressively elaborating a pattern she has noticed in the repeated addition of thirds (i.e., "it doesn't have to have a one third with it just, just because the other numbers have a one third with it."). An absence of necessity (i.e., "doesn't *have to*"; italics added) in this type of calculation is then followed by a statement of necessity (i.e., "you'll *get* three thirds *every* third hour") that is generalized across the repeated partitions of the journey line.

When Lampert asks for her opinion, Ellie agrees with this approach and then goes public with a pattern of her own: partitions along the upper and lower surfaces of the journey line create equivalent ratios (i.e., "thirty is *half of* sixty, *and* twenty five is *half of* fifty."). Unlike her earlier talk, calculation, and writing on this problem, Ellie then follows with what may be a stable, dimensionally specific description of mixed units and the structure of rate (i.e., "sixty minutes is one hour, and if they're going fifty miles per hour, then um, the fifty would be at sixty minutes.").

Lampert announces, and we agree, that these students have generated two independent accounts of the intensive relation between numbers in upper and lower dimensions of the journey line. After an inaudible exchange, she calls another student, Sam, in on the possibility of collecting together iterated additions:

01:48:38 to 01:49:28 (11/14/89 B)

Lampert: So we don't even have to figure out these in between numbers, do we? Sam?

Sam: Well, um, I revised my thinking. I agree with Sharoukh.[13] But I would like to know what a third is supposed to stand for.

Lampert: When you say what it, what you, what it should stand for, what do you mean?

Sam: I mean numbers, like some of them up there are point three and point five, and point five is half of a number.

Lampert: OK, I think that, that we have to stop now and that would be a very good thing for you to think about between now and Thursday. (*classroom murmur*) You don't want to think about that? Ok, so, yeah, we don't have math tomorrow, and we're gonna have a quiz on Thursday and you're gonna need to draw a diagram for the quiz.

Lampert may have hoped to encourage students to substitute multiplication for addition in using the journey line as a calculating device. However, Sam raises a new problem: What are fractions supposed to stand for and how do they relate to other representational forms for nonwhole numbers (i.e., "I mean *numbers*, like some of them up there are *point three* and *point five*"; italics added). In our participation map, Lampert's teaching practice

[12]As mentioned in Lampert's journal (11/13/89, p. 153), Sharoukh proposed $8\frac{1}{3}$ on the 13th, but he was the only person willing to explain this conjecture to the whole class.

of inviting private contributions into a public setting has led to what we see as a reorganization of roles in learning: A student closes one line of inquiry (i.e., "I *revised* my thinking. I agree with Sharoukh.") and opens a new one (i.e., "*I* would *like to know*"). As in the prior cycle of activities, Sam's new question carries the conventions of a representational form at its center (i.e., "what one third is *supposed to stand for*."). Although Lampert's students may make bids for control over the problems they are asked to work on, the period is over and they will be taking a quiz at the next meeting. Lampert folds Sam's problem back into private settings and finishes the day.

DISCUSSION

Pulling one thread of interaction out of ongoing classroom activity has produced a lot of complexity. Our initial case analysis raises more questions than it answers about reciprocal dilemmas of teaching and learning the mathematics of rate: What is the role of familiar contexts in learning difficult mathematical concepts? What sorts of conventional forms of representation help teachers and learners work with intensive quantities? How can the work of shared understanding be distributed across the classroom? We think these questions, in all their interactional complexity, need to be addressed if we are going to understand the social construction of mathematical meaning in a way that helps reorganize instruction.

Our approach to looking for mathematical activity as it moves across private, local, and public settings provides an initial road map for following how these dilemmas get resolved into a stretch of school mathematics. The case we have developed in the preceding sections follows Lampert, Karim, and Ellie over a few moments of classroom interaction. This is a brief selection from the body of materials Lampert provided for our analysis, but it illustrates a structure of participation that fosters the development of something we value as a mathematical thinking practice.

In terms of our analytic map, we have described a path, among a great many, that might fit together into an account of the full terrain of mathematical thinking practices in this classroom. As with any representation devised to explore a complex territory (Turnbull, 1989), there are many places to go wrong in this approach to a thinking practice: We may focus on a single path that turns out to be seldom traveled or a trivial excursion within the broader terrain, our map may omit features of the terrain that are critical for understanding the development of mathematical thinking, or we may have the structure of the terrain so wrong as to create features that distort our understanding.

With these hazards in view, we have presented a case that illustrates two full cycles of activity across settings, both anchored in a form of representation (the journey line) that helps students work explicitly with the two-dimensional structure of rate. Ellie's private complaint about not understanding time–speed–distance problems (11/8/89) is redistributed into a local setting by Lampert, and Karim's local explanation for Ellie is later reworked in a public setting to produce an increasingly articulate explanation for "WHY:: you multiply" on these kinds of rate problems (also on 11/8/89; see Fig. 8.1). We have illustrated a second cycle of activity in more detail. Ellie takes parts of her private consultation with Lampert—an "Experiment" for deciding among different conjectures—into a local setting with Karim and Ivan (11/13/89). Finally, Ellie gives a public account of why one conjecture (among many) works on this difficult problem of the day (11/14/89). In the first cycle, Lampert plays an active role in structuring student participation, while in the second, we see evidence that students selectively take up both the organization and content of a participation structure for mathematical thinking that Lampert is hoping to create.

What Is This a Case Of?

The case we have presented would be compatible with many different accounts of learning mathematics, but we argue for one that stays close to the details of classroom activity available in these data and that productively engages the relations between teaching and learning dilemmas that lead our analysis. In our account, Lampert's introduction of the journey line, and its use across settings on problems of the day, creates a complex participation structure within this classroom. This structure provides students with various opportunities to participate in mathematical practices that are authentic in two senses: They involve (a) sustained, joint inquiry on problems where (b) material results are (literally) carried forward into further work on related problems. Students' contested conjectures about how to get and explain precise results for distance–speed–time problems are one point of entry to the central mathematical concept of change.

This case supports several observations, but we assume the analysis could continue in many interesting directions. First, these excerpts should make it clear that representational practices in mathematics—what we have framed as making, using, and reading conventional representational forms—are less stable and more detailed than many textbooks or studies of instruction presume. Throughout these excerpts, what Lampert and her students call a *diagram* is multiply (and variably) reconstructed in activities of drawing, partitioning, labeling, reading, and calculating. The journey line becomes a stable form for representing rate only as it travels across the private, local, and public settings where people jointly use it. Our second point, then, is that particular forms of representation have a complex history of production across the participation structure of this classroom, and so are the shared enterprise of many participants. Third, given the distributed nature of work in the classroom, determining what is known and by whom are serious problems both for cognitive theory and educational practice. The kinds of data that Lampert has collected give us a chance to begin exploring the distributed character of doing and knowing mathematics, but we have only just begun this exploration.

Our map for a participation structure identifies different places for doing and teaching mathematics, each assembled in the moment and filled with different participants who approximate (at times) preferred discursive patterns in their mathematical work. When one participant explains or challenges their own or another's reasoning, forms of social and material interaction appear that are critical for learning. We could alternately describe these participant-constructed settings for learning as forms of legitimate peripheral participation (Lave & Wenger, 1991), guided participation (Rogoff, 1990, 1995), or mutual appropriation in a zone of proximal development (Newman, Griffin, & Cole, 1989; Vygotsky, 1986; Wertsch, 1985). A complex set of practices is transacted in these places: (a) finding and solving mathematical problems; (b) sharing conventions for making, using, and reading different representational forms; and (c) presenting and refining one's identity as a person who does (as well as understands) mathematics.

Knowing Versus Doing Mathematics

As forms move across private, local, and public settings, different people in the class can be both makers and users of mathematical representations, taking up notational conventions that are not only precise, efficient, or portable, but also the means by which one can agree with, challenge, or explain mathematical ideas. The conventions that result are not taught so much as they are constructed, and while students might know a set of mathematical concepts that are covered in other forms of instruction, we suspect that Lampert's teaching leads them to do mathematics in quite different ways.

This hypothesis, along with many others, lies outside the scope of materials available for this study, but we would be interested to see studies that follow students out of a setting like Lampert's classroom into more advanced mathematics instruction. Our guess is that these students are learning a part of mathematics that typically develops late in a learner's school math career, if at all. However much we value discursive patterns of explanation, challenge, agreement, or exploration in mathematics, we cannot be sure that students evaluate these activities in equally positive ways (e.g., Ivan's ironic "COPYING" of what turns out the be a correct conjecture). In addition, even for students who value these kinds of participation, subsequent school math experiences may well lead to disappointment because traditional forms of instruction or assessment do little to encourage or detect these patterns of activity.

Although the apparently final, public explanations of Charlotte and Ellie suggest that they individually know how to manage dimensionally related quantities, and the bid by Sam to focus on a new kind of mathematical object (i.e., "what a third is supposed to stand for") suggests that he has learned a particular way of finding and asking questions that are important for division with remainders (e.g., 50 divided by 6 gives 8 and one of these objects), do we really know what sort of mathematics is known by students across the class? One intriguing possibility, poorly tapped by forms of assessment that have been traditionally accepted in mathematics classrooms, is that Lampert's students know about a set of mathematical topics that may be comparable to more traditional forms of instruction (knowledge *that*), but they can also do things with these topics and associated representational forms (knowledge *how*) that students from more traditional classrooms would be hard pressed to match. We would need to expand the scope of this case study considerably to explore this question, but we hope that our analysis at least makes this kind of question important in a consideration of how Lampert's teaching is effective.

Replicating Thinking Practices?

Part of the complexity of this classroom comes from getting 29 students to do something together in a typical institutional arrangement for schooling. As studies of language and interaction in classrooms have shown (Amerine & Bilmes, 1987; Cobb et al., 1992; Orsolini & Pontecorvo, 1992; Wells, 1993), there is a reciprocal artfulness to the way students and a teacher are accountable to each other in the ordinary context of schooling. In and out of school, people conduct themselves in regularly patterned ways, but the meaning and progress of their work depends on open-ended interactions with each other and the materials at hand. Within the social organization of this ordinary complexity, we still have much to discover about whether, how, and what people are learning. In our view, the interesting complexity in Lampert's classroom comes about by design: She works at creating a particular kind of participation structure. We have tried to show how this structure is supported in the craft of Lampert's teaching, taken up in the developing thinking practices of her students, and filled with work on a stream of problems that are given and discovered over successive days of mathematical activity.

We should close this chapter, then, with what is probably the most vexing question for any case study. How can an analysis of a particular place, group of people, and set of activities help to understand some larger class of situations that the case is taken to represent? If we are right in assuming that a thinking practice can develop in response to design, what are the prospects for replicating this kind of mathematical practice in other settings? With varied results (Cohen, 1990; Stevenson & Stigler, 1992), many mathematics teachers adopt a constructivist stance toward their students' learning, organize class work in groups, use contextually specific problems as part of their teaching, and consult with students about their private or local work on these problems. What distinguishes Lampert's teaching is the way she does these things: her analytic stance toward student contributions, her active willingness to defer getting to a right answer in favor of talking about what makes answers right, her careful work with students' documentary products, and her consistent pedagogical pursuit of what she prefers as authentic ways of doing and talking about mathematics.

Attempts to replicate the conditions we have illustrated for the development of a mathematical thinking practice cannot physically include Lampert. However, we suspect that creating classroom environments like this will require the presence of an adult who simultaneously acts as a teacher and a researcher, in and out of the classroom. Probably as important, the institutional arrangements of teaching mathematics in a fifth-grade classroom will need to change in ways that can provide the kinds of resources available to Lampert (e.g., time to reflect on and prepare for teaching mathematics, connections to a broad network of professionals with similar interests). These are not unreasonable investments if we really value the teaching and learning of mathematics. Given these conditions, the case analysis we have presented (along with the work of many others) might turn out to be a useful map for getting started.

ACKNOWLEDGMENTS

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APPENDIX: LAMPERT'S OVERVIEW (EXCERPTED) FOR THE TIME–SPEED–DISTANCE UNIT

One way to think of the unit that we did between October 23 and November 30 is as a series of problem situations in which mathematics could be used to connect information that was known to information that was needed. The particular piece of mathematics that was used most in this unit was the operation of division.

This packet of information is an attempt to place the case of mathematical work that we will be analyzing in the context in which it occurred. We have looked closely at three lessons that occurred in Lampert's mathematics classroom . . . using documentation in the form of videotapes of individual, small-, and large-group work; students' writing and drawing during lessons; and the teacher's written plans and reflections. (The three lessons were chosen to represent the range and kind of mathematical work that occurred across the whole year, as well as for the technical quality of the documentation available.) From these materials, we have each chosen some aspect of the work to study.

The following table lists (some of) the materials collected during 1989–1990 to document the teaching and learning in Lampert's classroom. The time–speed–distance unit materials are a subset of this collection (* indicates types of materials received by Hall and Rubin for the analysis reported in this chapter).

Classroom Lessons	*Teacher's Point of View*	*Students' Points of View*	*Others' Points of View*
Videtotape* of most lessons across the year	Daily journal* recording preparation for lessons and reflections on what occurred	Photocopies of students math notebooks*	Videotaped interviews with observers
Audiotape of every class	Videotaped interviews after particular classes	Photocopies of students' homework	NCTM Curriculum and Evaluation and Teaching Standards
Photographs (slides) of chalkboard	Commentary on lesson transcripts	Photocopies of students' quizzes	State and district curriculum guidelines
Observers' notes for each class period using a standardized format		Standardized test scores and test booklets	District report cards and commercial standardized tests
Transcripts* of selected lessons		Audiotaped interviews with every student at the beginning of the year	Audiotaped commentary and analysis by practicing teachers and teacher education students

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CHAPTER

9

Emergent Arithmetical Environments in the Context of Distributed Problem Solving: Analyses of Children Playing an Educational Game

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The view that cognition is inherently situated—linked to the cultural practices in which individuals function—is common to recent sociocultural treatments of cognition (e.g., Cole, 1990; Greeno, 1991; Hutchins, 1991; Lave, 1991; Wertsch, 1991). From the sociocultural perspective, cognition—whether the mathematics of candy sellers in urban Brazil (Saxe, 1988, 1991), the blueprint/scale knowledge of construction foremen (Carraher, Schliemann, & Carraher, 1988), or the engineering knowledge of electrical technicians (Janvier, Baril, & Mary, 1993)—takes form in relation to a range of social and cultural processes, including the particular artifacts and tools that are valued in practices, power and role relations that emerge and become institutionalized in practices, and social interactions with others. From the sociocultural perspective, knowledge as manifested in practices is culturally mediated and socially shared (Cole, 1991).

Sociocultural views of cognitive functioning pose interesting conceptual and methodological challenges for the study and analysis of children's learning and cognitive development. We need conceptual models of cognitive development that can be used to organize analyses of cognition in situ—models that reflect intrinsic relations between the constructive, sense-making activities of the individual and sociocultural life. We also need methods for observation and analysis that extend such conceptual models into the field—methods that reveal the culturally textured character of cognition as it emerges in people's daily practices.

This chapter sketches a general framework for the study of children's learning environments informed by sociocultural perspectives of cognitive development. Central to the framework is the construct of emergent goals (Saxe, 1991). Emergent goals serve as a basis for both the analysis of children's construction of cognitive environments in practices and a conceptualization of children's learning. Guided by the framework, we explore questions about children's dyadic play of an educational game in their classrooms: Under conditions of dyadic activity, how can we understand the learning environments that are taking form for individuals?

Our efforts to extend the *emergent goals* framework to methods for the analysis of children's dyadic play have led to intriguing problems in coordinating analyses of what tasks the dyad is solving and the emergent goals that individuals are constructing and accomplishing in their joint activity. We describe two types of data, each of which addresses these issues. One type involves a case-by-case analysis of videotaped excerpts of joint play. The other involves the aggregation of case-by-case analyses through a framework-based coding scheme. In concert, these techniques provide a means of revealing general characteristics of the relations between the cognitive work that dyads accomplish as a unit and the cognitive environments that emerge for individuals.

THE GAME

The educational game, Treasure Hunt, is depicted in Fig. 9.1. The game was developed by the UCLA Peer Interaction Group[1] to serve two functions. First, it was designed as an enrichment activity: It was an effort to bring insights from field studies of mathematics learning in daily practices into the elementary school classroom (see Saxe, 1995, for a discussion). Second, the game was also designed to support our analysis of the mathematical environments children construct in play. In developing the game, we made sure that the principal artifacts that children manipulated for number representation were easily identifiable by an observer and recordable on a video camera and that the game supported children's verbal interactions about their math-linked activities.

[1]The UCLA Peer Interaction Group has included Joseph Becker, Teresita Bermudez, Kristin Droege, Tine Falk, Steven Guberman, Marta Laupa, Scott Lewis, Anne McDonald, David Niemi, Mary Note, Pamela Paduano, Laura Romo, Geoffrey Saxe, Rachelle Seelinger, and Christine Starczak.

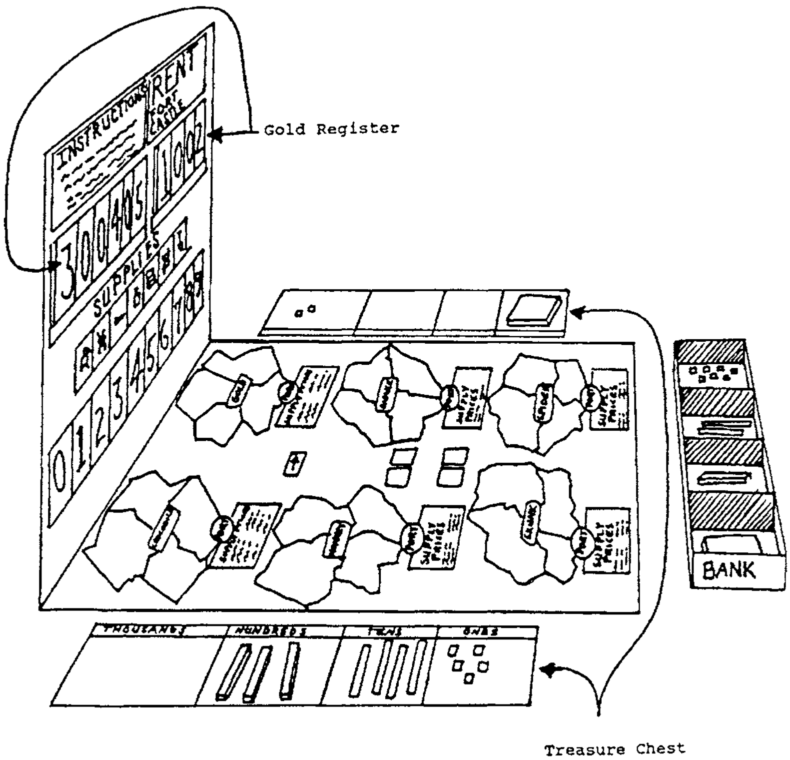

FIG. 9.1. The Treasure Hunt game.

Children play Treasure Hunt in pairs; the prescribed objective is for each child to acquire more gold than the other. To this end, children assume the roles of treasure hunters in search of gold doubloons—gold painted base-10 blocks in denominations of 1, 10, 100, and 1,000 units. Children store their gold in treasure chests that consist of long rectangular cards organized into thousands, hundreds, tens, and ones columns, and children report the quantity of their gold on a gold register with printed numerals. The child who acquires the most gold wins the game.

Children alternate rolling a die on a large rectangular playing board that consists of six islands. As a function of the roll of the die, players move to new islands, purchase supplies at the island ports, and then move, with the draw of a colored card, to one of four geographical regions on the island. At the region, players receive messages that offer opportunities to use their supplies either to gain additional gold or to protect their existing gold. (An enlargement of Snake Island—its ports and geographical regions—is contained in Fig. 9.2.) At the end of each turn, players must report the quantity of gold in their treasure chests by placing numerals on their gold register.

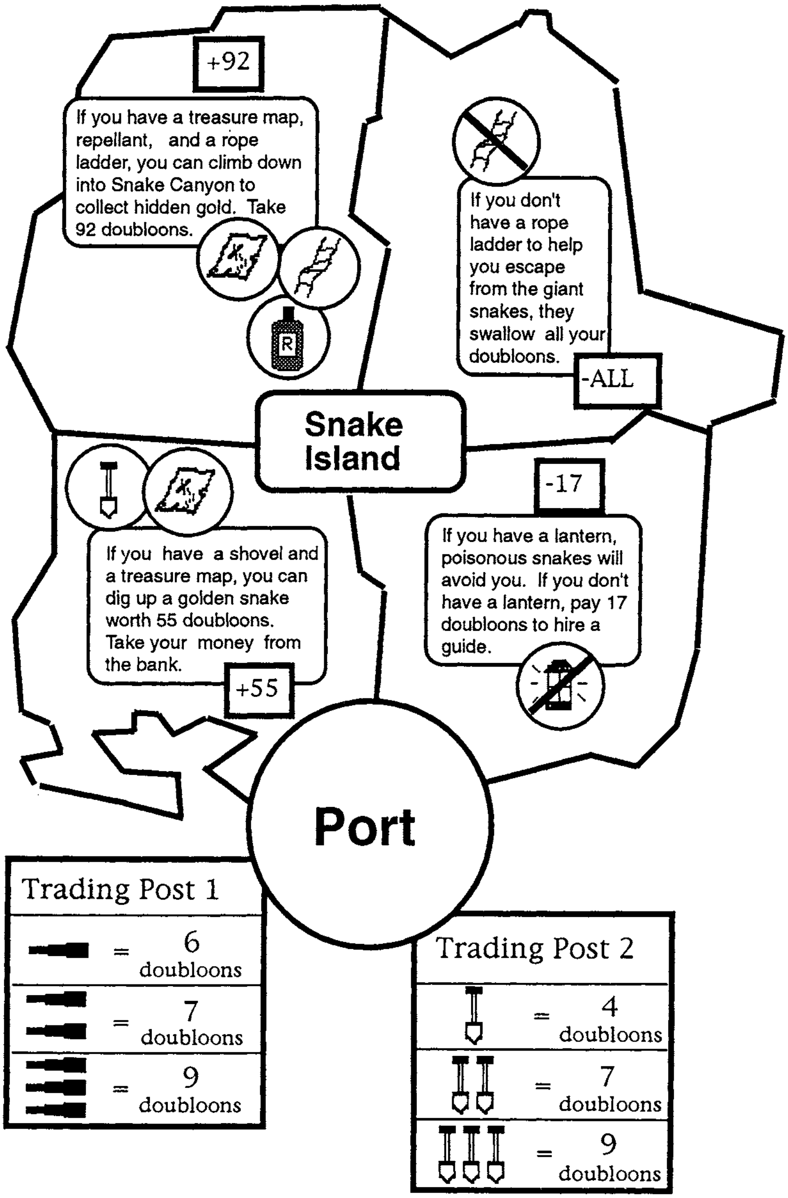

FIG. 9.2. An enlargement of Snake Island.

Players are subject to challenges from their partners for inaccurate gold register reports (e.g., reporting 9 hundreds, 8 tens, and 15 ones [9(100) 8(10) 15(1)] as 9,815). In our study of children's play, we observed and videotaped 32 dyads, including 16 third- and fourth-grade pairs, 8 third-grade pairs, and 8 fourth-grade pairs. Participants were children attending an inner-city school in Los Angeles.

THE EMERGENT GOALS FRAMEWORK

The emergent goals framework was developed in prior work on children's learning in cultural practices (Saxe, 1991). Central to the framework is the view that children create learning environments through their construction of goals. Goals are not static forms that exist ready made in the minds of subjects. Rather, goals emerge as children bring to bear their own understanding to organizing and accomplishing problems that emerge during their participation in cultural practices. We designed Treasure Hunt to simulate a cultural practice—that is, we provided norms of interaction (e.g., turn-taking rules) and artifacts (e.g., gold blocks). As we discuss later, children's goals are influenced not only by the structure of the game but by their own prior knowledge, thematic role play, and sense-making efforts.

The emergent goals framework consists of three components, each of which takes as its starting point the centrality of goals in cognitive development. The first component is concerned with the analysis of how goals emerge in practices: the way children's active sense-making efforts become interwoven with sociocultural processes in their construction of goals. The second component is concerned with cognitive development—the dynamic interplay between cognitive forms and functions as children construct ways of accomplishing emergent goals (Saxe, 1991, 1992; Saxe, Guberman, & Gearhart, 1987). The third component is concerned with the interplay between cognitive achievements across practices—children's efforts to appropriate understandings from one practice to accomplish goals in another practice. In this chapter, we limit the analysis to the first component: how goals emerge during children's joint play of Treasure Hunt.

The Analysis of Children's Emergent Arithmetical Goals in the Play of Treasure Hunt

In their play of Treasure Hunt, children form a wide range of goals. Some involve the construction and implementation of strategies to win. Others involve making a friend of their partner. Still others involve efforts to help their partners understand how to accomplish a computation. For the pur-

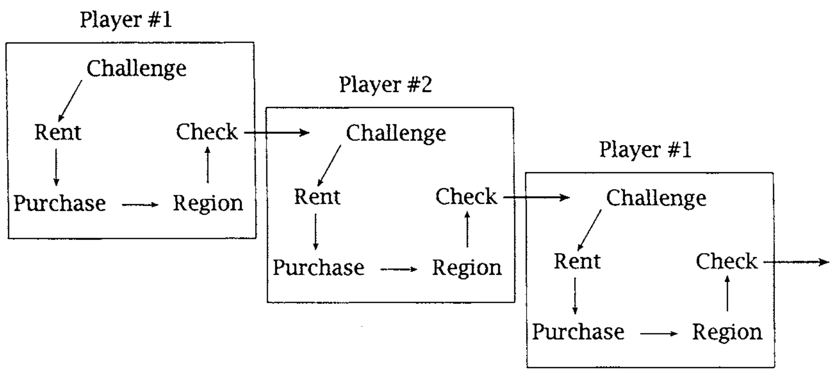

FIG. 9.3. The five-phase turn-taking structure of play. Each square (consisting of challenge, rent, purchase, and check phases) represents a single player's turn.

poses of this chapter, we focus strictly on the arithmetical goals that emerge in the web of children's concerns and motives in play.[2]

To analyze the emergent goals in play of Treasure Hunt, we focus on four parameters, each of which is implicated in the process of goal formation. The parameters include activity structures, social interactions, artifacts and conventions, and prior understandings. Below we extend the four-parameter model developed in prior work (Saxe, 1991) to the analysis of Treasure Hunt, pointing to how the model frames our analysis of children's emergent goals in the context of distributed problem solving.

Parameter I: Activity Structures. The structure of Treasure Hunt consists of five phases in a turn-taking organization—an organization that supports the emergence of a wide range of problems. The structure is depicted in Fig. 9.3 and described in detail elsewhere (Saxe, 1992). Within this general structure, children's purchase of supplies is a principal phase of the game that could emerge in every turn; it is this phase during players' turns that provides the context for our later analyses. During the purchase phase, players consult the supply menus posted at the islands' trading posts (see Fig. 9.2) and select supplies to buy.[3] The purchase phase substructure sets

[2]In this chapter, we use the construct of arithmetical goals (and subgoals) to include both the conscious objectives that individuals create as they are accomplishing emergent problems as well as the less-than-conscious arithmetical constraints that individuals satisfy in the course of their activities to accomplish arithmetical problems. In forthcoming work, this distinction is elaborated in a discussion of the emergent goals framework.

[3]The supplies take on significance during the next phase of the player's turn when the player draws a color-coded card that directs him or her to one of the four geographical regions. At the region, the player receives a message indicating whether he or she may trade some of the specified supplies to either gain gold or avoid losing gold.

the stage for the emergence of various kinds of arithmetical goals. For instance, players often choose to buy a number of supplies—choices that lead them to add or multiply supply values and then subtract the sum from their gold.

Parameter 2: Artifacts and Conventions. During a purchase, children's mathematical goals are interwoven with the principal artifacts of the game. These include the price-ratio menus used at island ports, base-10 blocks (see Fig. 9.4), and the numerals for representing gold on the gold register. These artifacts constrain and enable the emergence of particular arithmetical goals. For instance, in the purchase of supplies, players need to accomplish subtraction problems in the medium of base-10 blocks. Due to their physical characteristics and conventional significance, the base-10 blocks afford particular kinds of solution approaches. For instance, some emergent goals linked to paying for supplies require children to construct equivalence trades to achieve an adequate solution, as when children need to pay for supplies but do not have exact change. In such cases, players need to construct goals to produce one or more equivalence trades of a larger denomination doubloon [e.g., 1(100)] for smaller denomination doubloons [e.g., 10(10)].

Parameter 3: Prior Understandings. The prior understandings that children bring to Treasure Hunt have implications for the arithmetical goals that emerge during play. For instance, some children have difficulty understanding the denominational structure of the blocks. They may treat all blocks with a value of unity, not conceptualizing blocks of different size with reference to their many-to-one equivalence relations [e.g., 10(1) is equivalent to 1(10)]. As a result, when faced with a problem that requires payments when no exact change is available [e.g., paying 14 when one has only 9(100) 7(10)], children may structure subgoals in which the denominations of the

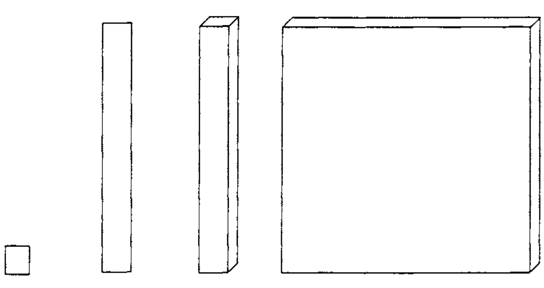

FIG. 9.4. Gold doubloons (gold-painted base-10 blocks) are one of the principal artifacts of play. Doubloon units include 1, 10, 100, and 1,000 pieces.

blocks are not respected in the formation and accomplishment of the arithmetical problems. For instance, a child who owes 14 doubloons may treat all blocks as unity and pay with 14 blocks of varied denominations [e.g., 7(100), 7(10)]. Thus, goals are rooted in children's conceptual constructions, and analyses of children's arithmetical environments in the context of distributed problem solving must be grounded in a treatment of children's prior understandings.

Parameter 4: Social Interactions. Children's goals often shift and take form as they participate in practice-linked social interactions. As a function of these interactions, children's goals may become reduced or elaborated in complexity. For instance, in children's play of Treasure Hunt, we noted two patterns of social interaction during the purchase of supplies, both of which served to sustain play and led to alterations in children's arithmetical goals and subgoals. In one, a player received direct assistance from another (often when the player encountered difficulty in accomplishing a problem). In the other, thematic roles emerged during the purchase of supplies that supported the less knowledgeable partner. In such interactions, one child typically played customer and the other storekeeper—a distribution of labor that often supported the solution of arithmetical problems and ensured continuity of play.

EMERGENT GOALS IN DISTRIBUTED PROBLEM SOLVING: METHODS OF ANALYSIS

We now turn to techniques to study children's play of Treasure Hunt. We point to two approaches derived from the four-parameter model. One technique is qualitative, focusing on individual cases. The other is quantitative, involving the development and application of a coding scheme that has permitted us to aggregate observations over turns, individuals, and dyads; measures were then constructed from codes and analyzed using inferential statistical techniques.

For illustrative purposes, we frame the discussion of qualitative and quantitative techniques with regard to two questions:

1. *What is the complexity of the arithmetical problem that the children accomplish as a dyad?* In our case study analyses, we specify problem complexity by detailing the denominations of doubloons that players have in their treasure chests and the quantity of doubloons the player must pay. In the aggregated analyses, we dichotomize problem complexity into two types: (a) problems that do not require denominational trades for an adequate

solution, and (b) problems that require one or more trades to produce an adequate solution.

2. *What numerical goals do individuals structure and accomplish in the context of the dyadic activity?* In both the case study and aggregated analyses, we make inferences about the goals and subgoals children structure–goals that emerge as the dyads accomplish emergent problems. Such inferences are generally based on an analysis of children's activity–for instance, when a child gives his or her partner one 100 block and asks for ten 10 blocks, we infer that the child generated a goal (or subgoal) to accomplish an equivalence trade of one 100 block for ten 10 blocks.

The two methods–the qualitative and quantitative–complement one another in the analysis of children's emergent environments in play. The analysis of individual cases is a means of gaining insight into the dynamics of distributed problem solving: How are the framing and accomplishment of problems *stretched over* (to use Lave's, 1991, term) individuals and artifacts in joint activity? The quantitative analysis of behaviors across cases is further removed from direct observation; however, it allows us to test general claims about processes of goal formation. For instance, we ask: How does variation in players' arithmetical understanding (as indexed by their grade levels) affect their formation and accomplishment of arithmetical goals in play? How are the formation and accomplishment of goals affected by the grade level of one's partner? With what regularity do particular types of interactions occur in dyads?

Analyses by Cases

We began our analysis of cases by observing instances of children's joint problem solving during the purchase phase of play. Through an inspection of video tapes, we found two prototypical forms of distributed problem solving. Within each form, we found variation in both the arithmetical environments children were structuring and the opportunities to construct more complex goal structures that the more competent players provided for their less competent peers.

In the case of direct assistance, the distribution of problem solving emerged through one player's initial decision to purchase a particular set of supplies. Subsequently, at some point in the solution process, the player had difficulty structuring the arithmetical subgoals–such as determining the total cost of to-be-purchased items, determining how to pay for the purchase–that would lead to an adequate solution. The process of goal construction and accomplishment then became interwoven with assistance from the partner, often under the press of the partner's concern to keep the game moving.

In the case of thematically organized assistance–the second type of distributed problem solving–the solution arose out of the thematic roles children invented: Some children came to assume the roles of storekeeper and customer in the purchase phase–roles that, on occasion, became institutionalized over the course of play. Thus, a customer might select the supplies to purchase and, in turn, a store keeper might then sum the cost of the supplies and tell the customer the purchase price. The customer might then produce a payment and the storekeeper the change.

Sometimes thematic roles and direct assistance became blended with one another in interesting ways. For instance, when there was distribution due to thematic role divisions, sometimes the storekeeper required assistance from the customer in formulating or accomplishing the arithmetical goals and subgoals of his or her role.

A Case of Direct Assistance. ERI and KEV, as a dyad, successfully accomplished many problems that required denominational trades in play. However, when looking at ERI and KEV's individual participation, we observed differences in the arithmetical goals that they structured in play. Through his choice of supplies to purchase, KEV often generated complex arithmetical goals–goals that required two and three equivalence trades of doubloons to be solved successfully. It was ERI, however, the older and more competent of the two players, who made it possible for KEV to purchase his supplies by constructing and accomplishing the subgoals necessary for KEV's purchases. Consider one example of this activity.

> KEV said he wanted to purchase one treasure chest and two bottles of insect repellent, which cost six and seven doubloons, respectively. KEV had difficulty formulating the arithmetical goals to add the quantities (6 + 7), and ERI quickly took over, determining that it would cost KEV 13 doubloons, plus 5 more for an earlier debt. KEV only had 900 pieces [9(100)], so his payment goal would require two trades if he were to pay with exactly 18 doubloons: 1(100) block for 10(10) blocks, and 1(10) block for 10(1) blocks. KEV, apparently unaware of the value of the blocks, asked if he needed to pay with all of his nine (100) pieces. ERI realized that a more appropriate subgoal was to subtract 18 from one of KEV's 100 blocks. She then proceeded to take 1(100) from KEV's treasure chest, put it in the bank, and determine how much change he should get. She covertly (mentally) performed the subtraction and appropriately gave him 8(10) blocks and 2(1) blocks in change. KEV then counted his doubloons, denomination by denomination, and changed the numerals on his gold register appropriately.

In this example, KEV initiated the construction of the arithmetical problem of paying 18 doubloons through his intention to purchase supplies, but it was ERI who structured and accomplished the necessary subgoals for the subtraction. Although ERI's contribution enabled KEV to remain involved and continue participating in the game, the way in which she accomplished the subtraction subgoals did not afford KEV access to the processes used to accomplish the higher order goal of paying for the purchase. For example, she did not (a) verbalize what she was doing, (b) explain that the subtraction could be accomplished through trading, or (c) break down the process into trades that KEV could witness. She did not even explain the concept of block value and block equivalence when KEV was about to pay with his nine 100 blocks. Although as a dyadic unit the children structured and accomplished complex arithmetical problems, their individual construction of arithmetical goals and subgoals differ. ERI constructed, composed, and decomposed values in play. In contrast, KEV was not engaged with similar arithmetical constructions. Nor did ERI provide KEV with access to her construction of goals and subgoals—access that may have served as a model for KEV's subsequent activities.

Thematic Role Divisions Leading to Distributed Problem Solving. VER and TON, a similar dyad in composition to KEV and ERI, provide an interesting contrast. Like KEV, VER, the less competent of the dyad, also initiated purchases, whereon TON constructed and accomplished the necessary arithmetical subgoals. However, unlike ERI, TON constructed these goals in a manner that granted VER access to the processes involved in solving the problem by overtly labeling, verbalizing, explaining, and restating her activities. In the following interaction, this access took form in the context of a thematic role division.

> During a purchase phase, VER decided to buy one map and one parrot at a cost of six and five doubloons, respectively. TON, in her role as storekeeper, performed the addition step by step, saying, "the map is 6 and the parrot is 5" and counting on her fingers, "6, 7, 8, 9, 10, 11. Okay, 11 doubloons." VER had blocks only in denominations of (100)s and (10)s, and therefore could not pay with the exact amount of doubloons. Instead, VER handed TON 2(10) blocks and asked for change. TON handed her the change by counting on, "12, 13, 14, 15, 16, 17, 18, 19, 20," like a cashier.

When it was TON's turn, VER assumed the role of the storekeeper; she was then responsible for performing the subgoals necessary to accomplish the higher order goal set by TON. Because she was less competent in math, VER sometimes ran into difficulties trying to accomplish these subgoals. When this happened, TON intervened and assisted VER, guiding her through the necessary processes. Consider another example:

> TON decided to purchase one lantern, one ladder, and a castle (composed of three rooms) and asked VER how much it all amounted to. Lanterns and ladders cost three doubloons each and the castle rooms cost four doubloons

> each. VER, in her role as storekeeper, proceeded to add out loud, "ladders cost three, three plus three six, and three . . . nine." She stated the price of a fort room (three doubloons) instead of a castle room, and also added the cost of only one room instead of the three rooms necessary to build a whole castle. TON, although in the role of customer, intervened and counted on her fingers (with a "counting on" strategy; Fuson, 1988), concluding, "18, you buy three of these" (referring to the castle rooms) "so that's 18 altogether." They discussed it for a short time, with TON explaining why the purchase totaled 18 doubloons. After reaching an agreement, TON stated, "I'll give you $18." She then attempted to pay with exact change [1(10) and 8(1)], but did not have enough ones pieces. She then asked VER, "Could I have change? Here's $20." VER took the 2(10) TON handed her, and said, "$20," followed by a long pause. TON then again assisted VER by telling her "two of these" and pointing to the ones pieces in the bank. VER then handed TON two doubloons in change.

In this example, TON became the customer and VER the storekeeper. The roles supported VER's engagement in the construction of arithmetical goals. Were it not for these thematic roles, perhaps VER would not have become involved in trying to determine the sum or the subtraction, as was the case for KEV. Indeed, this thematic role division gave VER opportunities to participate, solve problems, and create more complex mathematical learning environments–opportunities that KEV never received. During play, VER was able both to observe TON's actions when TON was the storekeeper and assume the storekeeper's role although she needed assistance from the customer to solve the emergent problems. Therefore, she was able to have access to the processes involved in the accomplishment of the subgoals by observing someone else perform them overtly and by having opportunities to attempt them herself.

A Child's Effort to Provide Access to Subgoal Construction

WEN and ANG showed a particularly interesting display of a more competent player attempting to provide her partner access to the construction of arithmetical goals and subgoals over the course of play. WEN, the older and more capable player, functioned in the role of storekeeper (when it was ANG's turn), performing all the additions and subtractions (i.e., determining the total cost and providing change). However, when it was WEN's turn to purchase supplies, WEN made her construction of subgoals quite accessible for ANG by always paying with the exact change, first performing the trades required to pay with exact change if necessary. Consider the following situations that display these forms of interactions:

> WEN had to pay ANG 50 doubloons in rent (for landing on a region in which ANG had a fort), but only had 3(10) [in addition to her 100s blocks]. Rather

than opting to pay with 1(100) and involving ANG in a subtraction problem (100 minus 50), WEN first traded 1(100) for 10(10)s and then paid ANG the exact amount with 5(10). During the purchase phases, she engaged in the same behavior. For example, she once had to pay 29 doubloons, but only had 4(1) [in addition to her other denominations]. Rather than paying ANG with 3(10), which would have required ANG to perform the subtraction of 30 minus 29, WEN traded 1(10) for 10(1) and paid ANG with exact change.

WEN's actions during her own turns was another way of providing a player access to the processes involved in payment/subtraction, much like TON's cashier style. Although WEN's behavior did not require ANG to perform the necessary subgoals, ANG was able to observe the steps required to successfully achieve a solution both when it was ANG's own turn (during which WEN determined the cost of ANG's purchase and change) and when it was WEN's turn. WEN's style of interaction proved to be an effective learning situation for ANG. As the game proceeded, ANG appropriated WEN's trading behaviors during her own turns. WEN apparently engaged in this trading behavior during her own turns (and not during ANG's turns) because of her belief that ANG would have difficulty performing the operations required to give change. For instance, when ANG started to perform trades during her own turns, WEN stopped paying ANG with the exact amount and started requesting change.

Remarks on Case-Based Analyses

The previous examples present cases in which dyads were accomplishing arithmetical problems involving the summation of purchase prices and the payment of doubloons that required denominational trades. For all the children, the framing and accomplishment of the problems were distributed over the dyad and the materials with which they were engaged. However, the character of the distribution differed. The less capable children tended not to structure goals that required them to conceptualize doubloon values in terms of equivalence trades. Indeed, when such problems emerged, they were distributed over the dyads in ways so that the less competent player did not need to structure or accomplish the equivalence trade. In contrast, the more competent children were structuring relatively complex arithmetical goals in their solutions.

We also observed marked differences in access to the construction of more complex arithmetical goals that the more competent member of dyads provided the less competent players. Sometimes greater access involved restructuring a problem context so that the less competent player could first observe and then accomplish higher level problem solutions later. Other times greater access was provided by the more competent player's verbal explanations that supported understanding the purpose of higher level goals. For some, but not all, dyads and for some turns but not others, the social interactions provided contexts for the less competent players to structure higher level arithmetical goals.

In our analysis of individual dyads, we used the four-parameter model to frame the analysis of emergent goals, focusing on the arithmetical environments that emerged for individuals in the context of distributed problem-solving activities. Although these analyses provide a portrayal of emergent arithmetical goals in the context of children's dyadic interactions, to make claims about what larger populations of children do in Treasure Hunt, or the way in which children's performance varies by their and their partners' grade level, we turn to our aggregated quantitative analyses.

AGGREGATED ANALYSES BASED ON CODING SCHEMES

We developed coding schemes based on the emergent goals framework to extend insights gleaned from analyses of individual cases to an analysis of emergent environments across dyads. We aggregated codes assigned to individuals and dyads and then analyzed these aggregated codes as a function of the grade levels of the players and their partners. We sketch a small set of these schemes here. The examples illustrate some of the problems and merits of an aggregated approach to the analysis of emergent goals in play. (A forthcoming publication will contain a more complete presentation of schemes.)

An Introduction to the Coding Schemes

In the construction of a coding scheme intended for the construction of quantitative measures of learning in practices, one grapples with tensions between a conceptual treatment of the phenomena under study and two principal constraints: (a) the ability of multiple coders to replicate one another's application of the scheme to a corpus of observations (in our case, videotaped records of play), and (b) the distributional requirements imposed by the use of particular statistical techniques. The potential payoff with the scheme-based approach is that one has a base of evidence that can be used to support more general claims than case study evidence provides.

In the analysis of Treasure Hunt, the creation of schemes was guided by the four parameters of the emergent goals framework. The five-phase turn-taking activity structure of the game (Parameter 1) led us to code children's behavior by turn; within each turn, we partitioned behavior into problems that emerged in each of the five phases (challenge, rent, purchase, region, strained the problems that emerged during the phases. We coded two types of problems linked to this artifact: problems that required denominational trades to achieve exact payments and those that did not. Our analysis of the various forms of social interaction (Parameter 3) linked to the emergence and accomplishment of problems led us to code whether the organization of the interaction was based on thematic roles or whether the interaction was one of direct assistance. Further, we rated on a 5-point scale the extent to which the player (the child whose turn it was) accomplished the particular problem-linked goals and subgoals of the problem on his or her own or with assistance from the partner. Finally, we represented children's understandings (Parameter 4) in play through our selection of subjects, including third and fourth graders in our sample of players (who also were screened via a math achievement test): The fourth graders' arithmetical understandings were more sophisticated than were the third graders'.

In reviewing the coding schemes and the findings that they yield, we revisit issues addressed in the qualitative analyses of emergent arithmetical goals. Framed by an initial examination of the extent to which two principal problem types emerged and were successfully accomplished in play, the analyses focus on differences in the character of children's emergent goals in the context of distributed problem solving as a function of the players' grades and the grades of the players' partners.

Buying Supplies: Accuracy by Problem Type

We saw in the case studies that players frequently bought supplies. The emergent arithmetical problems that issued from purchases vary in complexity as a function of the denominational distribution of gold pieces that players have in their treasure chests and the cost of the to-be-purchased supplies: Sometimes players have the denominations to pay for their purchase with exact change and other times they do not. On occasions when they do not have exact change, we see that some players, like ANG, have difficulty accomplishing an adequate trade of greater for lesser doubloon pieces.

On the basis of the case study analyses described earlier, we expected that children's ability to adequately accomplish purchases would vary by the complexity of the emergent arithmetical payment problems. To accomplish the aggregated analyses, we coded the character of the gold problems with which children were engaged during their turns. Supply purchases in which a player was able to pay with exact change were coded as *No Trade problems*; purchases for which players would have to change one denomination for another to make an exact payment were coded as *Trade problems*. To determine whether children were accomplishing problem-linked goals, we also coded the accuracy of children's solutions. For each problem type we determined the percentage of accurate solutions for each child and then

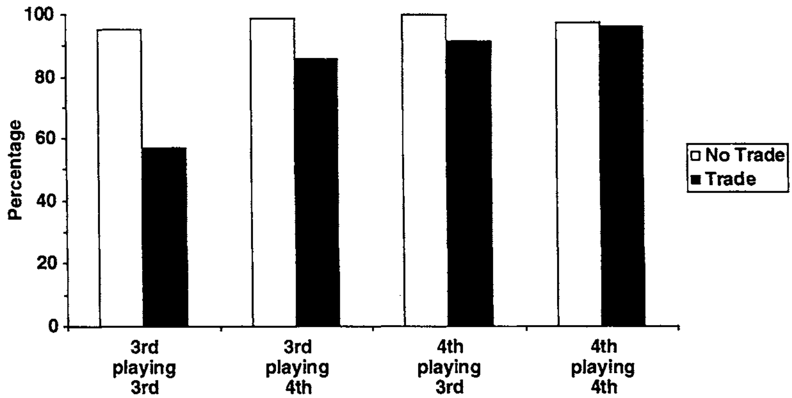

FIG. 9.5. Mean percentage of payment problems solved correctly.

we determined the percentage of accurate solutions for each child and then computed the mean of these individual percentages for each subgroup of children.

Figure 9.5 contains the results of the analysis—the mean percentage of payment problems that children solved correctly as a function of problem type, player's grade, and grade of the player's partner. The figure shows that when children were engaged with No Trade problems, they were usually accurate, regardless of their grade level or the grade level of their partners. Thus, in their play of the game involving payments, even the third graders playing third graders participated competently when No Trade problems arose, constructing goals of counting and composing single- and ten-unit doubloon pieces.[4] However, when children were engaged with Trade problems, group differences emerged. The third graders playing other third graders solved fewer of these problems correctly than did third graders playing fourth graders or fourth graders playing either third or fourth graders.[5] These findings suggest that, although such problems emerged for all children, the third graders playing third graders had difficulty structuring goals involving trades.

Thematic Division of Labor

Recall, as in the case of TON and VER presented earlier, that the social organization of making a payment could vary markedly especially in the context of payments involving trades. Sometimes roles emerged during

[4]The cost of most supply purchases ranged between 6 and 30 doubloons.

[5]Details on the statistical analysis, reliability of the coding schemes, and sampling issues are presented in a forthcoming monograph.

payments in which one child became the storekeeper and the other became the customer. When such thematic roles emerged, the players' work of constructing and accomplishing the payment problem became distributed over the dyad: The task of making an initial payment was given to the player (or the customer) and the task of making change (if any) became that of the partner (or the storekeeper).

We also noted that there may be an important function of this emergent social organization for mathematics learning. Under thematically organized divisions of labor, some third graders were able to participate in the construction and accomplishment of complex arithmetical problems, which they were unable to solve on their own. Indeed, in thematically organized divisions, third graders were constructing and accomplishing goals similar to those associated with their solutions to No Trade problems (making exact payments), although they were participating in the solution of the more complex higher order Trade problems (making equivalence trades).

To determine the extent to which thematic role divisions occurred and whether such divisions occurred more frequently for some groupings of dyads than others, we coded whether a thematic division of labor emerged for each purchase. We then determined the proportion of each player's Trade problems for which there was a thematically organized division of labor. Figure 9.6 contains the percentage of Trade problems for which children assumed thematic roles as a function of the player's grade and the grade of the player's partner. We included in the computation only those occasions that resulted in accurate solutions.

We see in Fig. 9.6 that when third graders played fourth as opposed to other third graders, more thematic role distributions emerged. This suggests that the greater success of the third graders paired with fourth graders as opposed to other third graders (as shown in Fig. 9.5) was due to the

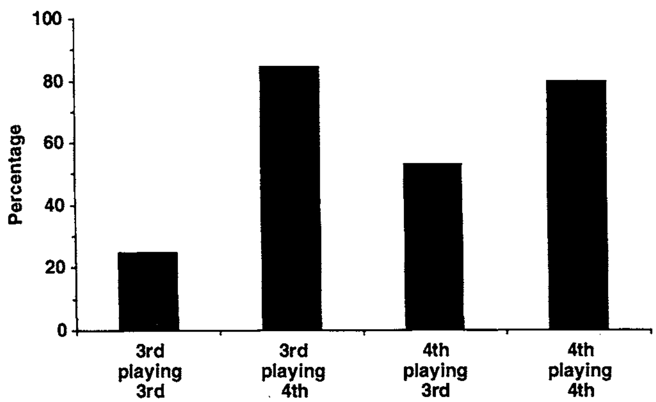

FIG. 9.6. Percentage of trade problems solved with thematic division of labor.

thematically based division of labor that emerged in these dyads. Also noteworthy is that, in mixed-grade dyads, the thematic role divisions occurred less frequently for fourth graders than it did for third graders. This drop in frequency suggests that division of labor was critical in third but not fourth graders' adequate performance on Trade problems.

The Player's Contribution to Accomplishing Equivalence Exchanges Under Thematic Divisions of Labor

As described in the case studies, TON and VER's thematically organized interactions show a further subtlety in how payments can be accomplished in mixed dyads. When TON, the more competent child, was the storekeeper, she structured and accomplished the trade and change goals on her own (with no assistance from VER). In contrast, when VER assumed the role of storekeeper, she relied on TON to help her accomplish the more complex emergent goals of the Trade problems. Indeed, regardless of her thematic role—storekeeper or customer—TON was constructing and accomplishing more complex arithmetical goals than was VER.

We suspected that when fourth graders played the role of customer, they (like TON) would contribute more to the construction and accomplishment of goals than would third graders when they were in the role of customer. To test this, we used a 5-point scale to code the extent to which the player (in this case, the customer) accomplished the emergent trade problem when there was thematic division of labor. Figure 9.7 contains the resulting distribution of mean player contribution scores for the Trade problems when there was thematic division of labor for third graders playing fourth graders

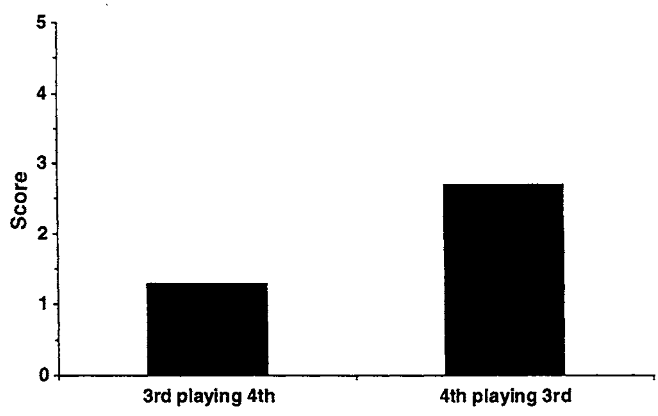

FIG. 9.7. Mean player contribution scores for change problems solved with thematic division of labor.

and for fourth graders playing third graders. Consistent with our expectation, we found that when the turn was the third graders', they contributed little to framing and accomplishing the goals of making change. In contrast, when the turn was the fourth graders', they participated significantly in the construction and accomplishment of the change-making goals.

Summary of Aggregated Analyses

Our aggregated analyses reveal that the character of children's emergent goals differed by grade level of the player and grade level of the player's partner. Dyads as a unit accomplished the majority of the emergent problems accurately. However, when we shifted our unit of analysis from the dyad to the individual, we found that the high accuracy levels for the third graders were due, in part, to the uneven distribution of problem solutions in the course of play: When third graders played fourth graders, they were able to participate in problems that required denominational trades of doubloons without forming goals to produce equivalence trades because of the assistance provided by their partners.

CONCLUDING REMARKS

This chapter made use of case study and aggregated coding methods, both of which focused on emergent goals in play. We see each as compatible with our basic effort to understand learning environments, but these techniques serve different functions. Our case-based analyses provide a window into the particularity of emergent environments for individuals—particularities like the forms of access one child might afford another to the mathematics used in play. Our aggregated analyses provide us with understanding the extent to which the regularities we observe in any particular case might be more general, linked to characteristics of children's prior understandings or the dynamics of dyadic interaction. The information produced by each is wanting, although together these analytic tacks strengthen and enrich one another.

In closing, we note that the analysis of goals that individuals are constructing and accomplishing in practices is a daunting task. Goals are aspects of activity that are invisible to an observer and complexly related to children's understandings and their socioculturally organized activities. Despite the difficulty the construct presents for analyses, we see the focus on emergent goals as an area of inquiry uniquely suited to an analysis of learning environments. Indeed, emergent goals are a pivotal analytic unit because they provide a common ground for the analysis of the constructive, form-building character of children's activities with the analysis of the activity structures, social interactions, and artifact use that are central to understanding cognition in collective practices.

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CHAPTER

10

RESEARCHING THE THINKING-CENTERED CLASSROOM

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For more than a decade, a growing number of educational research and development efforts have been trying to root thinking-oriented curricula in American schools. People have hoped that schools could become places where teachers and students would organize classroom activity structures emphasizing problem solving and conceptual learning.

Emergence of thinking-centered classrooms would require some fundamental changes in approaches to schooling. One change would be a break from transmission models of learning, which perpetuate the notion that facts, skills, and concepts in the subject areas are fixed entities that can be delivered from the teacher to the students. If this conception of learning was no longer the hallmark of the schooling enterprise, memorizing algorithms and facts would give way as a predominant learning activity, and content goals, classroom organization, and teacher and student participation structures would all evolve in new ways. Classrooms would become environments where teachers would make use of their knowledge and content expertise for guiding and facilitating students' learning. The development of problem-solving abilities would be supported, and learning how to think and analyze would be respected, practiced, and sought by all students, rather than being considered a supplementary enrichment for those identified as the best and the brightest. Students would work collaboratively, asking and responding to intriguing questions that required thought, analysis, and synthesis of ideas and knowledge in response. They would get hands-on experience using manipulatives, props, experiments, and applied problems (Dewey, 1916). They might learn content and skills that are specific to the subject areas through modeling the activities and practices of the disciplines they study. All of these changes to classrooms would be supported by assessment practices that require performances around higher order thinking skills, problem solving, and the learning of concepts.[1]

Currently, these ideals are central to many school reform activities. Historically, teachers, administrators, and parents have led school reform efforts (Tyack & Cuban, 1995), placing school reform squarely in the practitioner's domain. Educational research has played, at best, an evaluative role. In the last decade, the community of researchers concerned with learning and cognition has begun to take notice of school reform and participate directly in helping to understand the role that thinking can play in classrooms. This chapter focuses on the contributions that researchers studying learning and cognition make in creating and establishing thinking-centered classrooms.

For most of this century, our educational system served only the elite in thinking-centered classrooms. The majority of students received an education aimed at the acquisition of basic skills and routine knowledge (Resnick, 1987; Resnick & Resnick, 1992), whereas those considered smart or gifted were given access to some problem-solving and discipline-specific intellectual work. The current wave of reform and cognitive research recognizes all students' abilities to think, reason, and problem solve across the subject matter disciplines and the life span. The recognition that all students can benefit if they have access to a thinking-centered classroom also means that schools and classrooms need to organize differently. Educational and cognitive researchers have begun to make contributions with research that demonstrates how complex social interactions such as classroom activities figure prominently in teaching, learning, and cognition.[2]

New theories and insights into intellectual growth, cognition, and learning have the potential to alter classroom organization and pedagogy. These insights are deepening our understanding of how students learn and how teachers can best teach. Overall, there is much more inquiry into how learning is negotiated, organized, and constructed by students and teachers.

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[1]Reform movements are not new to American education, and this is not the first time that reform has taken up the goals mentioned above (Cuban, 1987; Tyack & Cuban, 1995).

[2]The research community has been diverse in its interests and specific areas of concern, yet it has coalesced around a few ideas, methods, and goals. There has been a shift in theories about learning (Brown, Collins, & Duguid, 1989; Greeno, 1995), intelligence (Salomon, 1991; Gardner, 1993; Sternberg, 1994), and curriculum and assessment (National Council of Teachers of Mathematics, 1989; Brown, Ellery, & Campione, chapter 14, this volume), and the focus of research investigations, methods, and venues. The move to research in school settings has begun to alter the nature and outcomes of cognitive research. Researchers have reached across the disciplines to adopt methods and tools for gathering information and data, and have begun considering how cognition and learning are situated and constructed in the classroom milieu.

This style of research has begun to align with a new agenda in schools by providing some foundational knowledge for reform.

The research and practice worlds are converging. As more research considering the social milieu generates results, researchers are contributing to classroom, curriculum, and the design of school structure. The chapters preceding this one are exemplars of the kinds of questions researchers bring to the thinking-centered classroom, the kinds of things researchers are able to learn when they look at learning-relevant interactions in math and science, and the kind of implications the research has for defining the structural, curricular, and social features of the thinking classroom.

This chapter discusses chapters in this volume by Hall and Rubin (chap. 8), Saxe and Guberman (chap. 9), and diSessa and Minstrell (chap. 7). It considers their contributions to the understanding and establishment of thinking-centered classrooms.[3]

THE CHAPTERS AND THEIR CONTRIBUTIONS TO THE THINKING CLASSROOM

The three chapters provide examples of reform-informing research. They report research that took place inside math and science classrooms, examining how teachers or students constructed intellectual and conceptual work. The researchers describe how students interact with, understand, and use mathematical and scientific concepts; in each case, they make claims for how the classroom teaching and learning come to be organized in the classroom. All of the researchers analyze video and observational data from classrooms and make a call to their colleagues for more discussion of emergent methodologies.

Together, the chapters provide a glimpse into the growing body of knowledge about how thinking and cognition get organized in learning environments. They support the following ideas:

1. Thinking practices and accomplishments in classrooms are socially organized across persons, activities, artifacts, and structures for participation.
2. Mathematics and the sciences are practices as much as they are content knowledge territories, and mathematics and science classrooms can be rich in disciplinary practices.

[3]I should like to thank members of the MMAP research, analysis, and writing group who read this chapter and talked through the issues with me. Doris Perkins and Tina Syer were especially helpful.

3. Teachers have much to learn and do with their students if they are to create learning experiences rich in disciplinary ideas, practices, and inclinations.
4. Much work needs to be done to reorganize the knowledge, material, and institutional resources in schools for establishing successful, thinking-centered classrooms.

A quick tour through the chapters highlights these particular contributions. diSessa and Minstrell examine the course of a high school physics lesson to characterize lessons critical to the science education enterprise called benchmark lessons. Hall and Rubin analyze students and a teacher as they grapple with how to handle a math problem privately, with each other, and with their entire class. Saxe and Guberman analyze 40 students and their partners as they play a game called *Treasure Hunt*, which requires mathematical transactions and strategies.

diSessa and Minstrell

diSessa and Minstrell concentrate on benchmark lessons, which they find essential to encouraging conceptual change in science students. Minstrell developed and relied on a series of benchmark lessons throughout his career as a high school physics teacher. The two authors describe a benchmark lesson and trace the course of its development.

diSessa and Minstrell make clear connections between benchmark lessons and the thinking-centered classroom. The lessons have a great deal to do with certain views of teaching and teaching practices and certain kinds of classroom interactions around the learning of science concepts. For example, benchmarks count heavily on the contribution of student ideas.

Benchmarks aim to develop classroom learning practices that run parallel to the practices and dispositions of scientists. The educational task is to provide students with scientific ways of being and doing, rather than simply focusing on knowledge and concepts in the narrow sense. Teachers work hard to develop students' ability to articulate and defend their ideas. The departure is subtle, yet important. The goal of science instruction is no longer to have a student solve a problem with a scientific concept, but for the student to solve a problem with a scientific concept while nurturing an inclination to pursue his or her own version of a scientific view of events outside the classroom. diSessa and Minstrell believe in the abilities of students and confidently state that children have the conceptual resources needed for undertaking this kind of learning approach.

diSessa and Minstrell present maxims for benchmarks. They are memorable and about important issues and may help students re-experience their familiar world, build on prior competencies, and are goal driven; they are the beginning of an extended process; they require the flexible use of many general strategies by the teacher; they assume unusual attitudes on the part of students and teachers (e.g., mutual respect, risk taking, opportunities for experimentation); and they are difficult to learn how to run but worth the rewards. Benchmarks are a tall order for students and teachers, and much time and energy must be spent on learning how to work in them.

The lesson described took place with a small class of academically oriented sixth-grade students who were participating in a research project with diSessa. The lesson described was one of a series. diSessa and Minstrell point out that the teacher worked extremely hard to break away from a "teacher-oriented, correct-answer focus that pervaded the school." The lesson breaks many of the stereotypical categories: It takes up a sophisticated question even though the students are young; it is hard to accomplish successfully even though the students are bright; at first glance it looks as if it is an unsuccessful lesson. The conversation seemed disorderly and out of control, the teacher seemed unsure of the correct answer to the students' questions, and the discussion led to no resolution.

In their chapter diSessa and Minstrell look at the ideas students brought to the discussion. They argue that good physics was taken up in the class discussion and that the students took up the subject matter through a continuing and expanding use of their own ideas. They examine some of the strategies the teacher used to cultivate the discussion and point out how disparate ideas and multiple threads of conversation came up and were handled. They look at this lesson and how it might be refined and improved as a benchmark.

The connection of benchmarks to the practices of scientists is clear. The authors present a caveat to all concerned: Teachers too often assume that the correct view of science is much more compelling to students than it actually is. They observe that teachers feel justified in presenting and nudging students toward what is right. They relate how, in their own teaching, they had to confront the fact that students who knew the correct view could use it effectively and even articulate the standard arguments even when they did not really believe it. Benchmarks are not about content correctness; rather, they are about scientific practices and inclinations.

They emphasize the importance of ownership of the lesson by students and view students and teachers as working together in a joint production. The teacher must assume that students have the ability to learn science, take their contributions seriously, and use them in moving the lessons along.

Questions of teaching and teaching dilemma rise in the discussion of benchmark lessons. When does the teacher intervene in discussion? diSessa and Minstrell provide some answers. Teachers intervene to save or fix it; explain or point out; organize activities, thoughts, and next steps; let himself or herself be ignored; introduce modes of inquiry; help students see; take back his or her own moves; and give cues as to what is important. The teacher is a curator who recounts decisions, prompts for reasoning, repeats and rephrases student contributions, snaps up contributions that might otherwise be missed by students, summarizes the state of the discussion, and questions students about the state of their comprehension. This comprises a tall order that calls for gradual growing and development. diSessa and Minstrell recognize that teaching is demanding and that creating benchmark lessons provides students with a constructivist science experience that can be based deeply in the essence of science.

Hall and Rubin

During the Thinking Practices Symposia in 1992, Hall and Rubin spent time with Lampert thinking about how they might collaborate. Lampert volunteered for analysis the materials she collected over the course of her fourth-grade math teaching year. The materials included multiple videotapes of each class, Lampert's planning and journal entries, and student journals. Hall and Rubin focused their analysis on a series of classroom activities on the mathematics of rate. In their chapter, they examine several aspects of teaching and learning around the concept. They saw in Lampert's collection an opportunity to gain insight into how students learn to reason quantitatively and examine a possible way to reorganize math teaching. They focused their analysis on videotapes of classroom activities and journals kept by Lampert and the students. They delineated a set of activities for learning mathematics and traced how these activities linked across activity settings and particular forms for representation and discourse.

Students in Lampert's classroom worked privately in their journals, locally with their small group, and publicly in whole-class discussions. Hall and Rubin looked at how a particular representation used by Lampert—the journey line—supported mathematical activity in the three different interaction settings. They contend that, although each setting provided particular opportunities for learning, the classroom was structured to encourage movement and opportunities for explanation across the settings. Their analysis supports their point.

Within a span of a few minutes, Lampert and the students explore conventions that govern the use of a representational form—how starting assumptions lead to conclusions that may or may not be compatible with conjectures about an answer, and how to calculate within and across the dimensional structure of rate to arrive at a plausible answer.

Lampert's mathematics lessons meet many of the benchmark criteria. Like diSessa and Minstrell, Hall and Rubin believe that Lampert fosters the development of what they value as a mathematical thinking practice. They conclude that Lampert plays an active role in structuring student participation. They see evidence that students selectively take up the organization and content of a participation structure for mathematical thinking that Lampert is working to create. Hall and Rubin like Lampert's structure and argue that it provides students with opportunities to participate in what they call authentic mathematical practices: sustained, joint inquiry on problems where results are carried forward into further work on related problems. They liken this learning environment to forms of Legitimate Peripheral Participation (Lave & Wenger, 1991) and mutual appropriation in zones of proximal development (Vygotsky, 1962). In the activities analyzed, Lampert's students learn a representational form (i.e., the journey line) that many students would know. However, Hall and Rubin contend that Lampert's students can do things with the topics and representations that other students would be hard pressed to match.

Hall and Rubin note how hard Lampert works to bring her classroom design to fruition in terms of the students' math learning; they wonder if it is possible to make this happen in other classrooms. They feel that certain practices distinguish Lampert's classrooms: She (a) takes a serious analytic stance toward her students' contributions, (b) is willing to defer on the correct answer in favor of talking about what makes a right answer, (c) works carefully with students' documentary products, and (d) consistently pursues her preferences for authentic ways to do and talk about mathematics. Hall and Rubin hint at the need to address teaching professional development when they question whether Lampert's uniqueness of practice can be brought to other teachers' classrooms.[4]

Saxe and Guberman

The chapter by Saxe and Guberman moves away from dealing directly with issues of how teaching practices organize disciplinary learning and moves us in the direction of looking at how students organize their interactions for accomplishing math goals. Saxe and Guberman propose a sociocultural view that "cognition takes form in relation to a range of social and cultural processes, such as the artifacts and tools that are valued in practices, power and role relations that emerge and become institutionalized in practices, and social interactions with others." They are concerned with developing research models and methods of analyses that embrace the situated activities of the individual, the "sociocultural life," and the culturally textured and emergent character of cognition.

They raise methodological issues, calling for conceptual models of cognitive development that can be used to organize analyses of cognition in situ, and models that reflect the intrinsic relations between the constructive,

[4]These questions are also taken up by Lampert in chapter 2 of this volume.

sense-making activities of the individual and the sociocultural life. They call for these methods to further apply to field work, so the culturally textured character of cognition is revealed as it emerges in people's daily practices.

The Treasure Hunt game was developed by the researchers and their colleagues at UCLA as an enrichment activity. Treasure Hunt is a board game where students must periodically make purchases for their hunt by consulting price-ratio charts and exchanging gold doubloons that come in 1, 10, 100, and 1,000 denominations. The act of purchasing requires students to develop arithmetical goals and use certain kinds of solutions (such as making equivalence trades). The researchers observed 32 student dyads from an inner-city Los Angeles school at play.

The analysis addresses two questions. What is the complexity of the arithmetical problem that the children accomplish as a dyad? What are the goals that individuals structure and accomplish in the context of dyadic activity? Both qualitative and quantitative techniques were used to complement each other and reveal the general characteristics of the relations between the cognitive work that dyads accomplished and the cognitive environments that emerged for individuals.

The analyses made it possible for the researchers to report on the distributed nature of problem solving. They observed whether students made problem-solving processes available to their partners, and they observed differences in the ways the different dyads negotiated problem solutions. They observed that differences in the characteristics of students' emergent goals were a function of the player's grade and the grade level of the player's partner. Fourth graders were generally more skilled than third graders, but third graders playing fourth graders found ways to use counting strategies to accomplish solving problems. The ways the students played Treasure Hunt emerged in interaction so they were not predictable before the game was played. The researchers matched older and younger students in play so there must have been some curiosity about the ways students would help each other accomplish the facets of the game. Although the implication is not made directly in the chapter, their analyses, like Hall and Rubin's, point to possible ways that they were trying to organize learning (e.g., creating the situations for scaffolding and zones of proximal development; Vygotsky, 1978; Newman, Griffin, & Cole, 1989). The methods used by Saxe and Guberman help reveal the emergent nature of the students' interaction and show us an environment that supports certain kinds of content-related problem solving.

How the Work in the Chapters Advances the Cause

The classroom activities reported on in the three chapters are all exemplars of thinking-centered classroom activities. The research orientation and methods employed by the researchers provide us with much-needed descriptions of teachers and students at work. In the three classrooms, teachers and students are developing new practices, communicating about content inside a number of collaborative structures, and using and sharing representations, artifacts, and problem spaces. We see how goal setting and work on problems emerge through the interaction of students when they play Treasure Hunt. We see students in Lampert's classroom using the representations and discourses of mathematicians. diSessa and Minstrell give us insights and goals for the teachers who must orchestrate with their students' intellectual discovery and ownership of scientific inclinations, and warn us about how long and hard teachers must work.

The three chapters make strong contributions to educational research and have implications for reform. In each analysis, there is confirmation of students and teachers working through disciplinary-based conceptual terrain. Each chapter is a proof of concept. The physics teacher helped to provide her students with a discussion that would have them grappling with a problem in scientist-like ways long after they left her classroom. Lampert's students were grappling with learning math in some very mathematical ways—making conjectures, communicating about their ideas using representations, and explaining their reasoning. The students playing Treasure Hunt had a resource that provided them with opportunities to teach and learn from each other as they generated arithmetic transactions. The chapters highlight the dilemmas that face teachers and researchers alike. When I read the descriptions of these classrooms, I wanted more classrooms to be like these and for these classrooms to be the norm rather than the exceptions.

Taken together, the chapters raise many issues about thinking-centered classrooms. Hall and Rubin know that Lampert has developed unique teaching habits, classroom practices, and discourse, and she has a unique set of professional circumstances that provide her with many resources not readily available to most teachers.[5] diSessa and Minstrell show that a lesson fulfills the requirements for excellence although it feels out of control to the teacher and students. There is advocacy in their work for a whole new set of struggles that must define classroom learning.

Still more is to be uncovered about how these kinds of environments for learning will appeal to teachers in the educational mainstream. The physics class is a high-end group and is composed of about one half the number of students in an average-size class. Saxe and Guberman show how pairs of students negotiate roles and develop collaborations that allow them to keep a game going by transacting mathematical work, but reserve judgment about the value of the goal-setting and problem-solving experience as an indispensable or supplemental aspect of math instruction.

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[5]See chapter 2 in this volume for a full description of Lampert's circumstances and its dilemmas.

The chapters make only covert references to the constraints of the larger institution of schooling and how it must adjust for a thinking-centered approach to take a center stage. When I read the descriptions of the classroom interactions and activities, I became convinced of their worth. In fact, I prefer them to what I see in many American classrooms. I do know that we need to consider and understand more about these environments. If we believe that students are getting something of real value in these science and mathematics classrooms, we must start to ask questions about what would have to happen for more teachers and students to have access to this version of school work. For example, two of the chapters make reference to the massive efforts that teachers will have to undertake to change their idea of disciplinary learning and communication processes in classrooms. In addition, we have to ask questions about how schools, classrooms, and curricula are organized to give or prevent access to thinking practices. We also need to know and confront the ways access plays out for students as individuals, as well as members of social, ethnic, and socioeconomic groups.

We need to understand how the curriculum is constructed and situated in wider contexts outside of the classroom; on that front alone, there is much to know. We must understand and confront the relations between how classrooms are structured, how curriculum is approached, and how, why, and on what students are assessed. If we move away from assessing individual student knowledge of isolated skills and have emergent, complex environments, how will we know how to look for, keep track of, document, and legitimate students' emergent intellectual practices, activities, and interactions? If we stay with current forms of assessment, how will we ever capture the complexity of students' learning as they take on the dispositions, discourses, and practices of scientists or mathematicians? If we do not do all of these, how can we ever build schools where intellectual practices—thinking practices—are taught, valued and expected for all students in all subjects?

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CHAPTER

11

DEMONSTRATING PHYSICS LESSONS

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"Who do you believe, me or your eyes?"

—Groucho Marx

In this chapter, we treat elementary school physics lessons as familiar, observable, and routinely organized activities that exhibit, for participants and analysts alike, how science can be produced through a manipulation of ordinary objects. By repeatedly examining videotapes of elementary physics lessons, we have sought to understand how science is generated from within the noisy field of practical actions and discursive relations that constitutes the classroom. Our immediate aim is to describe the ordinary production of classroom science. Our overall purpose is to address a foundational question for scholars in the sociology, history, and philosophy of science: What does it mean to act and speak scientifically?

In its familiar terms, the question invites us to reflect on topics such as the relationship between science and common sense, the nature of scientific explanation, and the role of authority in the production and reproduction of facts. As we construe it, however, the question remains alive and is practically addressed whenever science is done, whether by highly trained and theoretically informed practitioners or by children—novices in the classroom. It is an ethnomethodological question in the sense that it is a practitioner's question first, with no ultimate, academically certified, answer. Viewed this way, the question What does it mean to act and speak scientifically? points to practical situations of inquiry that are subject to provisional and (sometimes) practically adequate solutions.

Although the elementary classroom might be viewed as the last place in the world one would want to look for actual scientific practices, we argue that it provides an especially apt research site for addressing the fundamental question of how science is produced from an assemblage of ordinary actions and understandings. Radical insight about the practice of science has often been attained by reconstructing the historical invention of a scientific way of knowledge. Studies of early modern European science have shown that specific matters of fact and procedure, as well as the very ideas of matters of fact and the experimental method, were socially constructed in contingent and often contentious historical circumstances (Shapin & Schaffer, 1985). Although we find such historical research illuminating, we are interested in developing a different kind of genealogy by closely investigating how children are progressively enjoined to witness and explain a scientific spectacle. We do so without supposing that the ontogeny of scientific practice recapitulates the history of scientific knowledge. Rather, we believe it is possible to detail the practical organization and circumstantial establishment of what counts as science by studying the discursive struggle through which child masters of a natural language are persuaded, coerced, cajoled, and otherwise induced to speak and listen scientifically. To this task, the unfolding routines and contingent events of the classroom make up the local scene in which origin stories can be enframed and enacted. Starting out as an assemblage of ordinary witnesses who have been promised the spectacle of a science demonstration, members of the class are led to see and say what scientifically is going on before their eyes.

As we employ it, the characterization *scientifically* needs no claims or stipulations in advance of what counts as real or authentic science. Instead, it speaks of science evidently—its practical objectivity and observability for a particular occasion. The science of a science lesson is made locally relevant and recognizable regardless of how teachers' and students' understandings of the lesson's contents compare to what real physical scientists may know.[1] When describing the way teachers and students manipulate

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[1]Technical rationales for maintaining this methodological posture are developed in ethnomethodology and the sociology of scientific knowledge. Although there are significant differences between the policies of ethnomethodological indifference (the injunction to treat practical sociological reasoning as a topic of study rather than a privileged grounding) and symmetry (the idea that explanations of scientific developments should take the same form, regardless of any a priori conceptions of the truth or falsity of particular knowledge claims), both policies attune researchers to socially organized orders of practical reasoning and put aside the question of whether they correspond to contemporary professional standards of what is real or rational. In the present study, we intend to take seriously that the local relevance and recognizable presence of scientific phenomena and modes of explanation in an elementary classroom can be investigated as orders of scientific activity in their own right, independent of the correctness of the physics as judged from an authoritative standpoint (see Bloor, 1976; Garfinkel & Sacks, 1970).

materials, describe what they see, and explain what happens in a science demonstration, we are reluctant to use classic principles of scientific method or established physical laws, definitions, and principles as guidelines for identifying what they do or should do. This research policy requires an indifference to the classic distinctions between science and common sense, theory and practice, or abstract and concrete reasoning as stable bases for evaluating the field of discursive actions composing an elementary physics lesson.[2] Yet by saying these things, we are neither confessing ignorance nor ignoring the obvious fact that lesson plans are often designed to embody idealized prescriptions and explanations. Instead, we are attempting to avoid using entrenched presumptions about scientific and ordinary actions as normative bases for detecting and detailing the local organization of classroom lessons. We agree with Bruno Latour (who in turn credits Jack Goody) that "the 'grand dichotomy' [in this case between science and common sense] with its self-righteous certainty should be replaced by many uncertain and unexpected divides" (Latour, 1986, p. 2). In order to remain open to the discovery of science for all practical purposes, we will not make an issue of the adequacy or accuracy of the physics our classrooms produce. How they can be said to produce science at all shall remain a constant focus.[3]

(NOT SO) COLD SCIENCE

It may be helpful to contrast the ethnomethodological approach we are proposing to a well-regarded study of classroom science by Atkinson and Delamont (1977). The authors of that study (whom we shall call A&D, for

[2]See Smith, diSessa, and Roschelle (1971) for an extensive and helpful review and criticism of the robust line of science and math education research that conceives of education as a matter of correct expert knowledge replacing naive misconceptions held by students.

[3]To the arguments in hand, there is another that warrants our interests in these classroom materials. Increasingly, historians, philosophers, and sociologists of science are claiming that the natural sciences are not a unified body of theories, facts, or methodological precepts (Galison & Stump, 1996). Although we agree with the thrust of the disunity arguments, they do not provide for the manifest uses of conceptions of unified science in educational practice. Such usage has an inescapable relevance for how teachers, students, and educational researchers speak about, write about, and demonstrate something called *science*. Thus, an agenda for studies of science is to investigate the public communicational orders that produce and promote science along with various epistemological themes: observation, description, replication, measurement, discovery, experiment, and so forth. The recognizable relevance of science in human affairs can be studied without initially electing a principled version of real science. Examples like those we study here are primitive—that is, they are ethnographically accessible without need for specialized training. At the same time, they provide case material for investigating bona fide instances of the uses of experimental discourse, materials and instruments, and disciplined witnessing. For programmatic arguments that outline rationales for the ethnomethodological respecification of classic theoretical and methodological themes, see Garfinkel (1991) and Lynch (1993).

short) examine a program of guided discovery lessons designed to instruct British secondary school pupils on the practice of science. In theory, the lessons enable students to discover scientific principles by performing experiments on their own. However, as A&D point out, the reality presumed by such classroom exercises—real scientific practice—is not actually present in the classroom. The exercises and their results are largely predetermined, enabling teachers to assess students' performances as correct or mistaken, and often enough the exercises fail to produce sensible findings. A&D describe guided discovery lessons as "cold science," analogous to the "cold medicine" of hospital rounds, in which medical students recapitulate diagnoses already made by more experienced practitioners and already known by others in the room. The medical students know the difference between the cold medicine of rounds and the hot medicine of actual diagnostic tasks and occasions. Similarly, students practicing cold science "go through the motions of stating hypotheses, designing rigorously controlled experiments and deducing conclusions. Neither situation [cold medicine or cold science] is 'real', but both are parallels of 'real' processes" (Atkinson & Delamont, 1977, p. 95). Typical of the ubiquitous interactional organization of classroom instruction (Mehan, 1979), the teacher has prior knowledge of the results, whereas the students are asked to produce a simulacrum of the correct procedure for getting these results.

One persistent problem reported by A&D is that the classroom experiments they observed hardly ever worked. Unable to use the results to assemble the lesson, the teachers were "always falling back on statements such as, 'If the experiment had worked, you would have been able to see . . .' " (p. 96). For example, a physics teacher begins a lesson a week after such an experimental exercise by saying, "Last week you discovered an important relationship." A&D report that this is greeted by ironic laughs, which the teacher ignores while going on to explain relationships between force and mass (p. 96): "The experiment had failed, or the mathematics were too hard, or the conclusions had simply not emerged. Dr. Cavendish [pseudonym for physics teacher] would be forced to re-explain, or would do the experiment herself, or rework the maths" (p. 97).

Borrowing from Garfinkel and Sacks (1970), A&D speak of these classroom experiments as "mock-ups"—pedagogical devices that make false provision for selective features of the actual object or situation they purport to represent. Borrowing from Goffman (1974), they speak of the way the classroom experiments are stage managed and decoupled from the situations in which they usually are embedded. In their view, a kind of script or game operates in classroom science. What appears to be " 'discovery' is the recapitulation of the socially agreed nature of 'science,' 'medicine' and the natural world" (Atkinson & Delamont, 1977, p. 107). The key features of these mock-ups, and what alerts us to them, is that the teacher organizes and controls the demonstration situation even while the students participate in lessons designed to enable them to make their own discoveries.[4]

We agree with A&D that classroom science can only make false provision for the situations of inquiry in which professional scientists work. In addition to being designed with the correct results already in hand (Morrison, 1981), the science that is taught and demonstrated in classrooms is designed to be demonstrated on occasions built of the various organizational contingencies inhabiting the school setting. Normatively, these include issues of:

- Scale and timing. Experiments and demonstrations must be accommodated to the class schedule, the size and layout of the classroom, and the number of students. Temporal considerations are critical, both for one-shot performances and for projects that continue from one day to the next and for the pace of the science work itself.[5] Not just any science, or science spectacle, is available to the classroom laboratory, lesson, or hour.
- Division of labor. There is no staff of technicians, no complex division of labor, and no expertise shared among colleagues. Instead, table-top experiments tend to be preferred, in which all of the science is happening as part of a scene presented by the teacher for an audience of students (sometimes with volunteers helping) or produced by students acting individually or in pairs.
- Witnessability. The experiment is arranged so that the students can see what they are supposed to, where the witnessed affairs must be sufficiently evident or vivid. Opaque displays will not do.[6]
- Competency. The equipment, metrics, instructions, and explanations are graded for an audience with a limited mastery of the relevant techniques and vocabularies, and for teachers who generally have themselves none of

[4]Atkinson and Delamont (1977) emphasized that the classroom mock-up differs essentially and irremediably from what it is supposed to represent, whereas Garfinkel and Sacks (1970) paid more attention to the way the mock-up's false provision for the actual situation is the very thing that makes it effective as a model. Indeed, the false provisions are what make of it an instructive model (rather than a duplicate) in the first place. Without complaint, our attention then turns to the question of how the model is constructed as such and not how it fails to become science.

[5]Consider, for example, a grade school demonstration in which a celery stalk is placed in dyed water. A day later, the dye travels up the stalk to the leaves as a demonstration of capillary action. In an instance recorded on videotape, a teacher trainee mistakenly initiated this demonstration without taking into account that the result would only appear a day later. Having realized this as she placed the celery in the liquid, she turned to the students and explained what they would have seen a day later.

[6]Thus, children's science television programming is filled with smashing melons and magnets in flight (cf. "Beekman's World," CBS Television Network). The spectacles are evident, compelling, and often highly produced.

the experience to which their curriculum is held accountable (science discovery).[7]

- Equipment and cost. Electron microscopes, radio telescopes, and cyclotrons do not fit school budgets. Even on rare occasions when schools are able to offer sophisticated training in, for example, molecular biology techniques, a great deal of ingenuity may be necessary to secure the equipment, modify it to reduce costs and guard against commonplace misuses, and limit its access to only the most advanced students.[8]
- Safety. For obvious reasons, there is a tendency to avoid using radioactive materials, volatile or carcinogenic chemicals, high-voltage equipment, venomous creatures, and so forth.

Instead, classroom demonstrations tend to involve simple household items, standard school equipment (projectors, screens, table tops), readily purchased supplies (beakers, Bunsen burners, test tubes, light microscopes, sacrificial frogs, and simple machines), and ordinary age/grade competencies to measure, count, manipulate, and assemble. Mock-ups of selected classic experiments adapted for school purposes tend to be given pride of place in the school curriculum (e.g., Galileo's demonstrations with pendula and inclined planes, some of Newton's simpler optical experiments, and Faraday's iron filings and magnet demonstrations). Although the curriculum does not recapitulate the early history of science, some classic experiments nicely lend themselves for modification into classroom exercises in which the original equipment is updated, simplified, and adapted to the facilities at hand. For very young children, "Galilean" experimentation is done with wooden blocks that are used to construct ramps of different length and

[7]Unlike public science demonstrations performed at museums and in courtrooms and government hearings, elementary classroom demonstrations are often performed by teachers who are not actively engaged researchers in the relevant discipline. Collins (1988) argued that members of the general public are given a distorted view of science because they are not let in on the practical contingencies and controversies that are characteristic of cutting-edge science. Instead, the spectacle of the demonstration works much like a stage magician's trick performed to an unwitting audience. The classroom physics A&D describe present a somewhat different story. The contingencies of performance are painfully obvious to the students, even when the teacher invokes an idealized version of what would have happened if only the experiments had worked. Like Collins, however, A&D are preoccupied with the difference between real science and the lesser, even corrupted, spectacles of science performed by (or demonstrated to) relative novices.

[8]These remarks are based on an interview by Kathleen Jordan with a Boston-area high school teacher who labored heroically to introduce molecular biology to select high school classes. The interview was conducted as part of an NSF-sponsored study, "The Polymerase Chain Reaction: The Mainstreaming of a Molecular Biological Tool" (NSF Studies in Science, Technology & Society Program [Award 9122375]).

pitch.[9] Contemporary students are not given replicas of Leeuwenhoek's simple microscope when examining droplets of pond water or of Galileo's telescope when visualizing the rings of Saturn, nor are they instructed to describe the "animalcules" like Leeuwenhoek does or speak like Galileo does of the ears that protrude from Saturn like handles on a teacup. In the grade school or high school classroom, there is little interest in giving a faithful account of the practices, historically specific conceptions, and social circumstances of Galileo's or Leeuwenhoek's adventures.[10] As A&D emphasize, the fact that the correct results of the experiments are already in hand guarantees that a crucial feature of discovering work is missing: the reflexive intertwining of assessments about the competent performance of an experimental run with the yet-to-be substantiated results of the experiment.[11]

These contingencies might lead one to conclude that classroom science demonstrations are cold—indeed, unrealistic and ineffective. This surely is a view held by many critics of science education who fault the content of science lessons. It is a view promoted by physicists who bemoan the errors purveyed by mistaken textbooks and ill-educated teachers. It is also a view held by education researchers who negatively assess students' intuitive understandings of physics. However, without denying that there may be serious problems with classroom science teaching, we are troubled by the way such criticisms presume that a correct or authentic version of physics can provide a backdrop for characterizing the classroom situation. Like historians who have criticized Whig histories of science, we are concerned about how a version of correct physics is often used as an inflexible backdrop for analyzing the intuitive understandings of students and for evaluating the adequacy of the curriculum.[12] Once we grant that the students (and very likely the teacher) cannot possibly know, let alone demonstrate, cor-

[9]An early grade school teacher's handbook gives instructions on using blocks to demonstrate "the effect of inclined planes on speed and distance" (Sprung, Froschl, & Campbell, 1985). For a study of actual situations where instructions of this sort were used, see Amerine and Bilmes (1988).

[10]Despite these differences, phenomenological analyses of contemporaneous attempts to redo historical experiments can inform, and be informed by, history and philosophy of science (Bjelic & Lynch, 1992; Collins, 1992).

[11]This is an allusion to the theme of "first time through" discussed by Garfinkel, Lynch, and Livingston (1981) and is related to Collins' (1985) idea of experimenter regress.

[12]Our argument here is analogous to Kuhn's (1970) attack on Whig historiography. Kuhn, and many sociologists of scientific knowledge who followed his lead, objected to the use of the vocabularies and understandings of modern chemistry to define historical events and sort out what actually happened at a time when the complex of understandings about oxygen were not yet instantiated. In the most transparent Whig histories of science, rationality is identified with whatever led to currently accepted scientific theories and facts, and error and irrationality are associated with doctrines and claimed results that have been bypassed by history (Bloor, 1976).

rect physics in such a situation, we can begin to investigate what it is they can know and do in the circumstances. Thus, without dismissing all interests in such comparisons, it is possible to develop a different orientation to classroom science lessons as: (a) orders in their own right; (b) assemblages of equipment, embodied practice, witnessing relations, descriptions, and explanations; and (c) developing organizations of competency. We return to these points after presenting materials from two classroom physics lessons.

PRODUCING SCIENCE SPECTACLES

The transcripts used in this chapter are taken from two videotapes of classroom demonstrations. One tape recorded a third-grade science lesson in New Mexico,[13] and the other recorded a training session for teacher education students at a college in the state of Washington. In the latter case, a teacher trainee presented a brief lesson to a group of three primary school students. Both lessons are table-top demonstrations performed by the teacher using simple materials to demonstrate elementary physical phenomena. Both lessons are organized in phases, where the teacher mobilizes a set of materials to establish a set of relevancies and comparisons, performs the demonstration while enjoining the students to witness and identify what is going on, and then solicits an explanation. In both cases, a key part of the explanation is an invisible entity–molecules–which is invoked to make sense of what the students witness. In the New Mexico lesson, the teacher places two droplets of red food coloring into each of the three containers—one filled with ice water, another with tap water, and the third with hot water. After watching the dispersion of the food color through the containers, she solicits descriptions, comparisons, and explanations about how and why the color in each container behaves. In the Washington lesson, the teacher performs a sink-and-float exercise, dropping a coin and poker chip of roughly equal size into a beaker of water. After watching what the coin and chip do, she solicits explanations as to why one object sinks and the other floats. The lesson continues through subsequent phases using different sets of materials. For present purposes, we focus only on the first sink-and-float phase.

The question we address with these video materials is: How is science relevanced in these scenes? Specifically, how is science instruction locally produced and exhibited as a spectacle for an audience of students? This differs from the question we raised at the outset and to which we will return at the conclusion: What does it mean to act and speak scientifically? Rather than trying to come up with a general definition of *science*, we intend to identify some of the discursive moves and gestures through which a scene

[13]See Macbeth (1996) for further analysis of this tape.

of activities becomes implanted with scientific identities, rationales, and phenomena. The tapes enable us to elucidate four related themes: (a) positioning and disciplining witnesses, (b) managing and orchestrating an observing assemblage, (c) securing and shaping descriptors, and (d) upgrading commonsense explanations.

Positioning and Disciplining Witnesses

Much of the work documented by the tapes has to do with the production and maintenance of classroom order. However, this order is more than a matter of keeping unruly kids in line. It involves the orchestrated management of an unruly plenum of accounts and activities.[14] The discipline of the classroom is a concerted ordering of eyes, ears, hands, entire bodies, equipment, and discursive actions, all of which are brought into focus on a materially witnessed phenomenon. In the New Mexico tape, the teacher initiates the demonstration by asking the students to leave their seats and gather around a table on which an array of equipment is deployed. The teacher navigates through the crowd of bodies while maintaining an orientation to the equipment, occasionally restraining one or another of the students while warning of the hot water in one of the beakers. A phenomenal field is set up, reflexively shaped as the students assume the collective attitude of an audience gathered around a bench where a spectacle unfolds (see Fig. 11.1).

In the course of the demonstration, the students are introduced to an array of materials and material properties, including water that is demonstrably hot, cold, and room temperature (tap water). The students are not fully active coexperimenters, nor are they completely passive spectators. Instead, they are positioned as attentive witnesses enframing the spectacle who can be called on to explain what is happening.[15] Particularly significant

[14]Husserl (1970) used the phrase *sensible plenum* (*einer sinnlichen Fulle*) to speak of the full sensible contents of a life world from which mathematical physics abstracts pure shapes and relations. In our usage, which borrows from Garfinkel (1991), the unruly plenum describes the open field of discoverable and specifiable possibilities for seeing what something is, describing what is happening in an immediate spectacle, and identifying stable relations between things and practices.

[15]A number of education researchers who witnessed a portion of the New Mexico tape at the November 1992 Carnegie Workshop at Stanford University objected to the one-sided delivery of the demonstration by the teacher to the students. The teacher was criticized for ineffective, and perhaps oppressive, instructional methods. One participant, who had earlier performed a structurally similar demonstration of making pasta to the conference audience, was especially bothered by the interactional asymmetry of the videotaped lesson. Although there may be good reason for such criticisms from a normative educational standpoint, for our purposes it is enough to note that the passive students who witness the demonstration are visibly engaged, evidently oriented, and discursively responsive to the teacher's moves, and thus they are active co-producers of the demonstration in just those ways. For commentary on this point, see McDermott and Webber (chap. 13, this volume).

FIG. 11.1. Witnessing the demonstration.

for our purposes is the way the teacher both relies on the spectators to see (and say) what is going on while producing an array of clues, prompts, instructions, indications, and corrections that highlight, shape, and articulate specific ways of seeing and saying.

In the Washington tape, after establishing the identity of two objects as a coin and a poker chip, the teacher builds a story frame around the initial phase of the demonstration. She animates the story by handling the two objects, walking them up to the beaker, and poising them above it.

1. Teacher: Let me tell you a story about these (.) guys.
2. They decide to go swimming one day.
3. ((Teacher holds chip and coin to illustrate story))
4. (S): Em hmm.
5. T: *So:*, they go walking along. a:nd, they jump up
6. ((Teacher demonstratively taps the chip and coin on the
7. table, "walks" them up to the beaker, and then holds them
8. above the beaker, as the students laugh.))
9. T: an' they just gonna fall in.
10. (S): (An' they both)
11. T: What's gonna happen?

After soliciting responses about which of the two objects will sink and which will float, the teacher continues with the story. The students as well as the teacher maintain the animistic story frame alongside an evident orientation to physical relations.

12. S1: He drow(hh)ns and he floa(hh)ts.
13. ((Overlapping laughter by other student(s)))
14. T: Who's gonna g- Which one will float?
15. S1: (hm hmm hmm) (Tha-) th' checker. (It's) lighter. (0.4)
16. It's lighter. (0.2) An' that one's heavy, so it'll, it'll float.
17. T: (hmm hmm) Everybody agree with this?

18. S1: Yeah.
19. (S): *Yep*
20. T: 'kay, let's test this ou:t.
21. (1.6)
22. T: oo:hp ((drops the coin and chip into a beaker of water))
23. There he go:es.

Note the intertwining of the animation and science spectacles as the teacher cuts off the phrase, "Who's gonna g-" replacing it with the question, "Which one will float?" The student who answers the question identifies a checker and specifies a material property of that object ("It's lighter"). After soliciting agreement, the teacher proposes to "test this out," thus identifying the action with a canonical experimental term. She then resumes the animistic frame ("There he goes") as she performs the demonstration.

22. T: oo:hp ((drops the coin and chip into a beaker of water))
23. There he go:es.
24. (S): [(heh heh)
25. (S): [(all the way)
26. T: (think we'll help) this guy.
27. (1.0)
28. S1: (Well, we saved him).
29. (S): [(tch)
30. S3: ((laughs loudly))
31. T: [(was it)
32. So::, was our prediction (.) correct then?
33. S3: Yes (yes).
34. T: Arright. (0.6) Well:, (0.8)
35. *What's* an explanation for what jus happened?
(2.5)
36. T: David?
37. S2: They both fell in the water? (0.4)
38. T: (They) what?
39. S1: heh heh
40. S2: both fell in the water.
41. S1: Heh heh hh (Wro(hh)ng.)
42. T: Why did one sink though, and the other one float?
43. S1: Wull, because he's lighter than the other.

Both teacher and students make use of the "two guys" story as a removable gloss, which for the most part does not interfere with the scientific story. The latter is made relevant through the use of methodological terms to gloss the action. The question "Was our prediction correct?" retrospectively glosses their prior action as a concerted prediction and testing of the prediction. As soon as she gets a "yes" answer, the teacher then solicits and pursues an explanation. By overtly using such canonical methodological expressions—as opposed to playing a guessing game or simply asking a question without marking what is to come as an explanation—the teacher exhibits the phases of the action in classic scientific terms. To do so, however, she introduces and relies on a story frame, along with an ability to ask and answer questions, which is independent and yet constitutive of the science lesson. It is as if these ordinary devices become a scaffolding on which the lesson is built, intermittently abandoned, and resumed in pursuing the lesson's scientific point.

In both the New Mexico and Washington demonstrations, a phenomenal field is constituted in which all eyes are drawn to a stage where a material play unfolds in several acts. The witnesses are disciplined in a double sense. First, the assembled bodies are positioned as an audience ready to respond to the teacher's questions and commands. Second, the students become accountable witnesses to the intellectual contents of a discipline. The assemblage of bodies, gestures, talk, and equipment produces and makes visible an order of things in real time.

Managing and Orchestrating an Observing Assemblage

In the New Mexico tape, the teacher gives repeated injunctions about what the students are about to see, what they are seeing at the moment, and what they have just seen: "Just a moment, you're not seeing anything yet. . . . I wan' chu ta' see what happens, okay? ... What's happening here?" These perceptual expressions describe complex temporal and relational configurations of what is, what should be, what has been, and what is just about to be seen, watched, or noticed.[16] Note the following running commentary as the teacher performs the demonstration:

54. T: ... I wanna(h)(h)- I wanna put- two drops. =
55. I hope I make it (two) drops.
56. Watch, what happens. Watch to tha food coloring ( ) =
57. What happens. R'member thissus ice water.
58. (5.0)
59. One.
60. (2.5)
61. Two. (0.7) Watch it. watch what happens. (2.0) Kay? Now.
62. (4.5)
63. Now watch what happens here. Scuse me. D'wanna- hurt- ( )
64. (2.0)
65. One.
66. (10.0)

[16]For a discussion of the varieties of perceptual expressions and their implications for philosophical views of seeing and seeing as, see Coulter and Parsons (1991).

67. Two.
68. (1.0)
69. Watch there. (1.0) Watch there.
70. (5.0) ((whispers))
71. Neet, huh?
72. Ss: Yeah.

Again and again, the teacher summons the students to watch. These calls to vigilance are accompanied by bodily gestures toward each beaker in the series; with dropper in hand, she gives the injunction to "watch" just as she squeezes the drop. What they are supposed to watch she does not say in so many words. Rather, she specifies this "what" indexically, indicatively, and with variable directedness and specificity ("watch what happens," "watch what happens to the food coloring," "watch very carefully," "watch it," "watch there"). The teacher's slow-paced enactment of the spectacle is punctuated by these injunctions to "watch"; injunctions that enjoin, maintain, and reassure an observing assemblage whose eyes are turned on a field, the full sensibility of which has yet to be disclosed. It is not just the case that the field has not yet been completely described. Instead, the incompleteness of the spectacle is explicitly marked by the teacher's instructions. The pacing of her talk is tied to the work of securing the phenomenal field and checking out its membership (who happens to be "in," who may be wandering out, who may be wavering).[17]

Many elements of the scene work together to overdetermine the field in view. These scenic elements produce a highlighted show of rapt attentions, with the teacher's hands, eyes, and voice all calling the witnesses to watch within an unfolding space. Like a carefully designed puzzle, something is left out or deferred, but at the same time this "missing what" is repeatedly pointed to. The witnesses are put on hold, waiting for the appropriate moment to discover what is unfolding there, before their eyes, in a vivid spectacle. Although the field is overdetermined by the compounded indications, references, and rapt attentions, the fact in question is underdetermined.[18] Rather than pointing to an essential epistemological problem, underdetermination is the point of the demonstration, enabling the nominal

[17]We are indebted to Dusan Bjelic for demonstrating (as well as describing) the practical origins of a phenomenal field. For an allusion to this, see Bjelic and Lynch (1992).

[18]Quine's (1980) well-known argument against inductivist philosophy of science, which states that scientific theories are underdetermined by empirical evidence, is often cited in constructivist science studies because it seems to warrant the substantive thesis that something besides evidence determines theory change. Various social, ideological, cultural, and rhetorical factors provide candidate augmentations for this determination. In the present case, that the material spectacle of a demonstration underdetermines the theoretical point the students are being led to appreciate can be viewed as a resource in the temporal unfolding of the demonstration. The surplus of possible accounts (the unruly plenum) produces a condition that is remedied by a single, nonintuitive resolution of what, after all, was witnessed.

lesson to be open to (re)discovery. It promises a revelation and permits the demonstration to be revealing.

Securing and Shaping Descriptors

In both tapes, the teachers secure the science of the displays by soliciting names and descriptions of the relevant materials from the students and then shaping the descriptions through dialogical interventions. This is done through well-known sequential moves, such as in the following sequence where the teacher repairs the identifier supplied by the student without overtly correcting or replacing it (Jefferson, 1987):

3. T: In this container, I have what, Mr. Nichols?
4. S: Ice.
5. T: Ice water. And in this container is tap water....

The teacher does not simply replace the student's answer ("ice") with a more complete one ("ice water"). Instead, her correction supplements the student's answer in a way that builds continuity among the three beakers; each holds a kind of water and "water" becomes a pivotal identity providing a common reference point for the movement from one container to another. The "proper" phrase ("ice water") is not decided by reference to the object alone. Rather, its job is to establish a moment in a field of relatively constant, comparable, and variable relations. In the Washington tape, the teacher retrospectively and prospectively suggests, inserts, and shapes the terms of the story she is demonstrating, evidently highlighting a hypothetico-deductive frame:

14. T: Who's gonna g- Which one will float?
15. S1: (hm hmm hmm) (Thah-) th' checker. (It's) lighter. (0.4)
16. It's lighter. (0.2) An' that one's heavy, so it'll, it'll float.
17. T: (hmm hmm) Everybody agree with this?
18. S1: Yeah.
19. (S): *Yep*
20. T: 'kay, let's test this ou:t.
21. (1.6)
22. T: oo:hp ((drops the coin and chip into a beaker of water))
23. There he go:es.
24. (S): [(heh heh)
25. (S): [(all the way)
26. T: (think we'll help) this guy.
27. (1.0)
28. S1: (Well, we saved him).
29. (S): [(tch)
30. S3: ((laughs loudly))
31. T: [(was it)

32. So::, was our prediction (.) correct then?
33. S3: Yes (yes).

The teacher self-corrects in the first line,[19] repairing "Who's gonna" with "Which one . . . ," thereby shifting out of the animistic story frame into a more exclusively "material" story. The student who answers the question picks up this reference. However, note that the teacher resumes the story frame after establishing reference to "the checker." Note also how the phrases "Let's test this out" and "So, was our prediction correct then?", which are positioned just prior to and just after the demonstrated event, bracket it with terms recognizably associated with an experiment.[20] This frame is not keyed all at once. Initially, the teacher simply asks the students to make a guess: "Which one will float?" After soliciting agreement and marking what is about to occur as a *test*, she drops the two objects into the beaker of water. Her follow-up question—"So::, was our prediction (.) correct then?"—identifies what the students had just witnessed as the moment relevant for assessing a prior prediction that can now be said to have been correct or not. What started out as a story told with material props, leading up to a guess, has been shaped progressively into an empirical test of a prediction. In other words, the teacher makes use of different registers for speaking of the activity that she and the students are doing together while progressively assembling a story and then seeding it with experimental terminologies to punctuate its scientific moments. In these ways, a science spectacle is crafted from an array of ordinary objects and activities: narratives, next actions, questions, and answers.

These are only a few of the ways the teacher, with the students' competent complicity, progressively manages a collective description of what they are noticing, what they are about to see or have just seen, and what they are doing. These concerted practices discipline the field as a plenum. It is not only that the canonical version of the objects in view, and of the experimental actions taking place, are selected from an open field of possibilities; the science of the scene is produced by the versions, story frames, and interactional play through which the students and teacher together assemble a scene in which the selected formal gestures and scientific vocabularies are made relevant and visible.

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[19]Self-repair is the more common of the two main repair devices described by Schegloff, Jefferson, and Sacks (1977).

[20]The teacher trainee's discourse here seems transparently to have been drawn from science teachers' guidelines, such as the following from Sprung et al. (1985). "Once a problem has been posed, the scientific method has been broken down into the following steps: *predicting* (or in a young child's words, guessing) what will happen, *conducting* (or doing) *the experiment, observing* (or looking at) what actually happens, *making conclusions about* (or discussing) the results, and *documenting* (or writing down) the results" (p. 37).

Upgrading Commonsense Explanations

In both lessons, the teacher initiates an explanation phase after eliciting and shaping a collective description of what happened. For instance, in the Washington tape:

34. T: Arright. (0.6) Well:, (0.8)
35. *What's* an explanation for what jus happened?
35. (2.5)
36. T: David?
37. S2: They both fell in the water? (0.4)
38. T: (They) what?
39. S1: heh heh
40. S2: both fell in the water.
41. S1: Heh heh hh (Wro(hh)ng.)
42. T: Why did one sink though, and the other one float?
43. S1: Wull, because he's lighter than the other.

In the New Mexico tape, the teacher uses a less formulaic way of moving to this phase:

87. T: Whut can you tell me (1.0) happened here. (1.0)
88. What happened here. Huh? What happened here. (0.7) Lauren.
89. L: The coloring spreadded all over the water.
90. (1.0)
91. T: How fast? (0.7)
92. L: Like- real fast.
93. T: Real fast. = I wonder why (   ).
94. L: Cuz it wuz- (.) hotter.
95. T: Cuz it's hhhot. Okay. What happened here, in tha tap water.

In both instances, the request for explanation draws what might be called commonplace accounts: The poker chip was lighter and the dye spread in one of the beakers because it was hotter.[21] In many circumstances, such accounts are perfectly suitable, although here the teachers persist in pursuing further explanations. In the New Mexico tape, the teacher continues to pursue explanations and reorient the students to the demonstration while getting more of the same sort of explanation:

114. T: Why: Why not, Erica
115. E: B'cuz it wuz too cold.

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[21]The New Mexico teacher is engaged in producing the spectacle more palpably than we might imagine. Her question of Line 91 ("How fast?") is enunciated with a pace that produces the velocities at hand. She says the question "How fast" *fast.* Hearing the question as a feature of the same, relevant, physical field, Lauren then finds the relevant metric of "Like- real fast."

In the Washington tape, the most dutiful of the three students (Laura) attempts a *scholastic* explanation of why the one object sinks and the other floats; when this is questioned, she insists:

44. T: Arright, Laura?
45. S3: The (.) coin was made out of copper which is a (0.2) a
46. heavier metal than (.) a poker chip which was (thee uh) plastic.
. . .
48. T: Why is (.) it heavier than plastic?
49. (0.8)
50. S3: hh *hh I:: don't know it's just heavier.*

It is as if, having been asked for more than the explanation she has already offered, the student and the questioning encounter a bedrock of common sense, on which their "spade is turned" (Wittgenstein, 1958, sec. 217). There are many tried and true dichotomies that come into play in analyses of confrontations like these. Surface versus deep explanations and concrete versus abstract reasoning are among the most popular. What such distinctions obscure is the sense of entitlement, of claimed mastery, that her complaint ("it's just heavier") expresses. Where science claims its privileges, so can members claim theirs (see Bogen & Lynch, 1993).[22] The strongly claimed right to give, and have accepted, a commonplace account of a typical event is not necessarily a sign of a lack of imagination or curiosity, nor is it necessarily a sign of settling for an explanation that is less than adequate. For the demonstration in question, an explanation like "it's heavier" would serve perfectly well for a version of a sink-and-float demonstration presented to younger kids. Moreover, it articulates the demonstration in a familiar, sensible, and by no means erroneous way. It is not unscientific in the sense that scientists would be compelled in all work-related contexts

[22]This reminds us of a lovely exchange reported by one of Garfinkel's students, who pursued an exercise of persistently requesting clarifications of terms of talk in an ordinary conversation: "On Friday night my husband and I were watching television. My husband remarked that he was tired. I asked, 'How are you tired? Physically, mentally, or just bored?' "

(S) I don't know, I guess physically, mainly.
(E) You mean that your muscles ache or your bones?
(S) I guess so. Don't be so technical.
(After more watching)
(S) All these old movies have the same kind of old iron bedstead in them.
(E) What do you mean? Do you mean all old movies, or some of them, or just the ones you've seen?
(S) What's the matter with you? You know what I mean.
(E) I wish you would be more specific.
(S) You know what I mean! Drop dead! (Garfinkel, 1967, p. 43)

to avoid using such vernacular expressions like "it's heavier" instead of, say, "it has more mass."[23]

THE PRODUCTION OF INVISIBILITIES

In both cases, it seems the exhaustion of the students' explanations becomes a resource for the teacher to shift to a different phase of the demonstration. This shift is marked in both cases by mention of "things you can't see"—namely, molecules and atoms. With this turn in the demonstration's discourse, the students are released from the work of witnessing a material spectacle and return to the tasks of being competent classroom listeners. The science spectacle at the lab table goes into remission. It pales as the beakers of water become idle props to the teacher's talk about their invisible structure. No longer can the science be found there, vividly, for the seeing as promised from the outset.

In her question about the "very, very, very tiny" things that "you and I cannot see with our naked eye," the New Mexico teacher mentions that these had been "talked about before."

116.	T:	. . . There's something (.) that's very, very, very tiny, that you and
117.		I cannot see with our naked eye wthat we've talked about before.
118.		What is that- ( ) what are those things called.
119.		(2.0)
120.	S:	Molecules
121.	T:	[Mr. (Hoya). Molocules.

The student teacher in the Washington case raises the question tentatively:

52.	T:	Have you ever heard of (.) molecules?
		(0.4)
53.	( ):	Ye:ahh, (I've heard 'em)
54.	( ):	[(no::)
55.	T:	Atoms?
56.	T:	What di- Shhhh (1.6) What do the terms molecule and atom,
		what does that mean to you?
		(2.0)
57.	T:	Laura?
58.	S3:	hhhh (Cutting it about (.) something into bits) (0.5) (which is- so
		tiny you have to mark upon it jist to git-)
59.	( ):	[(hmm)

[23]For a contrary view, see Churchland (1979), who argued for a highly intellectualized version of human perception and action. Briefly summarized, his argument is as follows: (a) All knowledge is theoretical, (b) all perception is observational, (c) observation is theory-laden, (d) theories can be more or less adequate, and (e) scientific theories are the best we have available. Therefore, all knowledge and perception should be governed by scientific theories.

60. T: Everybody understand that? (0.4) Every *thing* in the world is made up of *such* small things (just) little bits, yeh can't even see them with yer own eyes.

In both cases, the lesson breaks out of its indexical relation to the materials of the demonstration. Especially in the New Mexico case, the explanation takes on a religious character, insofar as it invokes entities and relationships that the students can only accept on faith. This is not to dismiss all realist commitments to theoretical entities. Rather, it is to say that for kids in a third-grade classroom, molecules might as well be spirits, angels, or ghosts. An effort is made by the students in both cases to explain the demonstrated, consensually described phenomenon by means of molecular logic. In the New Mexico case, Billy provides the summary comparative description by building the relative spacing of the molecules into the account in a thoroughly vernacular way.

130. B: They got farther apart in each one. Tha molocules.
131. T: In which one.
132. (1.5)
133. B: This one, it was close ta'gether. This one is a little farther apart.
134. This one is tha farthest.
135. T: * kay * So- tells you that molocules are rather lazy (.) in things that
136. are (0.7) cold. In things that are cold.

The teacher does not mark this as incorrect, but instead adds a different vernacular account, "that molecules are rather lazy (.) in things that are (0.7) cold." This keys the issue of movement and moving energy as the teacher opens the closing of the lesson with an evidently familiar recitation, collaboratively finished by a chorus of student voices:

141. T: Aw'right. Exactly. hhHeat energy is moving energy, or energy in?
142. Ss: motion
143. T: Energy in motion. Now, (let's) go back to our desks . . .

In the Washington science lesson, the mention of molecules leads into another phase of activity, where the students are given paper and different-size seeds to represent the density of molecules in different materials. The students dutifully follow along with this modeling exercise, but in the end it is not clear what they have mastered. When asked by the teacher to summarize what they learned, the students show that they can use the word *density* in connection with *heavy* and that "molecules, can make a difference (an' stuff)."

64. A: (Well) we learned that um- alcohol is lighter than water?
65. C: (hih hih hih)
[

66. A: (which is::) *heavy*, the lesser d- uh density.
67. T: Goo:d. Anything else?
68. ( ): We learned that (   )
69. B: Well some (.) liquids are different than others an' *mo*lecules, can
70. make a difference (an' stuff).

This is not nothing. Indeed, it seems that the demonstration is largely a matter of shaping vocabularies and contexts of use.

Such molecular explanations, although perhaps appropriate to science lessons at an early grade, transform the immediate relevance of the demonstration materials. Although what was seen and said about the demonstration field was strongly guided and shaped by the teacher's interventions, it was also intersubjectively warranted by the visibly accountable spreading of dye in the one case and the differential sinking and floating in the other. With the passage into molecules and notwithstanding that the teacher in the New Mexico lesson relies on the students to come up with the term *molecules*, and to show that they recognize a slogan about heat energy, the lesson at this point is catechistical. The spade of discovery learning has been turned as well, and it leads us to wonder whether science lessons can be taught without resort to the opaque, magical authority of science. To do so would seem paradoxical. Because much of science has to do with phenomena that are invisible or theoretical, one can fairly ask how science could be taught without invoking facts as if from nowhere or at least nowhere to actual demonstration fields.[24]

(RE)SITUATING CLASSROOM LESSONS

Earlier we suggested that classroom lessons have an integrity and autonomy that is missed when an idealized conception of real science is used as an extrinsic standard of comparison. Without denying that versions of real science are programmatically incorporated into lesson plans and are used by educators for evaluative purposes, we have sought to avoid stipulating a *really real* version of science to stand in judgment of the *apparently real* versions promoted in and through classroom lessons. In light of this analysis, we can now substantiate how classroom science spectacles can be usefully understood as practical orders in their own right that are made of distinctive assemblages of equipment and practice and that produce developing organizations of competency.

[24]See Bjelic (1992) for a discussion and analysis of Goethe's morphological theorem and other natural sciences that are deeply embedded in phenomenal fields.

Orders in Their Own Right

Although it is always possible to think of classroom lessons as cold or inadequate representations of authentic practices performed outside the classroom, our strategy has been to treat them as practical accomplishments in real time. Although a third-grade lesson may exemplify a hilarious version of physics, assembling a classroom science demonstration is an activity in its own right and science is thematic to the assembly. As we have seen, the New Mexico and Washington lessons were alive with the work of disciplining witnesses and organizing common ways of seeing and saying, which emerged from, supplemented, challenged, and then replaced the accounts that the students were already prepared to give. That is to say, the classrooms were alive with local organizational practices that established the sensual presence and relevance of a science spectacle, populated by namable things, conducted along canonical lines, and explained by reference to nonvisible theoretical entities. This order-productive history is the work of these demonstrations, whose practical and thematic achievement is a lesson-in-science (the hyphens speak of the sense of an order in its own right, perhaps a site within a larger world of modern science places and things).

Assemblages of Equipment and Practice

The students and teachers made use of and concertedly developed ways of describing the equipment and materials, what they were doing with them, and how they were related or unrelated to science. Aside from how well or badly such vernacular descriptions exemplify professional science, they were comprehensible and comprehended well enough to achieve them by the performers and witnesses of the demonstrations. An immanent feature of the way equipment was deployed and characterized was that science was somehow at stake. This *somehow* was a members' production in and through a local complex of activities that teachers and students made happen (or not; recall Dr. Cavendish) in the classroom. Aside from the adequacy of any such production from the standpoint of a credentialled scientist, some version of science was made lively in the scene. The lessons were produced and recognized as lessons in, of, and as science.

Developing Organizations of Competency

Just as the grammatical and mathematical techniques taught to second graders are distinct from those taught to fourth graders, the physics taught at different grade levels differs systematically. Routinely, the difference has been conceived as formal matters of instructional objective and curriculum.

Yet these demonstrations also grow older with the students: The materials, characterizations, what counts as an explanation, and so on grow older and more sophisticated, not only as scientific matters, but as practical competencies and organizations of discourse, interrogation, joint action, and even cognition.[25] In other words, classroom physics is not a finite body of knowledge that gradually fills the students' brains as they become more educated. Nor is it a body of skills that child physicists learn on their way to becoming professional physicists. For the vast majority of students, such an eventuality is neither aimed for nor attained. For those who eventually join the scientific ranks, their professional competence has a deeply uncertain relationship to the cumulative products of primary school lessons.

Nevertheless, the lessons we examined do exhibit a teleological orientation to a progressive cultivation of a scientific way of seeing and speaking. This orientation is evident both in the progression of exercises from one grade to the next and in the teacher's efforts to correct the students' ordinarily adequate ways of explaining what they see in situ. It need not be viewed as a progression toward a professional goal in either case. At the least, it promotes an ordinary attunement to contexts of action and speaking in which the usual ways in which the students describe the things they see and account for their actions with them are repaired and scientifically upgraded. Another, not fully explicated, way of speaking—one that invokes a distant expertise and an invisible ontology—is introduced as the situationally adequate account of what the students are seeing. The classroom demonstrations promote an appreciation of a science that is accountably incomplete, insofar as explanations of the spectacle, although grounded genealogically in common ways of speaking of the things at hand, join an essentially remote ontology—a physics that, as far as its recipients are concerned, is metaphysical. More important, a properly situated understanding of this science would have to be gained before it all makes sense.

MOCK-UPS AND COMPLAINTS/CONTINUITIES

The compromised reality of classroom science has long been noted by curriculum designers who attempt to bring real science and discovery into the classroom. The fact that classroom learning is a mock-up or simulacrum that makes false provision for the instructed affairs continues to be a familiar theme in the education literature, embedded in proposals for its repair (Anderson & Roth, 1989; Brickhouse, 1990; Brown, Collins, & Duguid, 1989;

[25]The sink-and-float exercise described in this chapter is also taught to lower grade students with less stringent demands on their explanations of what they are seeing (E. Cavin, personal communication, November 1992).

Hawkins & Pea, 1987; Smith & Anderson, 1984). This fact is cited as a central problem or, alternatively, a central failing of science education and classroom education more generally. It animates a long history of calls for reform of teacher preparation, content knowledge, curriculum, or instruction as remedies for what is lacking in science education (viz., the genuine experience of scientific practice and discovery).

On reflection, however, the idea that 3rd graders (or 12th graders) could possibly learn (real) laws of physics by freely working with ordinary objects and materials in classrooms presumes what might be called a "residual inductivist epistemology of science"—a view that an adequate understanding of theoretical principles can be derived from empirical inspection. Although education researchers acknowledge that observation is not neutral (Brickhouse, 1990) and that theory is underdetermined by observation (Duschl, 1985; Hawkins & Pea, 1987), the tasks of teaching students and designing curricula often proceed with the expectation that it is possible, indeed, for students to discover for themselves the principles of a science.

An appreciation of the difficulties faced by designers of such discovery curricula can be gained by considering a study by Brickhouse (1992), which describes the development of a third-grade classroom lesson on light and shadows over several days. One phase of the lesson involves homework in which students are asked to report on where they find shadows at home. According to Brickhouse, the kids return the next day with all sorts of reports: multiple shadows, afterimages from staring into lights, and even ghosts.[26] The students' reports provide the teacher with a surfeit of idiosyncratic and relationally specific observations, which create initial difficulties for mobilizing the students to develop a consensus on a theory of light and shadows that is informed by physics.[27] Brickhouse concluded that "the out-of-school observations did not clarify scientific ideas, they muddied the water" (p. 52). She went on to argue that professional physics is constructed under highly artificial and controlled laboratory conditions; it is not designed to explain everyday experience and the data of everyday experience are comparatively messy and unpredictable. Thus, teachers are faced with a dilemma: concentrate dogmatically on formal physics (school physics) at the cost of losing the ability to extend its lessons to everyday experience,

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[26]Brickhouse (1992) variously characterized these reports as confused, bewildered, and lacking coherent explanation; indeed they are from the standpoint of a teacher's job of sorting out and relating them to a general framework of physical science. For our purposes, however, to speak of these reports of at-home observations this way gives away far too much to a general science way of framing the diverse collection of things kids were able to find. The unruliness of the world found in their kitchens and bedrooms is precisely the world that classroom demonstrations are designed to tame. To dismiss their reports from home is to already participate in the teacher's work of enframing the students' activities in a scientized way.

[27]Similar observations are made in a study by Amerine and Bilmes (1988).

or introduce everyday experience at the cost of swamping the physics lesson with the uncertainties of unruly experience and ideas enlivened by the plenitude of everyday spectacles.

Although Brickhouse's study provides rich documentary material about students' ability to order an unruly plenum of noticings about the world they inhabit, the two cases we describe here are not caught between separate worlds of classroom science (or formal scientific theory) and everyday action. Their lessons are everyday, situated productions. These classroom physics lessons provide access to a named science spectacle that the students are demonstrably incapable of producing on their own. That is, among the things the lesson demonstrates is that the kids' otherwise competent ways of describing what they see are marked as not quite sufficient for purposes of a scientific explanation. We are able to appreciate that the classroom is a social space in which students are introduced to a scientific way of speaking—a way of speaking that construes immediate social activities in terms of observations, reports, explanations, and theories, which reflexively inform what students see with an age-graded version of a physics vocabulary. This social space is not isolated from outside class experience. Rather, it draws on vocabularies and competencies that originate elsewhere and maintains a referential orientation to an outside class world. The classroom becomes a taming place in which the uncertain plenum of kids' witnessings and accounts is actively, collaboratively, and situationally managed and transformed to yield the science of their instruction.

If the possibility that students may discover physical relations for themselves cannot be decoupled from social organizations that are aimed at taming a recalcitrant world possessing a surplus of possible interrogations (e.g., interrogations and appropriations of the demonstrational spectacles whose disciplined use is required for the discoveries of the lesson in hand), it cannot be the case that a less directed presentation of demonstrational materials will naturally lead students to see the world with scientific eyes. Like pasta, the laws of science cannot be whipped up just any which way. Consequently, a solution to the problem of what's wrong with science education cannot be had by imagining that we can replace a demonstrational mock-up's false provisions with a more realistic or authentic practice. Alternatively, real (professional) science would be no less doomed to failure (or nonexistence) if we were to insist that its demonstration and communication of facts be stripped of all elements of simulation, dogmatism, and authority. Thus, the repair of the mock-up appears to be a hopeless task; we might be better advised to repair our understanding of the production of science phenomena instead. Such a move would relieve us of any impatience with the local and serious achievements of teachers and students when children are led to find, see, and hear an orderly and occasionally visible spectacle of science.

CONCLUSION

At the beginning of this chapter, we promised to address the following question: What does it mean to act and speak scientifically? We did not answer the question. Instead, and if this study has succeeded, we have shown that the question betrays a certain naivety. Thus, we shifted to a somewhat different and, from our point of view, more useful question: How is science relevanced in local scenes? Rather than supposing that classroom science lessons present students with a body of knowledge called *science* and that the students either succeed or fail to surpass their commonsense understandings of the world in which they live, the latter question frames a less global, less cognitivist picture of science and knowledge. Our analysis suggests that no general, formal, or programmatic confrontation between scientific and commonsense knowledge ever quite takes place. Instead, a series of situated actions unfolds and a great deal of ordinary discursive work is accomplished to set up occasional confrontations between students' ways of seeing/speaking and scientific accounts that variously supplement, respecify, correct, or certify what the students are already prepared to say. Although science is discursively relevant, it does not manifest as a discretely bounded body of knowledge separate from common sense.

The promise of science demonstrations is to exhibit witnessable science for nonscientists. However, the videotapes make clear that physics is not a monological packet of knowledge held by an expert community and imparted from teacher to student. Instead, in both cases, the demonstrations unfold progressively as part of collectively produced activities. Teachers' instructions on what to see and how to talk are situated in a carefully paced production; a spectacle in which indexical expressions mark and become sensible in terms of the phases and sites of an orchestrated and collectively witnessed scene. The collective witnessing is done through the use of words, but it is not done in so many words. The teacher's instructions are situated within a visible enactment that is designed to enable the audience to discover what the teacher does not give away in so many words. Finally, the lesson relies on the students' commonsense physics—their familiarity with commonplace objects and what those objects can do—both as a resource and an unfinished competency that needs instruction.

To an extent, we have employed an analytic vocabulary congruent with currently popular theories of situated cognition, knowledge, and learning (Brown, Collins, & Duguid, 1989; Lave, 1988; Lave & Wenger, 1991). These formulations offer a tandem critique of classroom learning and epistemologies: Classroom lessons both routinely misrepresent the practices they speak of and instruct (the actual practices of writers, mathematicians, scientists, etc.). They do so by an unwarranted and deforming abstraction of learning from the ordinary situations in which competent social members reckon their worlds. By these analyses, although lessons are designed to instruct competencies that are fundamental to a range of practical activities, they are nonetheless and hopelessly divorced from those activities. Unrealistic and peculiar contingencies operating in the classroom inhibit or distort the lesson's representation of authentic practice, regardless of whether authenticity is identified with professional expertise or the tacit skills of just plain folks. Part of the radical appeal of such criticisms turns on the insistence that mere adjustments of curricula are not enough to repair the essential inauthenticity that makes up classroom experience.

Our conclusion differs in at least one important respect. Rather than juxtaposing a situatedness originating from outside the school to a putatively desituated field of math and science taught inside the school, we have insisted that there is no great divide between the academic and ordinary settings, but only different articulations of no less deeply situated knowledges. It is far from our purpose to argue that classroom math and science lessons truly represent the skills that either professional practitioners or just plain folks cultivate in situations of their daily life and practice. Instead, we question the presumption that they could. More than that, we recommend not a complaint about the character of classroom lessons as mock-ups of the affairs taught, but a program of analysis that brings into view the serious contingencies and achievements of classroom teaching as mock-ups (see Macbeth, 1994, for an analysis of the essential instructional fiction of a fifth-grade grammar lesson).

The two cases discussed earlier provide ample evidence of what Garfinkel and Sacks (1970) observed about mock-ups: that they specifically and deliberately make false provision for their objects of reference. Using the example of a plastic model of an engine, Garfinkel and Sacks pointed out that the features of the mock-up that make it a false representation facilitate its immediate use as a model. Such false features allow the plastic engine to be purchased at low cost; to be assembled, disassembled, handled by novices; and inspected in a low-risk way in an instructional situation remote from the machine shop. In these several ways and others, the mock-up achieves great instructional efficiencies; a teachable curriculum in classroom time. The difference between the mock-up and what it represents does not, then, make for unreality. Rather, it makes for a real and intelligible mock-up to be assembled and used as such. The mock-up is not just an unreal version of an actual thing. It is a thing in and of itself fashioned for use in actual situations of use. It may be that the prior demonstrations are poor representations of physicists' and chemists' understandings of specific gravity and molecular diffusion. Even better, they may do little justice to more ordinary competencies with handling liquids and identifying objects and processes that children otherwise pick up outside the school. In our view, these features point to the distinctive situations of inquiry that constitute and animate the classroom spectacles we examined. They reference constitutive phenomena, rather than unwelcome riders, to the work of classroom instruction within a universalized public schooling system.

Thus, the general theme of *situatedness* is not a very helpful evaluative criterion for distinguishing between activities within and beyond the school. Classroom math and science exercises are thoroughly situated regardless of whether they represent the modes of reckoning practiced in situ by grocery shoppers, butchers, tailors, or professional mathematicians. Assuming, then, that the social world is not parsed into provinces of greater or lesser degrees of situatedness, a commitment to study situated cognition would recommend the study of the deep structures of sociability and joint construction that inhabit every scene. In brief, everything one might want to ascribe to structures of authentic practice—the essential indexicality of natural language, the intertwining of self and other in conjoint activities, and the tacit modes of enculturation—can be found in the classroom as well as in apprenticeship situations and other nonschool activities.[28] The task that follows from the insight is to treat such practices and occasions not as lesser versions of some other more primordial competence, but as enactments in their own right. Rather than arguing that classroom physics lessons provide inauthentic representations of actual science, we conclude that such lessons thematically situate science (whatever might be meant by *science* as a locally produced, witnessable, and accountable matter) in a temporally unfolding and interactionally organized scene of practices. That they do is, if anything, a point of deep continuity across scientific occasions.

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[28]We are perhaps belaboring this point, but it seems commonly ignored, forgotten, or dismissed without argument by those who, in our opinion, should take it to heart. See Macbeth (1996) for a more elaborate criticism along these lines, focusing on the arguments by Brown et al. (1989).

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CHAPTER

12

Making Mathematics and Making Pasta: From Cookbook Procedures to Really Cooking

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This chapter owes its existence, in multiple ways, to Jim Greeno. Its proximate cause is the present conference on intellectual practices. This meeting is only the latest in a long series of conversations and events in which Jim and I have explored the notion of what it is to understand and do mathematics, science, . . . , or anything else, for that matter. The discussions have been far reaching, as seems fitting when one's task is to understand the ways the mind works. Here, motivated by some of the not-worked-out suggestions in a recent paper of Jim's, I am going to stretch even farther than usual. These efforts should be understood as an exercise in the spirit of a tried-and-true problem-solving heuristic—consider extreme cases.

Part of the background for this attempt is as follows. Through the years, Leon Henkin has organized a mathematics education study group that gets together intermittently to discuss papers of interest. The group met this past summer. I volunteered to lead a discussion of Jim's article (Greeno, 1991) on number sense, having wanted to give it a careful reading for some time. That article is speculative, looking in various directions for ways to conceptualize competence. As one would expect, the notion of situated cognition was prominent in the article: A major hypothesis being advanced was that being good at an intellectual practice, such as doing mathematics, is, in ways yet to be elaborated, akin to being accomplished at activities such as cooking. Thus, for example, in one section, one finds the following:

> Learning the domain, in this view [the "environmental view"] is analogous to learning to live in an environment: learning your way around, learning what

> resources are available, and learning how to use those resources in conducting your activities productively and enjoyably. . . . In [pursuing] the metaphor of an environment such as a kitchen or a workshop, this section is about knowing how to make things with materials that are in the environment. (pp. 175–177)

As it happens, Jim's metaphor places two of my passions—mathematics and food—in close juxtaposition. The day that I was preparing Jim's article for discussion, I went to the market with some vague ideas about what I was going to make for dinner—a pasta concoction of some sort, most likely using goat cheese as an ingredient—and I had come home to invent a new (at least for me) goat cheese ravioli dish. Thinking about the issues raised in Jim's article, I decided to explore the parallels. Are there ways in which my understanding of cooking (and, specifically, of making pasta) are akin to my understanding of mathematics? Are there ways in which the learning and creative processes in both are akin? If the parallels exist, do they merely represent facile analogies or is there more than superficial substance to them? If there is substance, what are the implications? This chapter is the result of the resulting ruminations. If nothing else, the reader should emerge from it with the recipes for two pretty good pasta dishes.

PARALLEL I: THE DEVELOPMENT OF SKILL, AFFORDANCES

It is no accident that a great deal of elementary mathematics is referred to as *cookbook mathematics*—even supposedly advanced mathematics such as max–min problems in calculus, where one follows algorithmic or essentially algorithmic procedures to solve problems. In school mathematics, the analogy is even more direct: One learns step-by-step procedures for basic algorithms like base-10 subtraction. Following the procedures, like following a simple recipe, guarantees results.[1]

Over time, cooks forsake the recipes—or at least they forsake following them slavishly—and they come to work with the materials themselves. I think there is a meaningful mathematical analogy. Let me start with the pasta and then turn to the mathematics. In the case of making pasta, my own history is a case study of "learning to read the properties of the materials at hand" or, in current cognitive jargon, learning to perceive the affordances offered by the materials.

I started making fresh pasta about 20 years ago and my early experiences still reside vividly in memory. Here, from memory, is the distilled version of the recipe I followed back then:

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[1]Well, maybe—there is more certainty in mathematics recipes than in cooking, as anyone who has tried baking bread, for example, by following a recipe will tell you.

Mix together:

1½ cups flour
2 eggs
1 tablespoon olive oil
1 teaspoon salt

Knead the dough for 5–10 minutes until it is smooth and elastic. Roll out the dough with a rolling pin and slice to the desired width.

The first time I made fresh noodles at home, I followed the recipe to the letter. I made the dough, kneaded it by hand for 10 to 15 minutes, and then—no matter how hard I worked with the rolling pin—I could not roll it thinner than (about) ⅛ inch. The resulting pasta was tasty, but more than a bit on the chewy side. Making it was a lot of work. I did a little better the second time, but it took a long time to develop a feel for the dough.

A few years later, before they were available in the United States, I found and lugged home a pasta machine from Italy. Some of the dough kneading was then done by the machine—as the distance between the rollers was narrowed for successive passes of the pasta dough, some kneading resulted—but there was still the question of having the proportions right for the dough before it was put through the rollers in the first place. This was done by feel. The previous recipe gives an approximate start, but I had learned to start with a relatively moist dough and add flour bits at a time to keep it from getting too thick and unwieldy. Even so, it took many turns through the machine—first on the widest setting and progressively through more and more narrow settings—until the desired thinness and degree of kneading were reached.

A few years later, I bought my first food processor. Since then I have learned to let the two machines, in combination, do my work for me. As suggested earlier, I no longer follow a recipe to the letter. Interestingly, the character of the feedback from the dough has changed: The signals are now visual rather than tactile. Here is what I do.

I start by dumping a bunch of flour in the bowl of the food processor. The flour is not measured when I do it, although for purposes of replication I can tell you that there is between 1 and 1¼ cups of flour in the bowl. The important thing is that I put in less than I will ultimately use; I add the rest in increments as I need it. To the insufficient amount of flour, I add the rest of the ingredients: the eggs, a dollop of olive oil, and some salt. The oil and salt are measured approximately. Over time one gets to know (a) how to come close with approximate measures—watch any TV chef!—and (b) that such approximations will do just fine in the final product. I then turn on the food processor.

What results after 5 to 10 seconds is a large, gooey ball of dough. I add some flour, maybe ¼ cup or so. If I have added enough, the big ball of dough breaks up into pellets after the food processor is turned on. These pellets are irregularly shaped, but roughly spherical and somewhere between ⅛ and ¼ inch in diameter. As the food processor kneads the dough, these tend to congeal into a larger mass; I have to add more flour, but now in smaller increments. Each time I add flour, the pellets in the bowl of the processor break into smaller pellets; then, as the dough is kneaded, they congeal. I have got it right when, soon after I turn the machine on, the pellets are about 1⁄16 of an inch in diameter, maybe a little less.[2] I leave the processor on for about a minute and something interesting happens: The pellets remain about the same size, but they start adhering to each other. I start seeing wave forms in the bowl of the processor. The waves—the macrostructure of the dough—move slowly, although the blade of the processor is moving rapidly. The waves are composed of lots and lots of little pellets that have adhered to each other.

The dough is now ready. I take it out of the bowl and squeeze it with my hand to make a flattened ball. As I do, the pellets vanish and become part of a sheet of thick dough. I coat this flattened ball, which is extremely pliable, with flour and run it through the pasta machine—once through the widest setting, just to make it a sheet of dough, and then (after coating with flour once more) through the setting I want. The dough is so pliable and flexible that I do not even have to anchor the pasta machine to the counter. After these two passes through the pasta machine, it is ready to slice (a one-step operation thanks to the machine's cutting blade) and cook.

Note the changes. I no longer follow a recipe, although I have clearly internalized the recipe's main structure. More important, I have learned the features of the dough. I have learned to read its properties or perceive the affordances it offers to the point where the visual cues the dough provides tell me how to adjust the quantities of the major ingredients and when the dough is ready to go through the rollers of the pasta machine in a way that requires minimal effort on my part. With my experience has come not only skill, but a change in my relationship to the dough. Also note that I was never taught about these properties. (Although I do not doubt that many others have discovered the same things, I am not aware of any other description of the pellet method for making pasta dough in the food processor.)

Now could there possibly be a mathematical analogue? On the basis of some empirical evidence, I argue that the answer is a clear "yes." The

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[2]A few comments about the process. First, the flour is put in before the eggs for purely pragmatic reasons: The bottom of the food processor gets less gooey that way. Second, whether you have too little or too much flour at the start is of no real importance. If there's too much flour, the pellets are tiny and do not adhere to each other when pressed. The solution is just to add more liquid until the dough pellets are the right size and consistency. This process is one of balance by successive approximation, and excess on either end (flour or liquid) at the start of the process is just fine.

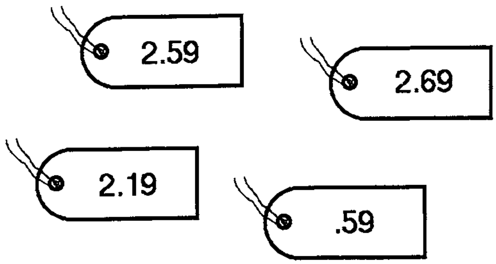

FIG. 12.1. The price tags attached to four items you would like to purchase. Can you make the purchase if you have $7.00 in cash?

domain from which I take my example is number sense (in specific reaction to Jim's article); the illustrative task is adapted from work by Lobato (1991).

Imagine that you have gone shopping. In the store, you picked up four items that you want to purchase. I am about to show you (Fig. 12.1) the price tags from those four items.[3] The question: You have $7.00 in cash. Do you have enough cash to purchase all four items? Please work the problem before reading further.

I have now posed the task to a variety of groups. As might be expected, people exhibit a variety of approaches to the problem. Here are four.

> *Method 1.* In some sense, the most straightforward way to solve the problem is to perform the addition: $2.59 + $2.19 + $2.69 + $.59 = $8.06, so $7.00 is clearly not enough.
>
> *Method 2.* Another way, also relying on addition, is to proceed by adding one item at a time, noting subtotals and stopping if the subtotal exceeds $7.00. This procedure has the potential to be most efficient if one starts with the more expensive items. Thus: $2.69 + $2.59 = $5.28; then $5.28 + $2.19 . . . exceeds $7.00 (the problem solver may note here that, because of the lead digits, there is no need to do the computation) and the problem is done.
>
> *Method 3.* One can start with a coarse approximation and then make adjustments. In this case, three of the prices are of the form $2.XX. Hence, the total exceeds $6.00, and a quick check shows that the small change is in excess of $1.00.
>
> *Method 4.* Yet another way is to note that two of the items each cost slightly more than $2.50, so together they cost more than $5.00. An additional $2.19 brings the total to more than $7.00, so you do not have enough.

Lobato's (1991) work indicated that, in general, the students with whom she worked are reluctant to make estimates; those students were, in essence, limited to the cookbook mathematical procedures they had learned and

[3]When Joanne had school children do the task, she provided them with the items and real price tags. For this audience, I have converted the task to more of a *gedanken* experiment.

tended to favor Method 1. (Indeed, students are taught estimation as rounding off—itself a cookbook procedure.) In contrast, none of the mathematically sophisticated adults to whom I have posed the problem (e.g., members of the mathematics education study group) has simply added the figures. Their methods vary, but the preponderance of solutions are in essence like Methods 3 and 4.

I do not think it is stretching to claim there are some significant parallels to the pasta example. Note first that Methods 3 and 4 are not taught in standard instruction (nor, as far as I know, is Method 2). Each of the mathematically sophisticated adults had, in essence, invented those procedures for him or herself. The invention came as a result of experience with the domain. (Such invention is, most likely, quite common: I am reminded of Resnick's finding that many children, when learning addition of integers, spontaneously invent "counting on from larger" as a more efficient way to add two whole numbers than "counting on from the first given number," the procedure they had been taught.) Hence, real expertise, even in domains as simple as that of whole number arithmetic, constitutes a progression from reliance on instructed procedures to the development of personal, flexible, and idiosyncratic methods. It also involves the development of and access to multiple methods, as Dowker's (1992) work on estimation documented. Those who are really good at a task are not simply mechanically good: They do not do the same thing over and over the same way, but have access to a range of methods they can use and may not distinguish among those methods unless the context calls for it.

Second and equally important, I think a strong sense can be made for affordances (i.e., that the numerical adepts have learned to perceive the properties of the numbers in ways similar to the ways that I have learned to perceive the properties of pasta dough). In this case, Method 4 is particularly telling. For a number of individuals, the $2.59 and $2.69 price tags jumped out as numbers that could easily be combined to yield a result close to but larger than $5.00. That is, features of the materials at hand may have alerted the (knowledgeable) problem solvers to ways of proceeding. This perception of features—or, more precisely, the fact that the features become salient and suggest a particular utilization for the task at hand—is, quite likely, task- and context-dependent. If asked to compute the precise cost of the four items, the person who spontaneously jumped to Method 4 in the approximation problem might not even observe that the two most costly items of the set {$2.59, $2.19, $2.69, $.59} add up to slightly more than $5.00. To hammer the point home, I might not think of any of a large number of properties of the ingredients in the pasta dough (e.g., the oil or eggs) because the properties are not relevant for the task at hand. The properties become salient when (a) I know about them and their utility, and (b) the context invites their use.

PARALLEL 2: THE ROLE OF EXAMPLES

I begin this section with some mathematical examples and then turn to the obvious culinary analogues. Here is a problem I have asked numerous mathematicians in recent weeks:

> Is there a continuous non-negative function f(x) defined on the interval [0,1] with the property that its maximum value is greater than 2,000,000 and that its integral [the area under f(x) between x = 0 and x = 1] is less than .03? If so, give an example. If not, explain why not.

The uniform response has been an almost instantaneous "yes," followed by either a quick sketch (sometimes done by moving one's finger through the air) or a statement like, "Sure, it's like a delta function" or "take a peaky thing and make sure it's high enough and compressed enough to work." Figure 12.2 shows a generic example.

Let R be the region illustrated in Fig. 12.2. (The region sits flush atop the interval [0,1] and is not drawn to scale; it is much higher and much thinner than illustrated.) If its height H is set at some value greater than 2,000,000 and the width of the peaky part, W, is less than .03/H, then R has the desired properties.

This particular class of examples—steep objects with a flat base defined over a closed interval, the simplest member of which consists of a tall, thin isosceles triangle glued atop the interval—is well known and is in every mathematician's repertoire. The boundaries of the class are flexible: When the situation calls for it, generic exemplars can be made to undergo non-trivial modifications.

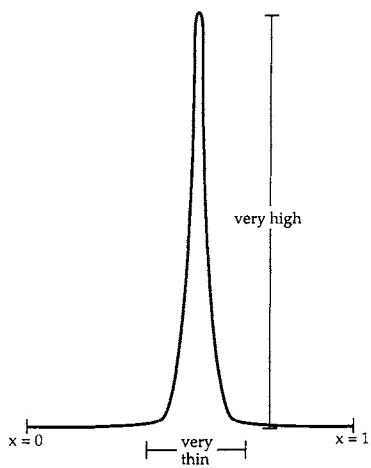

FIG. 12.2. A generic sketch of a function whose maximum value can be made arbitrarily large but (if the base of the peaked region is made correspondingly tiny) whose area can be made arbitrarily small.

The following description is taken from Rissland (1978), whose studies of the roles of examples in understanding mathematics and detailed investigations of constrained example generation (CEG) are both compelling in their own right and have strong culinary parallels to be explored here. A task that Rissland had students explore was of the same character as the generic example presented in Fig. 12.2 (and had essentially the same solution), but some of the responses pointed to potentially more constrained and complicated solutions. Rissland (1985) posed a question and described a subject's response as follows:

> The richness and complexity of the CEG process can be seen here in a synopsis of a CEG problem taken from the domain of elementary function theory:
>
> > Give an example of a continuous, non-negative function, defined on all the real numbers, such that it has the value 1,000 at the point x = 1 and that the area under the curve is less than 1/1000.
>
> Most protocols for this question begin with the subject selecting a function (usually, a familiar reference example function) and then modifying it to bring it into agreement with the specifications of the problem. There are several clusters of responses according to the initial function selected and the stream of the modifications pursued. A typical protocol goes as follows: . . .
>
> > Start with the function for a "normal distribution." Move it over to the right so that it is centered over x = 1. Now make it "skinny" by squeezing in the sides and stretching the top so that it hits the point (1,1000).
> >
> > I can make the area as small as I please by squeezing the sides and feathering off the sides. But to demonstrate that the area is indeed less than 1/1000, I'll have to do an integration, which is going to be a bother.
> >
> > Hmmm. My candidate function is smoother than it need be: the problem asked only for continuity and not differentiability. So let me relax my example to be a "hat" function because I know how to find the areas of triangles. That is, make my function be a function with apex at (1,1000) and with steeply sloping sides down to the x-axis a little bit on either side of x = 1, and 0 outside and to the right and the left. (This is OK because you only asked for non-negative.) (p. 164)

In the final solution produced by Rissland's subject, we see that the standard peaked triangle example has been invoked and slightly modified, subject to the constraint that the function have a particular value (1,000) at the value x = 1. Once the subject noted that the function need not be positive, only non-negative, and it need not be differentiable, only continuous, the more complicated initial choice of function based on the normal distribution was rejected and a simpler alternative used.

Imagine that Rissland had indeed asked for a differentiable function whose values are all positive. One could easily imagine the following kind of solution, which is a condensed version of the one I produced:

> OK, it's one of those "large maximum, small area" problems, so something like a steep triangle would ordinarily do it. But this function has to be differentiable, and it has to be positive. So I've got to use something like
>
> $$F(x) = e^{-x^2}$$
>
> (which is positive for all x but does have finite area underneath it) to get the positive differentiable part, and then scrunch it up like the triangle. F(x) has a maximum value of 1 at x = 0, so I can get a value of 1000 if I multiply F(x) by 1000. Of course, I've now multiplied the area under F(x)—which I know to be $\sqrt{\pi}$—by 1000, and I'll have to compensate for that. A change of variable should narrow the base of the function, so I should be looking at 1000F(kx) for some value of k. Let's see. Now for any appropriately integrable F(x) we have
>
> $$\int F(kx)\,dx = (1/k)\int F(x)\,dx.$$
>
> Thus replacing x by kx divides the area by k. So, if
>
> $$G(x) = 1000\, e^{-[(1001)(1000\sqrt{\pi})x]^2}$$
>
> G(x) is differentiable, positive, and encloses an area of 1/1001. It has all the desired properties but one. The only problem is that it reaches the value of 1000 at x = 0 instead of x = 1. I'll slide it over by a translation, which doesn't affect the area underneath the curve. The function that meets the constraints is
>
> $$H(x) = 1000\, e^{-[(1001)(1000\sqrt{\pi})(x-1)]^2}$$
>
> and I'm done.

I do not offer a detailed exegesis of this solution (e.g., each of the comments about changes of variables could be teased out in finer detail), but I make some coarse-grained comments about it. First, note that the solution borrows from two known classes of examples: scrunchable functions that meet the criteria of having large maximum values and enclosing small areas, and the class of exponentials that meets the criteria of smoothness, being positive for all x, and enclosing finite areas. Those provide the ingredients of a solution and the solution resulted from their artful combination—a combination that is respectful of the properties of the ingredients and adapted and applied to the second set of ingredients a procedure customarily used on the first. Although the objects and processes described here are somewhat familiar, there was legitimate invention in their combination.

Now to the first pasta dish. The main ingredients are the ravioli (a pasta shell that I had determined would have a goat cheese filling) and the sauce.

The cheese filling was to be light—a little goat cheese can go a long way—but I had decided that the goat cheese would be the main flavor of the dish. Hence, the sauce needed to be light and to serve as a foil for the filling: Heavy meat sauces or sauces as intense as a classic pesto would be inappropriate because they would overwhelm the delicate cheese flavor. Pesto variants were in the running for a while. I thought initially of having basil in the filling and using a basil-based cream sauce, but that did not seem to offer enough contrast—there would be too much of the same in sauce and filling. I also considered something like Miller's (1989) poblano pesto (find it and try it—it's wonderful!), whose major ingredients are poblano peppers and cilantro, but that too was too intense. To complement the filling, then, I decided to make a reduced cream sauce. What would the base flavor of the sauce be? Two of the ingredients from and the preparation methods for the poblano pesto suggested an idea: I could use a roasted sweet red pepper as the base flavor, adding roasted pine nuts to round out the flavor and offer a contrast in texture. (See the recipe in Appendix A for details on preparation.) To ensure that the cream sauce complemented the cheese filling, I would add a small amount of the filling to the reduced cream. This would produce a faint echo of the taste of the filling in the taste of the sauce and would make the dish cohere. The rest, as they say, is in the details.

Once again, I do not think it is stretching to say that the parallels between the mathematical and culinary examples given in this section are more than superficial. Solving each problem depends on the use of what Rissland called *reference* or *model examples*—standard and ubiquitous or general and paradigmatic cases. Those who know function theory know about the tall, thin functions illustrated in Fig. 12.2 and about positive, differentiable functions that enclose finite area; the solution depends, in fundamental ways, on accessing reliable base knowledge. It also called for (minor) creative leaps, applying methods from the first class to objects from the second.

Similarly, the ravioli dish depends on generic examples and procedures. For those who know how to make ravioli, the basic preparation in this recipe (e.g., making the pasta dough and filling and sealing the ravioli) is routine; the only way in which that part of the recipe differs from any other ravioli dish is in the specifics of the filling. For the sauce, we have a direct parallel to the earlier mathematical case: Objects and methods from two generic categories are combined in nonstandard ways.

I have, of course, swept much detail under the rug in this discussion, but I think the detail, if examined, is supportive. In discussing the preparation of the ravioli, for example, I ignored the preparation of the pasta dough. Likewise, I ignored the amount of practice it takes to get to the point where one can fill and seal ravioli shells without difficulty. These are skills that look easy and are learned hard, as the discussion in the first section suggests. I think they are analogous to the web of skills that supported the argument about scrunching the base of the exponential by using F(kx) instead of F(x) given in the prior mathematical example. There, too, a bit of thinking and a few scrawls on paper seemed to provide the information I needed. It may have looked easy, but if it did it is because a lot of prior struggle went into obtaining the background that made it look so.

More serious, perhaps, is the question of how general the argument given here may be. I have drawn parallels between two examples, but how typical are those examples and how widely does the idea apply? Let us return to Rissland's (1985) more general discussion of the ways that mathematicians use examples as part of their understanding.[4] She argued as follows:

> When one considers the different effects and uses examples can have with respect to teaching and learning, one can distinguish different epistemological classes. (There are similar analyses for results and concepts.) It is important to recognize that not all examples serve the same function. One can develop a taxonomy: . . .
>
> *Start-up examples* are simple cases that are easy to understand and explain. They are particularly useful when one is learning or explaining a domain for the first time. . . . A good start-up example is often "projective" in the sense that it is indicative of the general case and that what one learns about it can be "lifted" to more complex examples.
>
> *Reference examples* . . . are "textbook cases" which are widely accplicable throughout a domain and thus provide a common point of reference. . . .
>
> *Counter examples* are examples that refute or limit. . . .
>
> *Model examples* are examples that are paradigmatic and generic. They suggest and summarize expectations and default assumptions about the general case. . . .
>
> *Anomalous examples* are ones that do not seem to fit into one's knowledge of the domain, and yet they seem important. They are "funny" cases that nag at one's understanding. Sometimes resolving where they fit leads to a new level of understanding. (p. 154)

I do not pursue the parallels between mathematics and cooking here, but I note that there are many; thinking about them has been a source of both amusement and pleasure. The reader might enjoy thinking about culinary examples in each of Rissland's categories.

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[4]The productive use of examples was one of three major categories of understanding characterized by Rissland (1978). The three categories were: knowledge of examples, knowledge of results, and knowledge of concepts.

PARALLEL 3: MEMORY AND REPRESENTATION

If you spend a lot of time in the kitchen, as I do, you wind up inventing a lot of recipes and forgetting most of them, either because they were eminently forgettable or because the details of a particularly good dish, fresh at the moment of creation, have faded with time. However, there are some dishes you wish to remember and you try to do so. People who are more organized than I am may think to use pencil and paper, but I tend to be lazy. What I find is that I remember important parts of the recipe—things that allow me to reconstruct the rest. The most intriguing case for me is that of a second pasta dish—spaghetti with prawns and chile pesto. What makes it interesting to me is that I had completely forgotten the dish, although it had been absolutely terrific (and it is easier than the goat cheese ravioli). When my wife suggested I make "that shrimp and pasta dish I liked," I drew a complete blank. Then Jane reminded me of the key part: "It's the one where you dry-fried the shrimp, so the dish wasn't greasy like your shrimp dishes tend to be." From that comment alone, I was able to recreate it (see Appendix B). The information about the way to cook the shrimp was generative: From that alone, I could reconstruct the rest of the recipe. Now that is all I need to remember to make the dish.

If you spend a lot of time doing mathematics, as I do, you wind up solving a lot of problems and forgetting most of the solutions, either because they were eminently forgettable or because the details of a particularly good idea, fresh at the moment of creation, have faded with time. There are some problems or solutions that you wish to remember and you try to do so. People who are more organized than I may think to use pencil and paper, but I tend to be lazy. What I find is that I remember important parts of the solution—things that allow me to reconstruct the rest. Here is a case in point.

A polygon is said to tile the plane if you can lay down copies of it, side by side (i.e., nonoverlapping), so that they cover an infinitely long and wide planar surface without any gaps. The only regular polygons that tile the plane are equilateral triangles, squares, and hexagons. If you do not require the figures to be regular, there is more flexibility: rectangles and parallelograms tile the plane, as do deformed versions of them—see, for example, Fig. 12.3. (Such tilings can be interesting and aesthetic: One sees them as a main feature of Escher's graphics, for example.)

As Senechal (1990) observed, a person playing with tilings can "discover some surprising things, such as the fact that any quadrilateral, even one that is not convex, will tile the plane" (p. 149). The reader unfamiliar with this result may wish to stop reading here for a moment and think about it. I do not want to spoil the pleasure of discovery by prematurely spilling the beans.

Fortunately for me, one had to turn the page to see the diagram with Senechal's solution; I was able to put the book down and discover it for

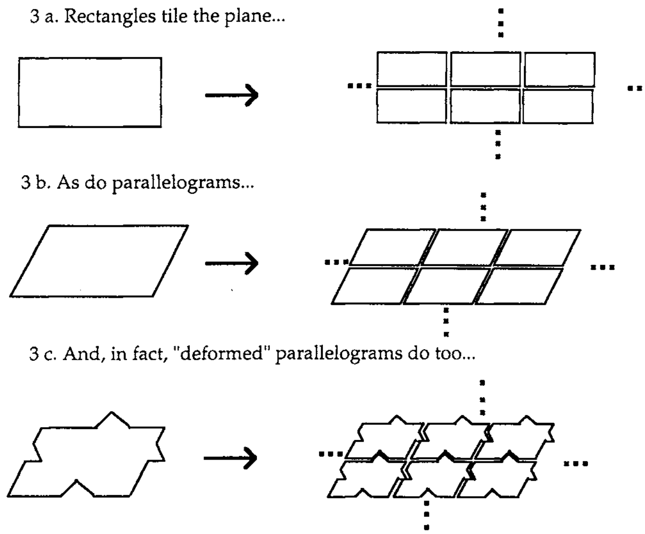

FIG. 12.3. Simple planar tilings.

myself. The solution can be found in Appendix C. The result *is* memorable. What I find of interest here is the way that I, and others with whom I have discussed the problem, have encapsulated the result once the discovery has been made: You fiddle with four copies of the quadrilateral until they fit together to make a deformed parallelogram. That figure tiles the plane.

This encapsulation is the precise analogue of the culinary encapsulation given previously. In and of itself it is not sufficient, but it has the key to a solution that allows me, with some trial and error, to generate the rest of what I need. In the culinary case, I rely on certain constraints imposed by the materials: They have to be treated in certain ways to work out right. These constraints narrow the problem space so they are essentially generative. In the mathematical case, there are similar constraints. In a complete tiling, the sum of the angles must be 360° where corners join together and the sum of the interior angles of the quadrilateral happens to be 360°. These two pieces of information narrow the search space to the point where a small amount of trial and error generates a solution (see Appendix C for detail).

I could go on, but I hope to have made the point that once one proceeds to the stage of doing mathematics and doing cooking (as opposed to following mechanical procedures in each), there are strong parallels in the way one draws on memory for purposes of functionality. Of course, issues of memory give rise to issues of representation. If, as Greeno (1991) suggested and most of the cognitive community believes, we rely on mental models for computation and some of the elements in those mental models have the status of concrete objects—conceptual entities—we run once again into the issue of affordances. As indicated in the discussion of Parallel 1, I think a strong case can be made that numerical adepts perceive and are receptive to properties in numbers in the same ways that culinary adepts perceive and are receptive to properties in the objects with which they work. Moreover, awareness of those perceptions is situation-specific: Some properties of numbers, salient in some contexts, will go unnoticed or unremarked in others; likewise for some features of a pasta dough in various contexts of preparation.

DISCUSSION

As the reader can surely tell, it has been great fun engaging in a compare and contrast of two of my greatest pleasures.[5] I hope to have indicated that the parallels between working in mathematics and in the kitchen are more than superficial and that those parallels and their implications are worth considering. Let me now turn to some of the implications.

The main point, I think, is that we need to reconceptualize what it means to do mathematics and, in consequence, how one might best learn it. I have suggested that the parallels are strong along multiple dimensions: what it means to be competent (Parallel 1), how one's understanding of the domain is organized (Parallel 2), and how one stores, retrieves, and operates on information in the context of solving real problems (Parallels 3 and 1). If the competencies in the domains are alike, the classic learning trajectories in them certainly are not. Save for the small but increasing number of mathematics classes taught "in the spirit of reform" (the spirit amply represented at this conference), mathematics as encountered by most students consists almost exclusively of dull-and-dry cookbook mathematics. It lacks a sense of purpose; it lacks a spirit of sense-making (see, e.g., Schoenfeld, 1990); it lacks meaningful feedback (let us not forget that cooks get to taste what they produce!; also that the help they get along the way is usually tempered with contextually meaningful suggestions as to *why* one does what one does); and it lacks the social, collaborative dimension to cooking that is so enjoyable, supportive, and ultimately productive. We might do well to ponder the parallels and see how instruction might be altered accordingly.

There are no absolutes here, but there are issues of balance. I am not suggesting that we all "get in the mathematical kitchen and play around" as a means of instruction—that would be the modern, situated cognition version of the standard caricature of collaborative discovery learning. As one

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[5] I am hardly alone in enjoying mathematics, cognition, and pasta. Cathy Kessel pointed out to me, in fact, that I am not the first to blend them in print (see, e.g., Barwise & Feferman, 1985).

who (and who knows why!) can give you the values of e and π to 15 decimal places, and can do elementary mathematics with sufficient fluency that I pay no attention to it (thus having energy and attention to devote to harder things), I am not about to demean the importance of memory or of basic skills. Nor am I about to demean the importance of learning to follow procedures. As I noted in Parallel 1, I started making fresh pasta by following cookbooks. The process did not go as smoothly as it might have with a live instructor, but it worked. More generally, having basic procedures down cold and having descriptions of others accessible (both for instruction and reference) is essential in mathematics and in the kitchen. I just counted, and my kitchen bookshelves have on them 47 cookbooks–some almost outgrown and rarely referenced, some frequently consulted, some general, and some specialized. I use them like I use mathematics books. They are ignored if I am on firm ground, consulted as a memory prompt if I am unsure about something or am looking for inspiration, and relied on carefully if I am exploring new territory or know I need to be careful about details. What is clear, however, is that I did not spend the first n years of my culinary life memorizing recipes or doing things like practicing boiling, poaching, sautéing, broiling, grilling, or . . . before I was allowed to make full recipes. Basic skills were learned, sometimes with drill, in the context of meaningful work. The work, like the work of writing this chapter, was a pleasure. I can only hope that we will learn to create learning environments for mathematics that have the same properties.

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APPENDIX A

Recipe 1: Goat Cheese Ravioli With Red Pepper Cream Sauce

This recipe makes 24 ravioli–enough for a nice dinner for two. The recipe has three main components:

1. The pasta dough
2. The filling
3. The sauce.

Machinery required:

1. Food processor
2. Pasta machine (unless you are macho or a masochist)
3. Ravioli maker (preferred; see below) or crimper.

I am going to assume that you know something about making ravioli—that is, how to lay out a sheet of dough, place the filling on it, lay a second sheet atop it, and crimp and cut into ravioli. If you do not, consult a standard Italian cookbook. My only comment: I tried doing it for years by hand and with a crimper and had major difficulties. Then I bought a particular kind of ravioli maker—one that looks like a serrated ice cube tray. You lay a sheet of pasta down, put in an insert to make filling-sized "dimples" in the dough, fill the dimples, baste with water the parts where the ravioli will be cut, lay down a second sheet of pasta, and run a rolling pin over the serrated edges to cut the pasta into individual ravioli. Magic! It works with no trouble and I give it my highest recommendation. With that as a preface:

1. The pasta dough

   Ingredients:
   2 cups flour;
   0, 1, or 2 eggs (see below);
   1 tablespoon olive oil;
   1 teaspoon or less salt;
   Water.

You will need enough dough to make 24 ravioli. The dough made with 2 cups of flour more than suffices; you will have some left over, which you can either discard or use to make spaghetti for the 5-year-old in your family who does not like goat cheese.

There are three dough options: (a) flour-and-water dough, (b) one-egg dough, and (c) two-egg dough. The main thing to remember is that the fewer eggs you use, the more pliable the dough will be. This is important because novices may find it hard to work with the two-egg dough; you may want to start with the flour-and-water dough and work your way up through first one and then two eggs if you like the egg-dough taste (which I do).

Place the 2 cups of flour in the bowl of the food processor. Add the eggs, olive oil, and salt. If you have used two eggs, start the processor and let it run for a while; the pellets you get will be too fine and you will need to add water slowly. If you are making one-egg or zero-egg dough, toss in a bunch of water and begin the pellet dialectic. See the discussion of Parallel 1 for details. I use the next-to-finest setting on my pasta machine for the last pass of the dough.

2. The filling

Ingredients:

5–6 ounces very light, creamy goat cheese;
2–3 ounces cream cheese;
2 ounces heavy cream (from an 8-ounce container; the rest goes in the sauce);
1 scallion (or other green spices if you prefer).

The flavored cheese has to be really light; otherwise the flavor of the filling will be overwhelming. Here in Berkeley we can get a 5-oz log of Laura Chenel's Sonoma County goat cheese, which is wonderful. If you can't get something comparable, I suggest something like a classic French Montrachet—rich and flavorful, but delicate.

Place all the ingredients in the bowl of a food processor and let the machine work for 30 seconds, until the mixture is creamy and the scallion is broken into little green flecks. This process makes a bit more filling than you need; reserve two tablespoons for the sauce.

Assembling the Ravioli. Follow the standard procedure; if you do not know it, see any standard Italian cookbook, but do get the ravioli maker mentioned earlier if you can. The ravioli it makes are squares 2 inches on a side. The filling, minus the two tablespoons you have reserved for the sauce, should give you enough to fill two dozen ravioli. About a teaspoon of filling goes into each one.

While you are doing this, you should be bringing a large pot of water to boil.

3. The sauce

Ingredients:

6 ounces heavy cream (from an 8-ounce container; the rest goes in the filling);
1 small red pepper;
a handful (3–4 tablespoons) of pine nuts (or pecans if the pine nuts are outrageously expensive);
2 tablespoons of the ravioli filling.

The treatment for the red pepper comes from Southwest cuisine and is derived from Mexican cuisine. Simply put, you burn the hell out of the pepper and then discard the burnt parts. Open the windows and turn on a ventilation fan if you have one. Hold the pepper directly over the burner with a pair of tongs and turn the burner on high. Let the pepper char completely—with time, it will get completely black. Then put the burnt pepper aside until it cools enough to work with by hand. (Some people put the burnt pepper inside a plastic bag and let it sit for 5 minutes, claiming that it makes the pepper easier to peel.) When the pepper is cool enough to handle, slice it in half the long way, remove the top and seeds, and remove the burnt skin. Most of the skin should come off with just a bit of rubbing. The rest can be scraped off if you are picky about such things.

Sauce preliminaries: Char the red pepper as described in the previous paragraph and then cut it into thin strips (maybe ¼-inch wide). Toast the pine nuts or pecans in an oven at 350 degrees, or in a nonstick frying pan, until they brown or crisp slightly. The pine nuts are fine as is; if you use pecans, chop them into smaller pieces.

Putting It All Together. The water for the ravioli should be boiling by now. Put a saucepan on the fire and let it get hot. When it is, pour in the cream. The cream should foam and sizzle and start reducing. In a short while, it will have reduced to about half its volume and then it is time for the final preparations. Turn the heat under the cream to a simmer. Dump the ravioli in the boiling water—it should only need 2 to 3 minutes to cook to the point where it is ready. (Cook it *al dente*, of course. Cooking the ravioli for too long will not only make the pasta dough too soft, but it may curdle the filling.) Returning to the sauce, stir in the two tablespoons of filling and add the slices of burnt red pepper and pine nuts. Simmer until the ravioli are ready. Drain the ravioli (do not rinse with cold water) and arrange on plates. Cover with the sauce, spreading the peppers aesthetically over the plate, and serve with a fresh green salad and a good chardonnay. Enjoy!

APPENDIX B

Recipe 2: Spaghetti With Prawns and Chile Pesto

This dinner serves two people with substantial appetites. The components:

1. The pasta
2. The chile pepper pesto
3. The prawns.

You prepare the three components first and get ready for cooking and assembly. The pesto needs no further work. The pasta will cook in 2 to 3 minutes, as will the prawns.

1. The pasta

Ingredients:
1½ cups flour;
2 eggs;
1 tablespoon olive oil;
1 teaspoon or less salt;
Water if needed.

This is the classic two-egg pasta dough; use the pellet method as described in Parallel 1.

2. The chile pepper pesto

Ingredients:
3 medium-to-large mild chile peppers such as pascillas, poblanos, or anaheims;
1 small sweet red pepper;
a handful (3–4 tablespoons) pine nuts (or pecans if the pine nuts are outrageously expensive);
1 clove garlic;
2 tablespoons olive oil;
leaves from one small bunch (or ½ regular bunch) cilantro;
salt to taste;
juice from one small lime or ½ regular lime.

As in the ravioli recipe, toast the pine nuts or pecans in an oven at 350 degrees or in a nonstick frying pan until they brown or crisp slightly. Roast, seed, and peel the green chile peppers and the sweet red pepper. (See the previous recipe for details.)

Peel and mash a clove of garlic. Put the garlic, lime juice, salt, olive oil, and cilantro leaves in the food processor. Process for maybe 30 seconds until all the ingredients are finely chopped. Add the red and green peppers and the pecans if you are using them. Process in bursts until the pieces are small but not tiny—the texture and color are important. Add the pine nuts if that is what you are using and set aside.

3. The prawns

Ingredients:
¾ lb fresh prawns;
salt;
pepper.

Shell and clean the prawns. Rinse them and dry them. Salt and pepper them liberally. Preheat a nonstick frying pan (hot) large enough to hold all the prawns in one layer.

Assembly. At this point, the chile pesto should be sitting on the side ready for use. A large pot of water should be at the boil and the pan for the shrimp should be heating. Put the pasta in the water and let it boil for 2 to 3 minutes until it is *al dente*. While it is cooking, add the salt-and-peppered shrimp to the very hot nonstick pan; toss and fry until done (about 2 minutes—the prawns will be pink throughout). Arrange the pasta on a platter (or individual plates), cover artfully with the pesto, and arrange the prawns aesthetically on the platter as well. Toss the mix before eating and enjoy with a good chardonnay.

APPENDIX C

Any Quadrilateral Tiles the Plane!

As mentioned in Parallel 3, the key to this solution is twofold: (a) the angles where corners of the figures meet up have to add to 360°; and (b) quite conveniently, the angles of an arbitrary quadrilateral—call them A, B, C, and D—add up to 360°. Figure 12.4 shows how the arrangement works for a convex quadrilateral, the trick being to arrange four copies of the figure so that

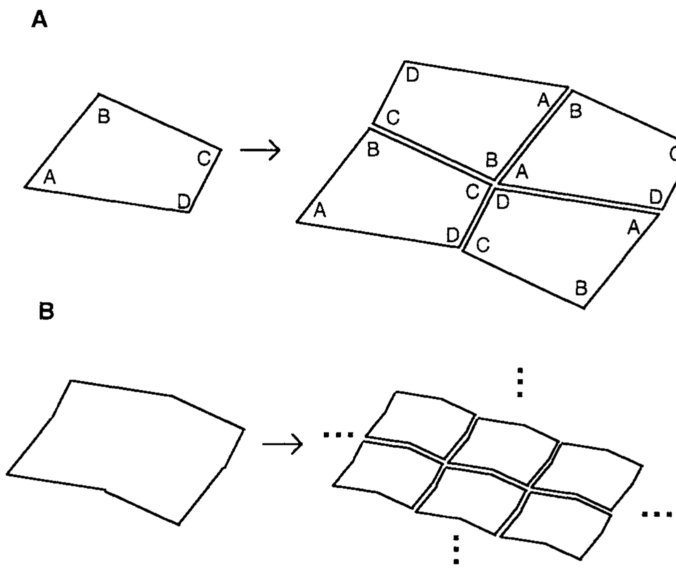

FIG. 12.4. An arbitrary convex quadrilateral tiles the plane. (a) Four copies of a quadrilateral (some flipped over) can be arranged to make a deformed parallelogram, (b) which tiles the plane.

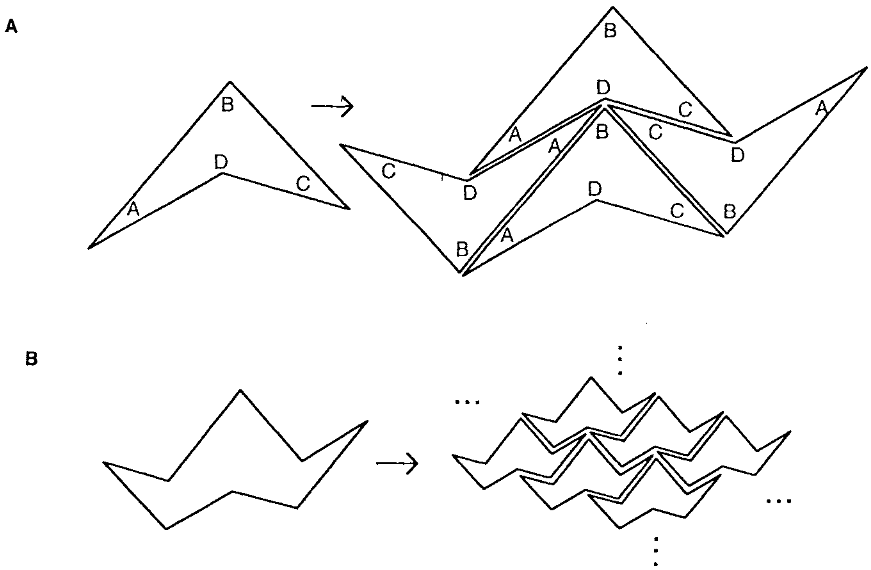

FIG. 12.5. An arbitrary reflex quadrilateral does too. (a) Four copies of a reflex quadrilateral (some flipped over) can be arranged to make a deformed parallelogram, (b) which tiles the plane.

angles A, B, C, and D are joined. Figure 12.5 shows that you can do the same thing with a reflex quadrilateral as well.

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CHAPTER

13

When Is Math or Science?

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> *. . . it is not men in general who think, or even isolated individuals who do the thinking, but men in certain groups who have developed a particular style of thought in an endless series of responses to certain typical situations characterizing their common position.*
>
> —Karl Mannheim (1936)

Any conference on thinking practices in mathematics or science education suffers from incessant attention to two foundational questions: (a) What is math or science?, and (b) What is the best way to teach math or science in school? Even a conference that would prefer other questions returns constantly to the stage set by native images of just what mathematics and science are (or should be) and native beliefs about what classrooms, teaching, and learning are and how they are best organized. Even a conference that focuses on thinking practices in social contexts to understand learning as historically arranged and institutionally consequential is disrupted constantly by the essentialist questions of just what is "real" math or "real" science.

Although the "what" questions are reasonable as stated, they can be lethal as taken. They seem to elicit a deeply felt origin myth about how mathematics, science, and schooling have always functioned and should function today. The basic myth has it that math and science are cognitively difficult; that access is available to only the smart or, in a pinch, the relentless; and that teachers of math and science are responsible for breaking a subject down into manageable pieces for all students—each according to the limits of individual aptitude—to learn as much as possible. The questions and their mythic connections leave unexplored the particulars of our current situation, the particulars of why most of our children either fail or opt out of math and science, as well as the particulars of how math, science, and schooling actually work in contemporary societies.

At their worst, answers to the two what questions leave us with an idealized version of mathematics and science and, more consequentially, a negative view of both the teachers and the children who do not live up to the inflated and false standards of idealized math and science. Mathematicians and scientists, goes the story, are taking the latest steps on the long road to progress by rational inquiry and proof by demonstration. They know what mathematics and science are. In comparison, teachers and children do impoverished, developmental versions of the real thing. They must be led to the water before they can drink. Just how real mathematicians and scientists operate remains generally unspecified, and just how people in classrooms can gain access to some of the wonder and rigor of formal inquiry is often reduced to a magic show in which teachers lead students from apparently foolish misconceptions of everyday life ways of thinking to the less obvious rational order of the well-trained mind.

Even reasonable questions, if sequenced into competitive practices that honor hierarchy and the enhancement of persons only at the expense of other persons, can be the source of misdirection and disillusionment. American schools are an important sorting mechanism for social structure, and there is nothing like mathematics and science achievement to divide so firmly the *haves* from the *have nots*. The what questions, so easy to the tongue, may be part of the sorting systems.

There are alternative questions, slower to tongue and pen perhaps, that may be more productive of change. Rates of success and failure at mathematics and science learning are strongly responsive to wider patterns in the relations of race, class, and gender. Underrepresented minorities and young women of all ethnicities drop out of math and science at an alarming pace. We must take this into account when we ask about just what math and science might be and how they can best be taught in turn-of-the-millennium American communities. Math and science are learned in institutional settings, and efforts to organize more math and science in the lives of children must deal with institutional demands and contradictions. To keep the political and institutional contexts in focus, we might prefer questions that invite answers complete with a specification of the social arrangements underlying the uses of math and science. For example, we might look to a diversity of settings as wide as supermarkets, diet clinics, milk factories, advertising agencies, street vendor negotiations, markets with a new currency, carpenter shops, pawnshops, and household budgets along with the traditional focus on laboratories and classrooms (in the order of mention, see Lave, 1988; Lave & Wenger, 1992; Scribner, 1984; Bensman, 1983; Saxe, 1991; Ueno, 1995; Millroy, 1992; Caskey, 1994; Zelizer, 1994). Instead of asking what math and science are, we might ask:

- When is math or science? By what order of persons in relation to what organization of things are moments put aside as mathematical or scientific? By whom, with what consequences, and by what means of accountability?

Instead of asking how we can best teach math and science to those who do not have it, we might ask:

- When, under what circumstances, and by what order of persons and behavior are there opportunities available to people in classrooms for making such math or science moments overlap systematically with the lives of the children? How are people given access to the methods and products of controlled inquiry and a vision of their consequentiality?

These questions are less foundational than they are questions about the behavior of people and the procedures they use in organizing their relations with each other and the world around them. In focusing on *when* math, science, and learning get *done*, to what ends, with what conditions on access, and with what consequences, we shift the focus from mathematics, science, and learning as isolated social entities and ask instead about the organization of certain activities in concert with other activities. In particular, in the context of American education, we should shift our focus from math and science as disciplines to the organization of doing mathematics, science, and learning activities in concert with the organization of doing competition, inequality, and the hegemony of the few over the many.

This chapter discusses the previous two chapters by Lynch and Macbeth (chap. 11) and Schoenfeld (chap. 12). It explores how they handle the transition from what to when questions and their pedagogical implications. First it summarizes the chapters and contrasts their messages and implications. Then it places their arguments in relation to three myths, two popular and one proposed, about the origin of math and science activities and their place in education. The primary goal is to celebrate both chapters for moving beyond traditional theories of math and science learning. It also points to ways in which they get caught in current dichotomies between traditional and reform agendas. It uses them to point to a different way of thinking about math and science—not just as hard things to be learned, but as ways of helping to change the world.

WHEN IS PHYSICS?

Lynch and Macbeth give us two quite ordinary, mundane science lessons from early elementary school. Neither lesson would command the attention of a scientist or teacher educator as an example of what should be happening in a science lesson. In fact, when their videotapes of the lessons were shown to the conference where the chapters in this book first came to life, the reform-minded audience actively refused to appreciate the tapes as examples of either science or education at work. Both teachers on the videotapes run the children through a prearranged experiment by using partial questions to elicit partial answers from the children while on the way to stating larger conclusions that were neither obvious in the observable evidence nor intelligible to the children. Fillmore (1971) once compared a conversation to a game of catch, with each person getting a turn to throw the ball (not an empirically interesting image, but metaphorically useful in this case). He identified a Socratic variation on the game in which a teacher controls the ball, throws it as high and as far away as possible, and waits for the children to find it and carry it back for a new turn. To the extent that the Lynch and Macbeth tapes looked like a bad Socratic monologue with children dutifully fetching the teacher's ball, it is the opposite of the model that most of us recommend to teachers.

Lynch and Macbeth have a much bigger story to tell. They did not want to analyze classrooms in terms of their preestablished ideas of what science is or what learning is. They were not looking for classroom materials to celebrate or complain about according to either traditional or reform normative agendas. Instead they insist on starting from scratch and asking the question of how science, any science, anywhere, under whatever circumstances—in research labs, at conferences, and even in third-grade classrooms—actually, behaviorally, sequentially, and consequentially gets "produced from an assemblage of ordinary actions and understandings." They want to know how science gets done by people organizing their collective attention to this and that in ways that are identifiably and accountably, in the people's own terms and in ways they can point to, scientific; in short, they ask, "When is science?"

By starting from scratch, they are able to find science where the rest of us might have found only bad teaching and oppression. Their corrective is necessary, although in laying out what their contribution is, we also can find the materials to see that their audience had an important point of its own. With Lynch and Macbeth's analysis in hand, the audience's point, in fact, can be strengthened.

For Lynch and Macbeth, science is not a unitary set of procedures easily isolated from common sense and identified specifically enough that people can be judged to be more or less a part of their workings. Instead the authors take an unusual and productive analytic stand that focuses on the work people do to make an engagement "evidently" and "accountably" an instance of science. This is an ethnomethodological stand that treats the question of "when is science" as "a practitioner's question first, with no ultimate, academically certified answer."[1] Applied to classroom science lessons, an ethnomethodological approach forces us to look at teachers and children not as inadequate performers of what real scientists do, but as real people working "to act and speak scientifically." For them, the classroom physics lesson is not a half empty glass of science, but a full glass of social interaction that sometimes manages to call itself science in ways that others can appreciate and even document as such. Instead of complaining that our teachers and textbooks do not properly teach real science or that our children are not sufficiently learned to acquire the knowledge they need to be real scientists, they show that the people in these classes are doing important versions of what can be socially identified, experienced, and learned as science.

Both lessons analyzed by Lynch and Macbeth involved a display, a *spectacle*, they call it, of the physical consequences of molecular density. Both the teacher and the children were attentive to organizing each other to notice aspects of the display as the kind of thing teachers and kids would do in a classroom and, more important, as the kind of thing teachers and kids doing science would do with each other. If their lessons are anything like other classroom science lessons on record, the children are doing formal classroom order and science, as well as gender, peer group hierarchy, and plenty of misbehavior (Goldman, 1996). Lynch and Macbeth only tell us about the children's behavior in relation to science, and it is surprisingly considerable. From only a few minutes of tape (a few pages of transcript), they are able to give numerous examples of participants orchestrating a constant focus on the display, organizing witnesses to testify about aspects of the display, struggling to develop categories descriptive of the display, and challenging commonsense explanations for what they see in the display. This is a great deal of science for the children and teacher to be showing each other. It is good for us to remember that science is enough of a well-formulated event in our culture that when people, even little people and teachers of little people, say they are going to do science, they can do it.

The audience response was hostile to the claim that science is really getting done whenever people identify it and make it available to each other. When is not enough; it has to be that certain kinds of problem are engaged and the proper procedures must be modeled. The Lynch and Macbeth tapes are not examples, went the refrain, of real science nor, and this is more

[1]See Garfinkel (1967) for the original formulation of ethnomethodology, Sacks (1982) for a simple account of ethnomethodological method, and Button (1991) and Lynch (1993) for an ethnomethodological approach to the history and practice of science.

passionately stated, are they examples of good teaching. For example, real science uses excitement, not prepackaged question–answer pairs, to move from inquiry to a point of discovery, and good teachers should engage children in that excitement, not just in an aimless quest for right answers. Going for the answers to predefined question–answer pairs may be the most prominent business of schooling around the world (Campbell, 1986). It should not be confused with science the way real scientists do it, nor should it be confused with teaching the way it should be done. The easiest way to scratch the surface of assumptions about what mathematics and science are is to show a piece of them in action and have everyone offer an account of what is missing. The Lynch and Macbeth tapes scratched deeply.

WHEN CAN DINNER BE CALLED MATH?

At first glance, in both its message and the way it was received, it is hard to imagine a more striking contrast with Lynch and Macbeth than Schoenfeld's chapter comparing pasta making with the work of solving a mathematics problem. The analogy holds well. Both cooking and math have many steps, steps within steps, and numerous steps to the side. Many of the steps are uncertain, and decisions are made on the spot in response to local conditions. Both jobs usually get done and both are satisfying. This is a cute chapter, delicious really, and the audience ate it up. There are also classroom implications to be taken from the kitchen. Cooking is not just measurement and math is not just calculation. Cooking is not just applying a recipe and math is not just the mechanical application of algorithms to preset problems. School math may be calculation and straining numbers through algorithms, but it should not be. Math, like making pasta, is a practical activity. Math, like making pasta from scratch, is an art form. School math should attend to math and science as practical and profoundly aesthetic activities. Math and science can do important jobs, look beautiful, and whet every child's creative appetite. The more kids are encouraged to find the usefulness and elegance of math in the world, and the more that experience can be made available to them, the more they will work on math problems. The more that a classroom is guided by the new consumptive attitude—that math is not so much difficult as it is good to eat—the more the children will learn.[2]

The contrast with Lynch and Macbeth seems at first profound. For Schoenfeld, math and science are naturally occurring activities; they happen

[2]Schoenfeld continues a long history of speculating on the relationship between cooking and thinking—a representative proportion of which has been collected by Curtin and Heldke (1992). More than 50 years ago, White (1949) published a series of papers in which he argued that, from the perspective of a cultural analysis, the genius and the kitchen hand are equivalently creative: They both take a culturally well-formulated problem and offer a new take; if everyone likes and remembers who did it first, the person is hailed as genius.

as part of the way the world works. Pedagogically, our job is to let them happen more often and more spontaneously in the classroom. For Lynch and Macbeth, math and science happen only when people organize for them to happen; they take work. Pedagogically, our job is to make them happen more often, even if we have to push a little by making teachers do demonstrations that kids may not be particularly interested in, but can learn from nonetheless. Even a mundane lesson leaves the children with practice in attending to science as science. If that does not lead to an understanding of molecular density this time, continued participation in well-orchestrated lessons will certainly work better than waiting for kids to discover a theory of density in their kitchens.

On second glance, the contrast is relieved somewhat. Like much of the rhetoric around the reform of math and science education and the traditionalist backlash that has followed, the contrast relies on some false dichotomies. Lynch and Macbeth state the hard choice that is facing most math and science teachers as they are being asked by reform movements and progressive parents, on the one hand, to alter their classroom practice in the direction of engaging as many children as possible in attractive hands-on activities and by traditionalist parents, on the other hand, to go back to basics and the way "we all learned math and science":

> Teachers are faced with a dilemma: concentrate dogmatically on formal physics (school physics) at the cost of losing the ability to extend its lessons to everyday experience, or introduce everyday experience at the cost of swamping the physics lesson with the uncertainties of unruly experience and ideas, enlivened by the plenitude of everyday spectacles. (pp. 291–292)

In various communities in California, the debate over these choices has become vociferous, where the reform is accused of slowing down the best and the brightest with a focus on communication—problem solving in essays worked on in committee—and the parents who want traditional calculations are accused of wanting precise measures of competencies on foolish tasks simply to keep their children undemocratically at the head of the class.[3] The argument has come down to people being in favor of either "thinking" or "calculation," and there are no two ways about it—no way to say I will take

[3]Actually, in one community under analysis, reform parents deny that they slow down the best students and point instead to an effort to give to all students a better grounding in thinking mathematically. In contrast, traditionalist parents have embraced what they are accused of, and they boldly state that they have learned math the hard way, they have used it to climb the social ladder at the expense of their peers, and they want their children to do the same. They are terrified by the prospects of a declining economy and downward mobility for their children (Newman, 1994). They are not terrified, but should be, of how, even in a prospering economy, their children, relative to their outlier successful parents, will face a regression to the mean in the often arbitrarily competitive wars of American education (J. Talbert, personal communication, July 1994).

a little of this for one set of purposes and a little of that for another set of purposes.

Fortunately, Lynch and Macbeth recognize the trap and identify a new focus for thinking about alternatives:

> the two cases we described ... are not caught between separate worlds of classroom science (or formal scientific theory) and everyday action. Their lessons are everyday, situated productions. (p. 292)

Yes, of course, physics lessons and math lessons are in the world, just like making pasta is in the world. Just because we have special names for laboratory experiments or class lessons does not mean that they are not in the world or subject to multiple uses. The particulars of how they are organized, and not simply what they are called, should make apparent to their participants and to us what they are good for and how they should fit into a curriculum.[4] Formal versus experiential, calculation versus thinking, remembered versus discovered—how did these get to be our designated kinds of learning, and how did they come to be opposed to each other? Who could afford to do without any one of them? How could it seem to the audience that it would cost them to appreciate all that was being worked on and learned in Lynch and Macbeth's tapes of traditional teachers do their thing? Why would it seem necessary for Lynch and Macbeth to worry about the pedagogical usefulness of science and math lessons that would imitate the world of professional mathematicians and scientists?

To answer these questions, we need to know something of the wider rhetorical structure that is the background for the math reform and the traditionalist response. To do that job, we offer three myths about the nature of math and science: two myths constantly articulated in current debates and one which we propose. Both Schoenfeld's and Lynch and Macbeth's chapters reject the first origin myth, disagree on the second, and neither takes up the third. Lining them up against the three myths shows them to be much more alike than they are different. It will also enable us to articulate how both positions, as two versions of falling short of our third origin myth, could be altered in a particular direction and made stronger.

THREE ORIGIN MYTHS AS ENVIRONMENTS FOR MATH AND SCIENCE REFORM

We offer three stories: the traditional story for critique, the reform story that confronts the traditional story, and a more utopian story that can guide

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[4]We were shown long ago the ethnographic good sense in assuming that "terms designating status are not to be understood or interpreted on a basis of a priori or philological meaning, but as references to the events in connection with which they were used" (Arensberg & Kimball, 1940, p. 60).

us to what we should be seeking in an educational reform. We offer them not because each one captures reliably any well-argued theoretical stand, but because each one allows for a caricature of various positions current in much discourse on math and science education. They should be fun and productive to play with more than they are descriptive. The traditional story is expert focused and reigns hegemonically over the institutionalized versions of math and science in contemporary culture. The reform story is novice focused and harbors the liberal lament in contemporary culture. Like all origin myths, they do not have to be true to be useful, but the ways in which they are believed can make their uses and consequences multiple, hard to define, and sometimes invidious. It is important to investigate their promise and problems. In response to the first two origin myths, we propose a third that invites a vision of social change at the heart of how math and science education might be organized in classrooms; it may be more outrageous than the first two, but it is the better to dream with and, when that is not possible, the better to use in appreciation of those who have been pushed out of math and science in school.

The Traditional Origin Myth

Once upon a time, a very smart man, and quite a man he was, found a mathematical problem. He worked on it for a long time until one day he had a great idea. He solved the problem in a flash of insight and, from that day on, people have been using his solution to solve other problems in the world. Although most students cannot expect to achieve the genius of the original mathematician, once the breakthrough has been made, many can participate in his findings and apply his tools to new problems. What is needed, of course, is a great teacher who really understands the material and can explain it well. Most will have to work very hard, run through years of drill and skill to grasp the basics, and wait for the pieces to fall together into the kind of insight gained by the founding father.

This myth of a golden past now accessible to the best minds is not a unique story. For example, it is as popular among literacy experts as it is among mathematics and science educators. In all cases, the story has a structure:

- the content, whether it is learning to read a prism or factor a binomial, is defined as difficult;
- access is assumed to be limited to those who are intelligent or at least hard working enough to master the difficulty; and
- teaching demands disciplinary expertise and is designed as a series of demonstrations and exercises each delivering a small skill that, taken

> cumulatively, may amount to a competence in reading and writing or a solid foundation for mathematical or scientific knowledge.

At its most extreme, in mathematics education, teaching can be reduced to a programmed text that offers thousands of steps from first-grade addition and subtraction through calculus. The Kumon program popular in Japan and now spreading through the United States is a good example of this way of thinking about knowledge and learning (Ukai, 1994; fortunately this is not the only way learning is organized in Japan, as nicely documented by Hori, 1994; Lewis, 1995; Rohlen, 1992).

Both Schoenfeld's and Lynch and Macbeth's chapters reject this great man and rote and mechanical learning view of math and science education. The great man theory denies the historical context of discovery and the full complexity of how many people it takes to define a problem well enough that someone can find a new solution. Neither goat cheese nor liquids of different density offer many affordances to any cook or student of science without a history of using them in specific ways in relation to other culturally well-defined things to think about and eat. As for the rote and mechanical view of learning, it denies that classrooms filled with teachers and children are a part of everyday life and instead holds to the impossibility that a classroom is a separate culture built around one person knowing and the others picking up the crumbs of their wisdom. Classrooms do not work well that way, and we have both been in many classrooms where the children brought their own crumbs and threw them at the teacher.

Behind every great man theory and behind every fantasy of how the greatness will trickle down if every novice simply practices enough is a disturbing theory of knowledge as separate from the activities of people. If the 18th and 19th centuries were taken up with the differentiation and celebration of scientific knowledge over religion, the 20th has re-created the problem by separating math and science as a kind of knowledge quite superior to the wisdom of everyday life (Adas, 1989; Randall, 1958; Tambiah, 1991). Instead Schoenfeld and Lynch and Macbeth might prefer Mannheim's claim that people think and learn—whether in kitchens or classrooms, whether alone or in a group—as a part of a wider community where they "have developed a particular style of thought in an endless series of responses" to the situations that they have created out of materials inherited from still others.[5] Both chapters would reject the view of knowledge as an inert store independent of conditions of use, and both would find it objectionable to find math and science enshrined as the only legitimate source

[5]In his inquiry into the culture of the Sepik River Iatmul, published the same year as Mannheim, Bateson (1936) called for an ethnographic social psychology that would study the mind as "the reactions of individuals to the reactions of other individuals" (p. 175). It was a good year.

of knowledge about the world. Believing that knowledge is a storehouse to which only a few have access is a setup for not noticing all the math and science that goes on around us in the world and even in classrooms. There are many versions of math and science, and they can happen whenever people work systematically to make claims about the formal and displayable structures of the world to witnesses. The institutional requirement that one needs a lab coat or a professor's mantle to claim knowledge is just that—an institutional requirement—and not to be confused with when math and science are made to happen.

The Reform Origin Myth

Once upon a time, and a very good time it must have been, there were complex accounts to be made of the workings of the world, and a developing math and science was found to be useful in making the accounts possible, precise, and elegant. In Frankfurt in the 15th century, for example, princes had to keep track of their domains and the ups and downs of their finances, and bookkeeping became essential. Along with the discovery of the usefulness of the new mathematics came a second problem of how to get it to all who could use it. Sensible solutions were found. Mathematics was isolated temporarily from the complexities of the world, and students could capture its powers one point at a time and apply them after a mastery had been achieved. A curriculum was organized. The princes of Frankfurt needed bookkeepers and they sent their sons to Venice to learn math. The first of many textbooks, *The Treviso Arithmetic of 1478*, was written and the students were taken through the book to learn the techniques of calculation that would prove useful on their return to Frankfurt (Swetz, 1987).

At the present time, and a very bad time it seems to be, there are many more textbooks to choose from, and math and science education, in the experience of our children, has been severed too completely from the real-world tasks it was designed to serve. Although millions labor at it daily, most experience failure, and only a handful—the princes of the modern electronic world—learn enough mathematics to put it to new use.

Versions of this myth of origin and contemporary decline—an old format for new stories—have been extremely useful in organizing the reform of math and science education. In all cases, the stories share a structure:

- the content is defined as sometimes difficult and sometimes not, but always functional;
- access is attained situationally and is ultimately available to anyone who hangs around long enough; and
- teaching demands designing problems that model the real world and invite mastery as an outcome of participation.

To our eighth-grade children who insist on asking why they must know the Pythagorean theorem, our answer that it helps to build bridges is too distant and our more immediate answer that it helps to answer a wide range of questions on math tests is uninspiring. Would not it be nice if we could recover for them the original excitement of discovering and applying the right triangle, of its possible usefulness to the Egyptians building not just a pyramid, but an empire, to the Chinese who may have done it first, and to Pythagoras who brought it to new heights of articulation (Swetz & Kao, 1977)? Would not it be helpful if we could deliver to children some real-world problems in response to which they could rediscover the power and beauty of the math and science we can make available to them? Would not it be nice if we could create environments for them to discover why they should be delighted to learn math and science to solve problems in the world?

The Schoenfeld and Lynch and Macbeth chapters show their differences most obviously in relation to the reform myth about how math and science work in everyday life and should work in classrooms, although the differences are slight compared with their respective responses to the teachers on the videotape. Lynch and Macbeth take the stronger stand and reject outright what some might take to be the pedagogical implications of their stand that math and science are contingent on local circumstances. They do not want to argue that, because math and science are used in the world to solve problems, the same problems in the same circumstances must be delivered as faithfully as possible in classrooms if children are to learn with a maximum of interest and maturity. In fact, they have the contrary point to make:

> . . . everything one might want to ascribe to structures of authentic practice—the essential indexicality of natural language, the intertwining of self and other conjoint activities, and the tacit modes of enculturation—can be found in the classroom as well as in apprenticeship situations and other non-school activities. (p. 295)

There is enough understanding in classrooms of how math and science are done for teachers and children to learn what has to be learned; there is no need to trick children into being interested.

Schoenfeld is only a little less critical of "the caricature of collaborative discovery learning" that would have us all "get in the mathematical kitchen and play around":

> . . . I am not about to demean the importance of memory or of basic skills. Nor am I about to demean the importance of learning to follow skills. (p. 313)

Math textbooks, like cookbooks, are sometimes necessary and even helpful. We can assume that Schoenfeld would say the same of teacher-run experiments and even a spectacle like lecturing on goat cheese pasta to make a point in mathematics education. The general rule is that it should be interesting. The teachers on the Lynch and Macbeth videotapes, although good occasions for everyone to look and act scientifically, were not interesting. At the very least, a reform of math and science education, even when it does not turn all teachers and children into junior scientists, should be interesting.

We have seen that the Schoenfeld and Lynch and Macbeth chapters are united in their resistance to the traditionalist myth of math and science education and only slightly divergent in response to the reform agenda. In the hotly contested reform arena, however, only a small divergence can be a source of endless argument. The argument, in turn, can leave unobscured the vast darkness of the problem facing reform.[6] Both chapters have made important points about how capable everyone is—Lynch and Macbeth that children and teachers know a great deal about keeping each other scientifically focused, and Schoenfeld that everyday tasks and mathematical tasks often have an analogous structure available to anyone who would be engaged by them—and it would be a shame to have their argument keep us from turning to the question of what we should do with their findings. Perhaps the worst fate would be for them, for the rest of us, and for the national community of math and science educators—to give our time and energy to fighting how to balance drill-and-skill approaches with "the thinking curriculum" (Resnick, 1987). What might be better is to have a higher calling—a dream about why math and science learning must get done—and let the pedagogical how of it fall into place. In the past, national security has done that job; Sputnik, the arms race, and the automobile wars are all cases in point, but they netted us neither a society sophisticated in math and science nor a next generation that could focus the powers of math and science on making the world a better place. Schoenfeld and Lynch and Macbeth are united in not giving us a dream against which we could worry about the adequacy of math and science education. We offer next a dream.

An Origin Myth for Mathematics and Science Education as Social Change

Once upon a time, and a very enlightened time it might someday be, people were content. The problems they had to work on and the solutions they sought were well fitted to the structure of their society. They had developed an array of conceptual tools and made them freely available to everyone, who with creativity and earnestness set about to improve their world.

[6]Bateson (1972) often quoted Bertrand Russell's quip on Alfred North Whitehead's work on religion: Russell thanked Whitehead for leaving the vast darkness of the subject so thoroughly unobscured.

Mathematical and scientific tools were especially prized in this endeavor because of their elegance and wide applicability. The tools were distributed widely across the land, and many counted filigreed formulae and other mathematical devices (both delicate and robust) among their most precious and useful possessions.

Slowly a shadow of unease crept over this harmonious land. Critical seers among them, well possessed of the society's heritage of formal analytic power, noticed that the tools that had served them so well had an unanticipated, almost magical power of their own. The people grasped that their precious tools were not, as they liked to think, merely applied with intellectual artistry to achieve solutions to the problems at hand. Rather, they realized that the tools they used to apprehend the world also shaped the things touched. Both drawn and repelled by what they saw, they dared to look more deeply.

Students of math, science, history, society, and culture joined together in their quest because, in this land, no one imagined it to be an inquiry pursued by math or science alone.[7] Nonetheless, math and science education had become deeply embedded in the status quo, and it required constant attention by all the citizens to envision them in new ways for the good of all. Soon they discovered a bountiful bouquet of thoughts and practices that they recognized as formal for the first time (e.g., kinship systems, carpentry, and sand drawings), along with a wide range of predefined mathematical problems that had little relevance to life beyond competitive occasions in which people were asked to show off who was smarter than whom. Soon they encountered in many guises a choice between working on problems in ways that kept the order of social life unchanged and seeking new problems and ways of working on them that would transform their relations with each other. Math and science came to be learned as and through social practices rather than apart from them. Students learned not only how to use them powerfully, but to recognize and critique any misdirection of that power. Math and science happened when people were engaged in fixing the world and, for whatever reasons, thinking about the world. Although there are a few versions of this story, in all cases they have a structure:

- the content is defined as partial, a social activity among activities, all of them adding up to a way of life constantly under negotiation;
- access is assumed to be unlimited, ideally dependent on only people choosing one problem rather than another to work on; and
- teaching demands attention not just to what students must learn, but equal attention to the world that will make use of their efforts.

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[7]Jami (1994) has offered an example from late imperial China of a formal mathematics that did not stand apart as a kind of knowledge: the "mathematical sciences did not stand as an alternative, much less a rival, to classical learning" (p. 247).

In such a world, children would not have to be coerced into math and science, nor would anyone worry much about exactly how the learning was getting done. Learning would get done, much as learning is done constantly *en passant* by everyone today, but with the difference that learning in school could be addressed to solving problems in the world rather than who is looking smarter than whom.

In such a world, Lynch and Macbeth would not have to write an insightful chapter showing that teachers and children can make science "locally relevant and recognizable," and Schoenfeld would not have to defend so cleverly the mental powers of cooks by showing how they are made of the same right stuff as mathematicians. Nor would they have to argue over the best ways to teach math and science as much as they would press themselves to answer questions about the larger worlds served by what was recognized as math, science, and learning.

Just what is the larger world served by the teachers in the Lynch and Macbeth tapes? Contra to the American bias that teaching and learning is a dyadic dance through which the teacher imparts information to the students, the kinesicist Ray Birdwhistell liked to argue that the dance itself, the dance called *teaching and learning* in school, takes so much work of its own that it has little relation to genuine learning moments in which necessary information not available at one moment can enter the system in the next moment (McDermott, 1980, 1993). So it is in a science lesson; certainly, it takes much work for everyone to display the science of the lesson, but this does not ensure that any learning gets done. It is more than possible that children and a teacher can put on a mock science lesson, paying full attention to the institutional demands to look like a science class while fully subverting the point of the science lesson. A more detailed analysis of the lessons with more complete transcripts and a fuller account of the subrosa organization of the children in relation to each other might have given an answer to questions about the many worlds served by their behavior.[8] It is important to ask the question of just when is science and to identify and

[8]Please note that this is not the usual uninteresting complaint leveled against ethnomethodological descriptions—namely, that in focusing on the detail, they bypass the wider sociopolitical contexts that organize people's behavior. The call here is instead for a finer grained analysis that could tell us not so much about what happens elsewhere, but more about the politics of what happens in the interaction under analysis. While Lynch and Macbeth are careful to reach conclusions consistent with the small strips of transcript that they give us, more detail might have forced the analysts to consider science as simply one of a handful of local productions the children are working on at any given moment. Such findings might have further pushed them to identify the wider institutional pressures with which classroom behavior might in some next moment have to articulate. For risky efforts to understand school talk as a response to Western capitalism and American culture, see McDermott (1988) and Varenne and McDermott (1998). Schegloff (1987, 1992) has presented the strong case for context being behavior and not some vague entity in which behavior takes place.

appreciate by what work of everyone on the scene it gets done. It is also important to figure out, from the same data, just when is gender, race, success, doing better than others, or whatever else the participants make available to each other (and to those who watch). It is equally important to know when any of these doings are done for fun, pretense, or mockery. With even approximate answers to these questions in hand, we could ask Lynch and Macbeth to take up not what is the best way to teach science, but the best way to reorganize the world so that children might do science to change their lives. We could not only identify when science is, but we could build the world that would greatly expand when science happens and what people do with it.

Schoenfeld also stops short of imagining the world that may give children the reason for doing math.[9] We know why children need to eat, but we know less about why they may become interested in cooking goat cheese ravioli from scratch. We know why children need math, but we know less about why they may find it great fun. The culinary analogue brings upward mobility to mind.[10] What is fun anyway? Why do people seem to have fun in such different, indeed, mutually exclusive ways? What is it that makes gambling fun for half the high school and calculating probabilities fun for the other half? At the very least, fun is a socially well-organized way of relating to others—which others, to what end, and in what ways are all left unspecified. Compared with the dreams harnessed in the third myth of math and science education, Schoenfeld has left us and the children in schools looking for fun without a vision of what we would like to accomplish with math. Finding mathematical analogies in cooking is an important step. Two next steps involve showing the connections that both kitchen and classroom math make with the rest of the world and then dreaming about the world that new versions of math education make possible.

Few are ready to take our third myth of math, science, learning, and social change to heart. Dewey (1899) and Addams (1910) certainly headed in this

[9]Schoenfeld gives much more of a vision when his mind is not taken up with pasta (see e.g., Schoenfeld, 1991, 1992). We should also note the importance of his long account of one child across 7 hours of learning mathematics (Schoenfeld, Smith, & Arcavi, 1993). More accounts of this type in even more detail would teach us more about the social world of which a mathematics skill is a systematic part.

[10]Williams (1954) has reminded us that "culture is ordinary" in the sense of neither special nor private. Like wisdom, culture is everywhere and not just reserved for those with special access to received ways of displaying knowledge. Math and science are fully cultural and also ordinary in this sense. That they have been long tied to traditions of civility and entitlement (Shapin, 1995) allows for the illusion that they are much less ordinary than other ways of knowing. They are to common sense what goat cheese ravioli is to the stuff that comes in cans. Although it is much easier to imagine mathematics being compared to the making of goat cheese ravioli than to the making of, say, gruel, this is more a function of social structure than an inherent property of mathematics.

direction, Moses (1990) gave it a current context, and Horton (1990) pushed further than any of us dare to imagine. Current circumstances (e.g., the bifurcation of the country into rich and poor, the rhetoric of individual rights over the collective good, and the use of schooling to sort a next generation into downward mobility) seem as if they will push us, one emergency at a time, in the direction of having to reconceive of math, science, and education as a challenge to the accepted order. In displaying some of what teachers and children, even in the midst of an uneventful demonstration physics lesson, know about doing science, Lynch and Macbeth have given us a focus on what people can do while the rest of the world is urging us to think about what they cannot. Similarly, in showing us that mathematics uses the same human capacities as more mundane activities such as cooking, Schoenfeld has also given us a way to focus on people's strengths rather than their weaknesses. We need more of their work to guide our way.

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CHAPTER

14

CREATING ZONES OF PROXIMAL DEVELOPMENT ELECTRONICALLY

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American schools in the latter part of the 20th century face a dramatic shift in their mandate. Not only is the population they serve changing rapidly, but they are now held accountable for higher levels of performance from all, not just from an elite. At the same time, the demands of the workplace require increasingly complex forms of literacy—those that go beyond simple rote acts of reading and calculating. Increasingly, educated graduates need to be able to evaluate critically what they read, express themselves clearly in verbal and written forms, understand scientific and mathematical thinking, and be comfortable with various forms of technology that can serve as tools for thought. Schools are required to foster higher literacy (Resnick & Resnick, 1987) aimed at developing students' reasoning (Miller, 1988), rather than the low literacies of minimum competence that once served as exit criteria. In addition to the basic enabling competencies (Glaser, 1987) of literacy and numeracy, students are now called on to acquire integrated and usable knowledge rather than sets of compartmentalized facts rarely applied to novel situations. The call is for school graduates to be independent, self-motivated critical thinkers able to take responsibility for their own learning.

Although as yet poorly understood, higher order thinking skills are clearly needed for success, and schools are required to foster habits of mind of this nature. Ideally, it is in the initial school years that students develop a belief system based on rationality and sensitivity to evidence and a general attitude to learning based on reasoning in all areas of the curriculum. It is a fundamental part of our work that this expectation be extended to all children, however young or disadvantaged. Even those at risk for academic failure can be helped to develop critical reasoning abilities (Brown, 1978; Brown & Campione, 1981, 1990; Brown, Palincsar, & Purcell, 1985).

It is generally agreed that contemporary schools, little changed since the turn of the century, are not meeting this challenge. Schools have been contrasted with communities of adult practice (Bordieu, 1972) in which participants are gradually enculturated into the authentic practices, knowledge base, and discourse structure of a particular occupation, profession, or discipline. In contrast, schools have been accused of lacking continuity between both the culture of childhood and legitimate adult occupations (Cole & Bruner, 1971; Dewey, 1902).

Although frequently dismissed as true communities of practice (Becker, 1972; Lave & Wenger, 1991), we argue that, when redesigned, schools could and should become communities of learning and thinking where students learn about learning and learn how to learn intentionally (Brown & Campione, 1990; Scardamalia & Bereiter, 1991). Graduates of such communities would be prepared as lifelong learners who have learned how to learn in many domains. If successful, such learning communities would produce a breed of intelligent novices (Brown, Bransford, Ferrara, & Campione, 1983)—students who, although they may not possess the background knowledge needed in a new field, know how to go about gaining that knowledge. These learning experts would be better prepared to be inducted into the adult practitioner culture of their choosing. They would have the background to select among several alternative practitioner cultures rather than being tied to the one to which they were initially indentured, as in the case of traditional apprenticeships.

Ideally, in a community of learners, teachers and students serve as role models not only as owners of some aspects of domain knowledge, but also as acquirers, users, and extenders of knowledge in the sustained ongoing process of coming to understand. Ideally, children in such settings are apprentice learners, learning how to think and reason in a variety of domains. By participating in the practices of scholarly activity, they should be enculturated into a community of scholars during their 12 or more years of apprenticeship in school settings. Redesigning classrooms so that they can bolster this function is a primary aim of our research group (Brown, 1995; Brown & Campione, 1994). In our classroom interventions, we try to create a community of discourse (Fish, 1980) and practice (Lave & Wenger, 1991) where the participants are inducted into the rituals of academic and, more particular, scientific discourse and activity (Brown, Ash, Rutherford, Nakagawa, Gordon, & Campione, 1993; Brown & Campione, 1990, 1994; Lempke, 1990).

COMMUNITIES OF GRADE SCHOOL LEARNERS

During the past 10 years, we have been working toward the development of communities of learning and thinking in urban grade school settings. Although the community could not exist without the involvement of adults—teachers, outside experts, parents, researchers, and members of the wider community—our primary focus has been on the students—inner city grade school children.

Our main goal has been to develop a community of researchers of various degrees of sophistication, engaging in research, learning, teaching, and exhibiting what they know about a particular content area. We have concentrated primarily on environmental science. Our goal is that young learners not only come to know a great deal about a content area, but they also become increasingly facile at reasoning critically within and about that domain.

This chapter concentrates on methods of extending the research community throughout a school and beyond, primarily through the use of electronic mail (for other aspects of the program, see Brown, 1992, 1994; Brown & Campione, 1990, 1994; Campione, Shapiro, & Brown, 1995). Electronic mail is used as one method of infusing expertise and guidance into the system that is not readily available to the self-contained grade school classroom. First, however, this chapter gives a synopsis of the main practice of Community of Learners (COL) classrooms.

MAIN FEATURES OF A COL CLASSROOM

The primary aspects of a COL classroom relevant to this chapter are: (a) a set of familiar participant structures, (b) research into deep content, and (c) environments constantly reinvented that adhere to first principles of learning.

Familiar Participant Structures

Each COL classroom involves a variety of familiar participant structures of which there are five that have featured prominently over several reinventions of the program. In each of these activities, knowledge is gathered and shared and expertise is distributed to provide a richer knowledge base for all. Three of these activities involve small groups: reciprocal teaching, jigsaw, and guided writing; two are whole-group activities: benchmark lessons and crosstalk. Each is described in turn.

Reciprocal Teaching. Reciprocal teaching (RT), designed by Annemarie Palincsar and Ann Brown, began as a method of conducting reading group, once an established ritual of the grade school class. RT seminars can be led by teachers, parents, peers, or older students. Six or so participants form a group, with each member taking a turn leading a discussion about an article, video, or other materials they need to understand for research purposes. The leader begins a discussion by asking a question and ends by summarizing the gist of the argument to date. Attempts to clarify any problems of understanding take place when needed, and a leader can ask for predictions about future content if this seems appropriate. These four activities were chosen because they are excellent comprehension monitoring devices. Quite simply, if you cannot summarize what you have just read, you do not understand and you had better do something about it (for more details, see Palincsar & Brown, 1984).

RT was designed to provoke zones of proximal development (Vygotsky, 1978) within which readers of varying abilities can find support. Group cooperation—where everyone is trying to arrive at consensus concerning meaning, relevance, and importance—helps ensure that understanding occurs, even if some members of the group are not yet capable of full participation. Because thinking is externalized in the form of discussion, beginners can learn from the contributions of those more expert than they. Collaboratively, the group—with its variety of expertise, engagement, and goals—gets the job done; usually the text gets understood. The integrity of the task, reading for meaning, is maintained throughout.

Jigsaw. This idea of learning with a clear purpose in mind is a mainstay of all the components of the COL. In particular, it carries over to our version of Aronson's (1978) jigsaw classroom. Students are asked to undertake independent and collaborative research. As researchers, they divide up units of study and share responsibility for learning and teaching their part of the information to each other.

How does this work? Classroom teachers and domain area specialists together decide on central abiding themes visited at a developmentally sensitive level. Each theme (e.g., changing populations) is then divided into five or six subtopics (e.g., endangered species, rebounding populations, introduced species, etc.) dependent, in part, on student age and interest. Each group of students conducts research on one subtopic and then shares its knowledge by teaching it to others.

As a concrete example, recent classes of second graders chose to study the relationship of animals to their habitats. Some children studied how animals protect themselves from the elements or predators. Others became experts on animal communication or reproductive strategies. Still others studied predator–prey relations. Armed with this information, design teams were configured so that each member had conducted research on one part of the knowledge (e.g., reproductive strategies). These teams designed habitats for an adopted animal or invented an animal of the future and then exhibited these products to an array of audiences. In each group, someone knew about predator–prey relations and methods of defense and someone could talk wisely on the strengths and weaknesses of possible reproductive strategies or of potential methods of communication. All pieces are needed to complete the puzzle–to design the habitat or animal of the future, hence jigsaw.

Guided Writing. In preparation for teaching others and displaying their knowledge, older students produce written, illustrated texts, composing on the computer in small groups. These texts go through many revisions, some of which are guided by an expert (e.g., the classroom teacher, a researcher, or an older student). This expert sits with the group and helps them progress to higher levels of discourse using such prompts as: Do you think the reader will be able to understand that? Is this in your own words? What's the main point of this paragraph? Have you said how it gets food? Remember that the reader hasn't read about reproductive strategies and delayed implantation, is this enough to make it clear? Repeated exposure to these external prompts eventually leads to internalization in the form of self-editing procedures.

Benchmark Lessons. The major whole-class activity is the benchmark lesson (Minstrell, 1989)–an adult-led activity that serves several functions. First, the teacher (or visiting expert) uses the format to introduce a new concept that she judges the students are ready to learn. The new concept should draw the students toward higher levels of abstraction. Second, the adult leads the students to look for higher order relations, encouraging the class to pool their expertise in a novel conceptualization of the topic. For example, if they have discovered the notion of energy and amount of food eaten, the expert might lead them toward the biological concept of metabolic rate. A third benchmark activity is where the teacher uses these sessions to model thinking and self-reflection concerning how she would go about finding out about a topic or how she might reason with the information given, or not given, as in the case of reasoning on the basis of incomplete information (Bruner, 1969; Collins, Warnock, Aiello, & Miller, 1975). Finally, a simple but imperative type of benchmark lesson is when the adult teacher asks the group to summarize what is known and what still needs to be discovered, thereby helping students set new learning goals to guide the next stage of research.

Crosstalk. The final activity, also a whole-class activity, is crosstalk. It was designed and led by the students (Brown & Campione, 1994). After experiencing a RT–jigsaw cycle, a group of sixth graders complained that it was too late to do major revisions by the time they got to teach in jigsaw. When asked questions by their peers that they could not answer, they felt inadequate while realizing that they did not understand the subject matter completely themselves. Teaching others is an extremely powerful test of comprehension. Hence, the students designed crosstalk, whereby members of the various research groups periodically report in about their findings to date. Students from other working groups then ask questions of fact, clarification, or extension. Students carefully record knowledge or explanations they lack and use these indicators as the basis for the next round of research. Thus, the various groups talk across groups and provide comprehension checks for each other.

Research in Context

It is essential to the philosophy of the COL that the students be engaged in research in an area of inquiry that is based on deep disciplinary understanding and that follows a developmental trajectory based on research about children's developing understanding within a domain.

Deep Disciplinary Understanding. Although it is romantic to think of young children entering the community of practice of adult academic disciplines, awareness of the deep principles of these disciplines should enable us to design academic practice for the young that are stepping stones to mature understanding, or at least are not glaringly inconsistent with the end goal. For example, in the domain of ecology and environmental science, we realize that contemporary understanding of the underlying biology would necessitate a ready familiarity with biochemistry and genetics that is not within the grasp of young students. Instead of watering down such content, we invite young students into the world of 19th-century naturalists—scientists who also lacked modern knowledge of biochemistry and genetics. The idea is that, by the time students are introduced to contemporary disciplinary knowledge, they will have developed a thirst for that knowledge, as indeed has been the case historically.

Practically speaking, this means that as we revisit, for example, the topic of endangered species across age, we gradually reach toward increasingly sophisticated disciplinary understanding. Second, sixth, and eighth graders may be working on endangered and rebounding populations and all will be guided by the basic disciplinary principles of interdependence and adaptation. Different levels of sophistication will be expected at each age, with this level determined by prior research on children's understanding of biology.

Developmentally Appropriate Trajectories. An understanding of the growth of children's thinking in a domain should serve as the basis for setting age-appropriate goals. As we learn more about children's knowledge and theories about the biological and physical world (Carey & Gelman, 1991), we are better able to design a spiraling curriculum such as that intended by Bruner (1963, 1969). Topics are not just revisited willy-nilly at various ages at some unspecified level of sophistication, as is the case in many curricula that are described as spiraling. Rather, each revisit is based on a deepening knowledge of that topic, critically dependent on past experience and the developing knowledge base of the child. It should matter what the underlying theme is at, say, kindergarten and Grade 2; it should matter that the sixth-grade students have experienced the second-grade curriculum.

In our ecology/environmental science/biology strand, we seek guidance from developmental psychology concerning students' evolving biological understanding (Carey, 1985; Gelman & Wellman, 1991; Hatano & Inagaki, 1987; Inagaki, 1990; Keil, 1992). We know that by age 6, children can fruitfully investigate the concept of a living thing—a topic of great interest that they refine over a period of years, gradually assimilating plants into this category. Second graders concentrate on design criteria for animal–habitat mutuality and interdependence. Sixth graders examine the effect of broad versus narrow niches; by eighth grade, the effect of variation in the gene pool on adaptation and survival is not too complex a topic. Second graders begin to consider adaptation and habitats in a simple way, whereas sixth graders can distinguish structural, functional, and behavioral adaptations, biotic and abiotic interdependence, and so forth.

A similar developmental guideline governs our approach to reasoning within the domain. We initially permit teleological reasoning (Keil, 1992) and an overreliance on causality in general, but then we press for an increasingly more sophisticated consideration of chance, probability, and randomness. Eventually it will be necessary for experts, electronically linked or otherwise, to receive training in what to expect and push for with children of various ages.

First Principles of Learning

From its inception, the COL program has involved the development and refinement of a series of first principles of learning that guide the design and redesign of the learning environment. These are discussed in detail elsewhere (Brown, 1994; Brown & Campione, 1994). This section briefly describes a few central principles that underlie the design of the extended community, which is the main topic of this chapter.

The number of principles changes on each revisit. From the current pool, numbering between 12 and 16, we have selected five principles (in addition to the commitment to deep content just described) that are the essential underpinnings of the extended community:

1. Students, teachers, and experts are co-researchers, co-learners, and co-teachers.

2. Knowledge sharing is necessary: Collaboration leads to group and individual gain.
3. Common knowledge and distributed expertise are both essential ingredients in sharing.
4. A community of discourse involving negotiated meaning and appropriation of ideas is developed.
5. Multiple zones of proximal development permit the legitimization of differences.

Students, Teachers, and Experts As Researchers. All members of the community are called on to be researchers, learners, and teachers at some time or another. Even the youngest students have knowledge that they can introduce into the common discourse. Usually, however, adult teachers and outside experts bear the major role of expanding the knowledge base of the community. Our model of instruction is that of guided discovery (Brown, 1992; Brown & Campione, 1994). Classroom teachers, outside experts, and cross-age tutors all attempt to guide the discovery process of their charges rather than engage in direct knowledge transmission. All need help in developing this teaching mode, and it is not an easy role to fill. In the case where the teacher knows the answer and the students do not, the teacher must decide how long to let the students flounder, when to come in and direct, and when to leave them to their own devices. What about the teacher who does not know the answer him or herself? He or she must admit this and seek help. This is not an easy role for many teachers; it demands competence and confidence.

The provision to our classrooms of an electronic mail system that links the teachers and students to a wider community of scholars helps teachers handle the lack-of-knowledge problem. Our steps in this direction have been modest. We have been involved in recruiting local expertise within the community to join forces with classroom teachers and students to extend the learning community of which all are members. The essential principle underlying this is that all members are co-researchers, co-learners, and co-teachers who listen to and respect each other.

Knowledge Sharing. These communities rely heavily on knowledge sharing. Collaboration is not just nice but necessary for group and individual gain. Members of the community are critically dependent on each other. No one is an island; no one knows it all. This interdependence promotes an atmosphere of joint responsibility, mutual respect, and a sense of personal and group identity.

Common Knowledge Coupled With Distributed Expertise. Central to the COL classroom is the assumption of shared discourse and common knowledge (Edwards & Mercer, 1987), as well as individual expertise. Although the participants come to share a body of common knowledge, there is also a reliance on distributed expertise or individual majoring (Brown et al., 1993). Students are free to major in a variety of ways and free to learn and teach whatever they like within the confines of the selected topic. Children select topics of interest with which to be associated: Some become resident experts on DDT and pesticides; some specialize in disease and contagion; some adopt a particular endangered species; and others become environmental activists, collecting instances of outrages from magazines, television, and newspapers, demanding that the class write to Congress and complain. Within the community, these varieties of expertise are recognized and valued.

Community of Discourse. The extended community comes to rely on the development of a discourse genre in which constructive discussion, questioning, and criticism are the mode rather than the exception. The core participant structures of our communities are essentially dialogic. Sometimes these activities are face to face in small- or large-group interactions; sometimes they are mediated via print or electronic mail; and at other times they go underground and become part of the thought processes of community members (Vygotsky, 1978). Dialogues provide the format for novices to adopt the discourse structure, goals, values, and belief systems of scientific practice. Over time, the COLs adopt a common voice and knowledge base, as well as a shared system of meaning, beliefs, and activity.

Within this community of discourse, meaning is constantly negotiated and refined. Increasingly, scientific modes of speculation, evidence, and proof become part of the common voice. Successful enculturation into the community leads participants to relinquish everyday versions of speech activities having to do with the physical and natural world and replace them with "discipline embedded special versions of the same activities" (O'Connor, 1991).

Ideas and concepts migrate throughout the community via mutual appropriation (Newman, Griffin, & Cole, 1989). Within the discourse, ideas are planted by experts, teachers, and students. Some of these seeds come to fruition and others do not. Some ideas migrate throughout the community and are picked up (or appropriated) by some but not others.

Multiple Zones of Proximal Development. Theoretically, we conceive of the community as composed of multiple zones of proximal development (Vygotsky, 1978), through which participants can navigate via different routes and at different rates (Brown & Reeve, 1987). A *zone of proximal development* is a learning region that learners can navigate with aid from a supporting context, including but not limited to people. It defines the distance between current levels of comprehension and levels that can be accomplished in collaboration with other people or powerful artifacts. The zone of proximal development embodies a concept of readiness to learn that emphasizes upper levels of competence. These upper boundaries are seen not as immutable, but as constantly changing with the learner's increasing independent competence at each successive level.

Because varieties of expertise and talent are encouraged, and there are multiple ways into the community (Lave & Wenger, 1991), individual differences are legitimized (Heath, 1991; Heath & McLaughlin, 1994). Volunteer out-of-school activities such as Little League value and depend on an array of competencies:

> Central to the task of coaching many learners at the same time is acceptance of the value of differences among learners. A team cannot expect to have all members at the same level of ability in the same complex skills. Instead, the potential for division of labor depends on varying levels of performance in each niche; however, the general upgrading of performance for each individual rests in the social control potential of having knowledge about separate tasks shared and distributed among all members. Added to the general distribution of knowledge is the shared value of monitoring self and others . . . , which result in group improvement through individual achievement. (Heath, 1991, p. 121)

We use this as a metaphor for the design of classroom communities, taking pains that all members achieve identity through an area of expertise: art, technology, domain knowledge, social skills—it does not matter as long as it is valued and recognized.

This metaphor of a classroom supporting multiple, overlapping zones of proximal development that foster growth through mutual appropriation and negotiated meaning is the theoretical window through which we view the system of practices that involves the wider community supported by electronic mail. The next section concentrates on the role of outside experts and students in creating, supporting, and extending the learning community in this way.

THE ROLE OF EXPERTS AND NOVICES IN ELECTRONIC MAIL INTERACTION

We conceive of the use of electronic mail as an excellent device for infusing additional expertise into the community. Any learning community is limited by the combined knowledge of its members. Within traditional schools, members draw on a limited knowledge capital if the faculty and students are relatively static, or they face jarring discontinuity if there is rapid turnover, as is the case in many inner city schools. In addition, both teachers' and students' expectations concerning excellence, or what it means to learn and understand, may be limited if the only standards are local.

Schools are not islands. They exist in wider communities and we rely on them. Experts coaching via electronic mail provide us with an essential resource, freeing teachers from the sole burden of knowledge guardian and allowing the community to extend in ever-widening circles of expertise.

The Expert Role: Older Children

Adults are usually the expert in our system, but not always. Consider the interchange between fifth- and second-grade students studying endangered species (see Table 14.1). The correspondence is typical because it progresses from getting acquainted (Interchanges 1 and 2), followed by the older student sharing her research (Interchanges 2, 3, and 5), the introduction of the younger child's topic (Interchanges 4 and 6), and the provision of specific expertise by the older tutor (Interchange 7).

Tutoring, either face to face or electronically, is an excellent means of infusing expertise as well as morale boosting and community building. An example of the latter function is shown in Table 14.2.

The Expert Role: Outside Expertise

This section features two relatively short-term studies (6 weeks) where fourth through sixth graders were linked with outside experts. In the first study (Ellery, 1994), fourth and fifth graders studying Native American culture interacted with two domain-area experts. One expert (E_1) was a member of the local school district office for the study of Native American culture, himself a Native American. The second expert (E_2) was an employee of a local museum that specializes in Native American culture and artifacts. Both experts and students were novice users of electronic mail. The experts had not been trained in the philosophy underlying the COL program—notably to the ideas of guided discovery, zones of proximal development, and developmentally appropriate responses. The experts and their tutees had not met.

The two experts differed initially in how they answered students' queries. The first expert (E_1) began by providing more factual and direct responses, whereas the second expert (E_2) initially acted more like a guide leading students to think about their questions and their research activities. This expert (E_2) responded to a question with another question designed to produce deeper levels of inquiry. For example, consider the following interchange:

W: Hello. My group is studying Southwest Indians, can you help me with this question? What hunting tools did Anasazi people use? Thanks a lot.

TABLE 14.1
E-Mail Interchange Between Second and Fifth Graders

1. Fifth Grader's Opening Correspondence
   How is your research going? I just started a new research topic yesterday. Do you like your research? I like mine, it's whales. If I find any information on your research topic I'll let you know right away. How did you get your research topic? I had a lot of fun working with you, I hope you had fun too. Did you finish that QuickMail letter we working on. Please write back.
2. Second Grader's Response
   I got my research topic by my teacher. We picked three topics and if somebody takes our first choice topic, we go to our second one. If somebody takes our second topic we go to our third one and that's the one we get. What kind of whales are you interested in? I think the killer whale is a good one. I love my research. It's fun. I like Quickmail and research. I like my research topic because it's a fun topic. We have got lots of books but we haven't got a pop-up book yet. And I'm very sure we will. I hope we have it next year too.
3. Fifth Grader's Response
   How are you? I don't know what kind of whales, but I want to research killer whales. Did you like the Black History month assembly? Did you notice that all the songs had a message or was a song from a while ago? I like tutoring because I get to meet other people and their teachers. What's your favorite subject in school? Mine is math.
4. Second Grader's Response
   I like killer whales too. But they are kind of big just like all whales. What other kinds of whales do you like to study? I like sharks too. Do you? I like the big grey shark. What else do you research in your classroom? What kind of animals do you research? My research topic is defense mechanism, and we are on our fourth book. The second book we had was very, very hard. The teacher had to help us a lot to help us understand. What do you like to do? Do you know where polar bears usually live? I think the north pole. Do polar bears camouflage? I think they do.
5. Fifth Grader's Response
   I'm sorry it took me a few days to answer your message. I'm going to be studying the Gray whale. I wanted the Orca but while I was absent they chose their whales and I had to choose from what was left over! See you later!!
6. Second Grader's New Initiative
   My research topic is defense mechanisms, noncolor. I don't know how giraffes don't get sunburnt on their tongues. They are always sticking it out. How do animals defend themselves without color? Like a rattlesnake is deadly because of its fangs. Bye!
7. Fifth Grader's Response
   I know some animals fight back and some run from their predators. Others, like the skunk, spray oders or bit their predators which might poison them. Did you know that giraffes can't lay down!? They can't because if they do they swallow the tongue and die! Well, I hope you can use this information in your research paper. Talk to you later, bye!

Note. All communications begin and end with appropriate salutations; these have been omitted.

TABLE 14.2
A Comment on a Peer-Tutoring Experience Sent by a Fifth-Grade Tutor to Two Second-Grade Tutees

Dear J and A:

I had a nice time working with you guys the other day. I thought you were very nice and I thought you were working in a constructive manner which means that you were being very serious of what you were doing and that you were not being greedy of who will work with me. I would like to work with you again because you were so independent and very different and I like that because that means that you work together nicely because there is so much creativety between the both of you.

J, I like working with you because you were talkitive which means you talk a lot but I like that because that means that you could give me some ideas on a project that you are working on so I can completly understand what you are working on. I also like the fact that you talk a lot because you make since [sense] when you talk. I know some people who does not make since when they talk. I think you will succeed in life because you have the ability to work and be on task.

A, I like working with you because you do not talk a lot and are on task. You are willing to admit that you and wrong and I like that because that means you do not think of yourself as a goody-two-shoes and you are honest. I know some people who are not honest when they talk. . . . I think that you will succeed in life because people will trust you and will want to hear what you say.

I promise the next time it is rainy day I will come in your class and the next time I tutor I will come to your class. See you later.

Although E_2 could have given W a direct, factual answer to his question, she asked him another question.

> E_2: In the museum collection we only have a couple of Anasazi objects, none used for hunting. What kinds of animals did they hunt? That might help you figure out what kinds of tools they needed. Good Luck.

Another example of E_2 providing scaffolding for a student (L) is the following:

> L: What kinds of food do the Apache eat?
> E_2: I can tell you that we have quite a few objects that give clues to what Apache people traditionally ate. For example: Bows, a game catcher, a saguaro stick, a quiver, etc. What do these things tell you? Also you should look at a map of the area the Apache traditionally lived so you can get an idea of their natural landscape; it can help figure out what they ate.

In this exchange, E_2 gave the student (L) some clues to help her answer her own question. Additionally, E_2 suggested another resource (a map) that might also help L answer the question. Responses that provide scaffolding in the form of hints or clues to guide thinking were valued by students and experts alike.

The difference between scaffolding via hinting procedures and knowledge transmission was explicitly recognized by both experts and children (Ellery, 1994). For example, E_1 reported that he became dissatisfied with simply giving answers:

> In the beginning, I was probably giving them too much of an answer, and I would answer more than they really asked for. Which, I thought, was okay, but it absorbed a lot of time. But then I set myself up. Since I gave them all the information to begin with, they would expect more of an answer and consequently got to the point where they needed real specific answers, and I couldn't come up with answers as specifically as they wanted. So, what I felt they were doing was utilizing the resource to actually write their paper, so I would throw the question right back to them. And I felt kind of bad about that because being in the fifth grade, where do you go from there?

This expert spontaneously adopted the hinting mode to allay his fear that he was directly writing the students' papers.

The second expert (E_2) also reported the same transition, although she had more interchanges classed as scaffolding from the outset:

> Initially, I tried to respond directly to their questions, not really knowing what information they had and where they were asking from. That's how I started responding and it wasn't very satisfactory for them; and it wasn't very fun for me. Then I changed more to looking at *how* they were asking questions as opposed to strictly what they were asking about. I changed more to getting them to think critically as opposed to providing the fact-driven answers.

However, E_2 was quite explicit that there was a place for both factual and hinting responses:

> I would use the hints when I thought they didn't know exactly what they were asking. And when they were asking me a question that I thought they had . . . that they knew specifically what they were asking and they had formulated the question well, then I would answer it, if I could. And otherwise if I didn't think that they had really thought through what they were asking, then I would give them clues.

Interestingly, students shared the experts' beliefs that hints and clues to encourage thinking were more useful than factual responses. Of the 21 students interviewed about their experiences with electronic mail (specifically QuickMail; Ellery, 1994), 11 mentioned response styles. Of these, 9 preferred the hinting interactions.

- I really liked the answers that gave you ideas from the questions you asked. They gave me a lot of ideas that I wouldn't get from books or class.
- You learn more by looking up stuff.
- They give me a clue, then I can think of it in my own words.
- The hints and clues help you because you can do it by yourself.
- It gave me a chance to find out the answer by myself, and then I'll know without them telling.

Only two students wanted a direct factual response, and only one of these acted as if she wanted someone else to do her work for her.

- I like it when they tell me the answer because it's easier for me to ask them, rather than finding it myself. That would take a long time.

The other student who preferred direct answers justified this because she was already doing so much independent research:

- I prefer them to just give me the answer because that is helping me. Because I have a lot to do in my research and I'm already looking for a lot, so that's helping me out.

Far from wanting the experts to write their papers for them, the students welcomed the invitation to engage in independent research and higher levels of reasoning.

In general, because of the experts' lack of experience and training and the brief period over which the study was conducted, the sustained interactions between students and experts in Ellery's (1994) study consisted of more fact-based responses than we would regard as optimal. The value of these fact-based interactions, at least initially, for both knowledge and community building should not go unappreciated. An example of a valuable fact-based early interaction is shown in Table 14.3, in which a fourth-grade student sets up and follows through on a lively discussion on gender roles. In Interchange 1, C asked a question about gender roles. Because E_1 assumes that a girl would be more interested in the female role, he responds with details of female puberty (Interchange 2). The student (C) sustains the discussion, but asked for more information about males (Interchange 3). Again continuing the discussion (Interchange 5), C references the information E_1 has sent her and asks for clarification. This fruitful discussion between a fourth grader and an expert continued into other fields, including death rituals and burial patterns. Although largely fact based, the richness of the communication was valued by both child and adult.

TABLE 14.3
Interaction Between Fourth-Grade Student and a Native American Expert

1. C: Hi, My name is C and I'm studying the Cherokee Indians. My questions are; What age do children take on responsibility? What do the Cherokee children start doing when they first take on responsibility? what's the difference between male and female responsibility's In the Cherokee towns? Hope you can help me,
2. E_2: Hi C! Your questions are interesting and can be expanded upon with great answers, but I hope this brief answer will provide you with the information required. If not, write back and we can expound in more detail. At the age of 12 years, females are taught by the older clan women about the changes that are before her. Much of this is about the physical aspects described as "moon" or the monthly periods experienced by girls going through puberty. The responsibilities are taught to the young girl about the beliefs of the family, clans and the overall Tribe. The family and clan are the strongest influences that is provided for the guidance of her social, mental and Spiritual well-being, growing toward a respectful and honorable woman. One of the beliefs is not to marry within your own clan. As matrilineal Tribal people, the decisions are made by the woman of the household. Her oldest brother, with other clan members, will teach the ways of the people to the younger members of the family; about the clans, physical and mental changes for the male, and guided through initiation. Guidance for the young are presented through role modeling. The community is responsible for the overall influence for the young people.
3. C: You have helped me a lot about the responsibilities of the girls, their age and who taught them, but I think I need some more information. What are the males responsibilities? Who teaches them and what age do they start? You gave me a lot of information last time and I hope you can do the same this time.
4. E_1: Hi C; Male role models are very important yesterday as it is today. The male youth first learn that they are supported and will be disciplined in various manner. The Mother is the first role model, providing the loving support and nurturing the male infant. The Father supports the Mother by playing with the child and letting the child discover his new world. As the youth gets older, he undertakes the lighter male role responsibilities and begins to learn that the work load is shared by all family members. Although he may not grind the corn, he is responsible to plant and maintain the corn fields. Managing the livestock is another duty that is usually undertaken by the male. Again, the learning device is to model how things are done by the parents and relatives.
5. C: Thanks for giving me a lot of good information, again. I have a couple of questions about what you wrote.... You talk about things that the boys do. Does that mean that there are certain things that the girls do that the boys can't do and certain things that the boys do that girls can't do. What are some things that only girls can do? Thanks again,

Both of the experts reported so far were untrained (i.e., although they were domain area specialists, they were not used to working with young children). As E_1 states:

> I don't deal very well with young kids—younger students, 10 or 11 years old. They have to be intelligent. I don't mean to degrade them, but I had difficulty simplifying the language. That's where I need to start working: the middle grades and down. I don't usually deal with these people.

In contrast, the next expert was a domain area specialist, was known to the students, and was aware of the first principles of learning underlying the COL project (Campione, Brown, & Jay, 1992). A sample interaction between this expert (E_3) and sixth graders illustrates how a guide can lead students to higher levels of thinking by seeding ideas and pushing for their appropriation. This interaction is shown in Table 14.4. In the first comment,

TABLE 14.4
Interaction Between an Experienced Adult
Working With Novice Sixth Graders

1. DG: Our major questions are (WHAT HAPPENS TO THE BEARS THAT LIVE IN THE ZOO IF THEY CAN'T HIBERNATE?). [The science teacher] said that they don't need to hibernate because they are fed every day. But she said that was only a thought so I am asking you to please help us by giving us all you know and all you can find.
2. E_3: You probably think about hibernating in the same way as you think about sleeping, but they aren't the same. Bears hibernate in response to the weather conditions and the availability of food. If the conditions are reasonably fair (not too cold) and food is available the bear probably won't hibernate. I don't know, but I hypothesize that during the times when bears would usually hibernate, bears in captivity are probably a bit slower, still showing signs of their tendency to hibernate at that time of the year.
   How could you find out if my hypothesis is true? (Hint: provides telephone number of local zoo)
3. M (Member of DG) continues dialogue individually:
   I was wondering if you can find out an answer to this question. The question is does insects hibernate? The reason why we ask that is because [classroom teacher] read a book named Once There was A Tree. And in it, it said something about the insects slept in the bark of the tree when winter came. then when spring came they got up and did what they usually do till winter comes then they start all over again.
4. M: Bears hibernate because what ever they eat is gone during the winter (like berries) and they can't eat so that's what hibernation is for. It is for them to get away from starvation. So what does truantula's eat? Can they always get their food? If they can't get their food would they have to hibernate or die? Could we ask somebody that knows about insects?

   [Long discussion about insects in general]
5. E_3: So you ask . . . what does this have to do with your questions about hibernation of spiders? Consider the difference between the life style of your typical mammal and that of the typical insect. Why is hibernation important to some mammals? Why might hibernation not be a successful strategy for most insects? Some insect, such as tarantula, live for 10 or more years. Do you think that they might hibernate? How might their lifestyle be different from that of other insects.
6. M: I'm not really sure if tarantulas hibernate. What do you think?
7. E_3: I'm really not sure either. I do know that insects are cold blooded which means that they don't have a constant body temperature. This means that they depend on warmth from the sun or other objects in order to become active (move around and hunt). This happens pretty much every day. As the sun sets and it gets cold and cold blooded animals slow down. But hibernation is something that happens over a greater period of time (over a year rather than a day). Where do you think we could find out more about this question?

Note. Initiation by group DG querying the status of hibernation for incarcerated bears.

the expert responded to a query concerning hibernation with some information (Utterance 2). Admitting that he did not really know the answer, he suggested a hypothesis and provided a phone number for the group to find out more information on their own volition. Throughout the interchange, E_3 systematically seeded three pieces of information critical for an understanding of hibernation: the availability of resources, longevity, and warm versus cold bloodedness.

The topic is then dropped by the group, but taken up by one group member (M) who is majoring in insects and wishes to know about hibernation patterns in insects. She inquires to the network in general (Utterance 3). Receiving no response, the student then addresses E_3 directly about the topic (Utterance 4). As a gesture of good faith, she begins by offering some facts of her own before asking for information.

E_3 responds (Utterance 5) with another prompt to encourage the student to take the initiative and contact experts, this time at another zoo, pointing out that the contact person there is ready and willing to help. After two other interchanges, not shown in Table 14.4, E_3 responds again. Following a lengthy paragraph on the reproduction and survival strategies of insects, he continues with a series of questions intended to push the student to further and further depths of inquiry—a typical strategy of guides in a zone of proximal development. In this communication, he introduces the notion of *longevity*, prompting M to consider that, if an insect lives only one season, hibernation would not have much survival value for the species (Utterance 5).

Resisting this lead, M again adopts the easier path of asking for direct information (Utterance 6): "I'm not really sure if a tarantula hibernates. What do you think?", to which E_3 again responds with some critical information about warm bloodedness. The interaction continued for several days. E_3 gradually seeds the zone of proximal development with three critical pieces of information during this exchange. M picks up on two of these features (availability of resources and longevity), although she never understands warm bloodedness (Utterance 7).

Student Roles

Even in the brief studies described in this chapter (Brown & Campione, 1994; Campione et al., 1992; Ellery, 1994), fifth- and sixth-grade students were seen to: (a) engage in sustained inquiry over time, (b) emerge as experts, and (c) modify their questions with experience.

Sustained Inquiry Over Time. Both Tables 14.3 and 14.4 give excellent examples of students engaging adults in sustained inquiry over time. In Table 14.3, responses are more factual; in Table 14.4, they are aimed more at scaffolding reasoning. In both cases, the child is clearly the initiator (so too is the second grader featured in Table 14.2).

Students Emerge as Experts. In these dialogues, students emerge as experts as well as novices. For example, the following exchange took place between a fifth grader and both Native American experts:

> V: [V sent the following question to both experts at the same time]
> Hi. I am studying the Cherokee Indians. What is the real name for the Cherokee tribe and what does it mean? Thanks.

V got an answer from E_1 first. He told her what the Cherokee real name is and what it means. V then got the following response from E_2:

> E_2: I am pretty sure that the Cherokee refer to themselves as Cherokee. If you confirm that from another resource please let me know.

V quickly wrote the following response back to E_2:

> V: The word *Cherokee* is a French word derived from a Choctaw Tribal word for "The People of the Caves." The Cherokee call themselves Tsalag (pronounced Ja-la-gi) meaning "Principal People." Hope this information helps you answer other people's questions. Thanks.
> E_2: Thanks for filling me in; that is very helpful.

Question Changes Over Time. With increasing experience, the quality of student questions go from simple to more complex. For example, the following early student questions were classified as simple:

> Did the Hopi ever make their own tools?
> What kind of Indians made their houses on cliffs and out of rock?
> Is there more than one Southwest Indian tribe?
> I read in a book that Native Americans came down from the North. Where in the North did they come from?

In contrast to the preceding excerpts, these later questions could be classified as complex:

> How did the Hopi first learn how to make the tools . . . when there was no one around to teach them?
> In another person's group, you said women were very important. So if women were so important, why did you enroll in your mother's tribe instead of your father's tribe.

> Did the Apache women ever do anything the Apache men didn't do? This topic is interesting because I think that women should have equal rights as the men did and I am wondering if this true for the Apache.
>
> I was wondering if the people of the Pacific North West really believe that they had to return all bones and pieces to the water for the fish to come back to life?

The use of experts on QuickMail as a medium for sustaining and expanding zones of proximal development has exciting possibilities and is an essential feature of our learning environment. Through this medium, the knowledge community is enriched by the creation of wider and wider zones of proximal development for its members.

CONDITIONS CONDUCIVE TO THE USE OF E-MAIL

Merely rubbing a student up against electronic mail (e-mail) does not lead to spontaneous use. There needs to be a purpose for the activity and a rewarded purpose at that. After several successful and not-so-successful attempts to foster QuickMail use, primarily in upper grade children, we have found five factors that are likely to encourage use: (a) the system is robust, (b) there is a quick response, (c) an adult (classroom teacher or researcher, even an older student) models and regularly uses the system, (d) the respondent is known to the student in some way or other, and (e) there is a clear purpose for use.

The System Is Robust

It is notable that the students and experts (Ellery, 1994) were able to engage in the kinds of productive exchanges illustrated earlier despite less-than-ideal conditions. During the first half of this study, QuickMail was never up and running consistently for a 24-hour period. For the most part, students were able to sustain interest in their queries although some had to wait over 5 days for a response. The experts were extremely tolerant of the technical difficulties. During one of the times when the system was down, E_1 wrote his responses in a word processing application, printed them out, and a researcher picked them up and delivered the printouts to the students by hand. However, this is not the real world that inner city students are likely to face, and we wish to study the real world rather than the ideal.

Quick Response

The second desideratum for fostering use of the system, obviously related to the first, is that there is a quick response. This is particularly true for younger children. Indeed, second graders seem to have the idea that someone is sitting at the other end in real time (akin to a telephone) ready to respond to their queries as they occur. Accordingly, they are initially disappointed if answers are not quickly forthcoming. This need for instant response is not entirely missing from fifth graders' evaluations:

> Remember, I said they should take a day [to respond]. I think they could be on their computer at a special time, and while we're writing out stuff, they can—like—listen to what we're writing at the same time they're writing.

In one study (Ellery, 1994) of 21 fourth- and fifth-grade students interviewed about how long was a reasonable time to wait for a response, 38% wanted a reply within 1 day and 33% wanted a reply in 2 to 4 days. The remaining students who could tolerate larger delays were, interestingly enough, the least intensive users of the system. By fifth grade, however, students were beginning to realize that their demands might be unreasonable:

> It doesn't have to be today, some people are very busy.
>
> It doesn't matter because they should be able to take their time to do it—I'm not a rushing person.

In view of the need for a quick response, the time demands on experts should not be underestimated. Both of the experts responding to the prior children were busy professionals who needed to fit this responsibility in with other demands on their time. Expert 1 reported spending 20 hours a week at peak time and felt that he was overextended. Expert 2 reported a fairly consistent 6 hours a week. Expert 2 also reported that, because of her other responsibilities, it would be impossible for her to give a regular 45 minutes a day; she could only get to the task opportunistically.

One way around this problem is the use of gate keepers who moderate between the experts and students. We have used undergraduates to respond to the students' mail regularly, with comments such as: "X is out of town and won't be back until Monday," "so I've sent your question to Y," or "I'm not really an expert, but I think ___, let's check it out when X returns." This mollifies the eager young correspondents.

Adult Models and Uses

Our most successful episodes of e-mail adoption have been under conditions where an adult—preferably the classroom teacher—encourages students to use e-mail, sets aside regular time for its use, models how to use it, and is seen using it him or herself. Under conditions where the students are not given time for use in the classroom but must steal time from other activities, use is sporadic at best. It should be pointed out that few of the students with whom we work have access to computers outside school hours.

In one successful QuickMail classroom, the teacher modeled the use of computers on a daily basis, spending a minimum of 1 hour a day using the computers in the classroom, communicating through QuickMail or doing miscellaneous writing or planning tasks (ranging from organizing a kickball game to preparing homework assignments). As she put it, "They see me using the computer all the time." The teacher's attitude toward both her own and her students' use of computers was extremely positive. There was a strong sense in the classroom of the teacher enthusiastically joining with the students in the use of the computers.

This teacher showed early and consistent recourse to the use of QuickMail, corresponding with the students concerning their written projects, assignments, and often their personal life. She also corresponded with fellow members of the research team at Berkeley in the presence of students, thereby modeling the transmission of queries and comments and the receipt of replies. Students readily began communicating with one another and the University staff, due, in good part, to this modeling and encouragement. As a result, the students used e-mail as a routine part of classroom life.

In contrast to this, teachers who neither use the system nor provide time and encouragement for student use rarely foster an atmosphere of constructive use. Both students and experts are sensitive to these differences.

1. Experts:
   - I really would have liked more communication and collaboration from the teachers.
   - It was incredibly frustrating for me not knowing what the guidelines were and then realizing that there were none.
   - I think it would help if the kids' activities were valued and rewarded.
   - They (the students) are working against the grain if they have to sneak time to use it.

2. Students:
   - I really needed longer periods for researching and using QuickMail.
   - I would like the teacher to help us sometimes.
   - I wish she would let us do it more often.
   - I think it should be more organized.
   - We had a schedule, but it got messed up. She (the teacher) should get on the computer more herself.

- It's hard because we never get time to be on the computers and we forget.
- She should let us get on the computer each day with different groups.

Known Respondents

It is nice, but not completely necessary, that the expert be known to the students. This is again particularly true of younger children. Our greatest successes have come when the students have met the experts and know them personally. To this end, we have the students visit the University personnel and experts with whom they will interact. After such visits, the volume of correspondence picks up noticeably. Students select a friendly expert and address their comments to that person. This is particularly noticeable with second-grade students because they respond primarily to regular visitors to the classroom or their tutors in sixth grade (i.e., those who are regular face-to-face conversational partners, as well as e-mail correspondents).

Of course this is not a necessary requirement because many belong to networks where they do not know the participants personally. However, most of these distance learning circles take pains to have a "getting to know you" phase at the outset (see Riel, chap. 15, this volume).

Purpose for the Activity

Predictably, e-mail is rarely used by students unless there is a clear purpose for the activity. Within-classroom communications are somewhat forced because it is easier to engage in face-to-face communication with peers sitting 5 feet away. The most successful within-class activities have been crosstalk between research groups and teacher–student feedback of the traditional type, where a teacher comments on a student's work. Other systems are more suitable for sustaining within-class discourse (e.g., computer supported intentional learning environments [CSILE]; Scardamalia & Bereiter, 1991).

Our most successful use of e-mail has been to facilitate cross-site or cross-age collaboration. Just as in the case of correspondence with an outside expert, communication with peers at other sites or with younger children within a school (doing research on a similar topic) has a transparent meaning and purpose readily understood by all participants.

DISCUSSION

Although we are encouraged by the richness added to community resources that e-mail provides, we regard this work as pilot in nature. We have reported on interactions that were sustained for no longer than a 6- to 8-week period.

Our future plans call for a major effort to sustain e-mail over extended periods of time using a web of expertise that is interconnected. We also believe that, with careful preparation, the participation of both adults and students can be enriched and refined.

In the case of adult domain area experts, we believe that a training period where they are introduced to the key COL principles will enable them to adopt the role of coach in the guided discovery process, self-consciously and deliberately scaffolding students to higher levels of competence. We are encouraged that both of our novice experts spontaneously adopted this role and were aware of the differences between it and knowledge transmission alone. However, the experts were experienced teachers and we cannot assume that all experts will have this background.

Another form of background knowledge that will greatly enhance the contribution of adult experts is information concerning what can be expected of children at various ages. Note that at least one expert (E_1) felt uncomfortable with young children, feeling it necessary to simplify his language. Several students judged his commentary "too hard for kids to understand."

Simplification is not just a question of language. Indeed, in face-to-face interactions within COL, there is a deliberate attempt to enrich technical vocabulary and concepts so that discourse emulates disciplinary, mature usage rather than simplification (Brown & Campione, 1994). Simplification is a difficult concept that has bedeviled the design of science education. In contemporary curriculum design, for example, a misinterpretation of Piagetian theory has led to a consistent underestimation of young students' capabilities. A seductive simplification of this theory has encouraged sensitivity to what children of a certain age cannot do because they have not yet reached a certain stage of cognitive operations. Guidelines to experts of what to expect from children of certain ages must be couched in terms that lead them to push for higher and higher levels of competence—the upper limits of the zone of proximal development—rather than lower levels gated by so-called stages of cognitive development.

Children will also benefit from the provision of training in how to use expert resources. They already know that experts can be manipulated.

Question: Did you ask the experts questions that you could find out about in the book?
Answer: Yes.
Question: Was that a good use of the experts?
Answer: No.

Even young children can be encouraged to use overburdened experts wisely and sparingly. One class of sixth graders successfully distinguished between: (a) questions that required expert help versus those they could find out about themselves, and (b) picky, detail questions versus thinking questions (those that make you think). Sensitivity to these distinctions, coupled with a certain degree of rationing of expert time (only N questions permitted per week), did lead to strategic and economical use of experts' advice.

The second form of training that children need is that of research ethics. Without explicit instruction, grade school children feel free to incorporate expert correspondence into their own work without attribution. In this sense, there is a danger that experts online will do their papers for them, as one of our experts feared. At least by fifth and sixth grade, students can be made aware of this problem, coming to readily reference outside sources via footnotes and bibliographies.

Children apparently need to practice experiencing ambiguity, uncertainty, or the unknown. The epistemology of grade school children is such that they believe there are answers to every question and that those answers are known to someone if they can just locate the source. A great deal of modeling and discussion is needed before they realize that provisional knowledge, and the ability to reason in the absence of complete knowledge, is an exciting part of research. Experts can lead them in this direction.

Finally, students need to be led away from the notion that more is better—that research consists of the accumulation of as many facts as possible. By fifth or sixth grade, they are beginning to realize that it is appropriate to think more about less, to consider a central principle deeply, and to revisit it often. Again, guidance by experts is an important avenue for instilling these habits of mind.

Extending a learning community beyond the classroom walls to form virtual communities across time and space not only enriches the knowledge base and modes of reasoning to which its members are exposed, but also helps students develop interpersonal and intellectual skills necessary for survival in the technological future (see Riel, chap. 15, this volume). Schools of the future will require high literacy (Miller, 1988; Resnick & Resnick, 1987) and alternatives to Victorian schools are needed to foster such practices. Designing schools to form communities of learners that extend beyond the classroom walls is one step in this direction.

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CHAPTER

15

LEARNING COMMUNITIES THROUGH COMPUTER NETWORKING

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The chapters in this book address the gradual evolution in our conceptions of learning and teaching in schools from cultural transmission to knowledge construction. Contributing to this transformation is current research exploring the social dimensions of intellectual development. These constructivist theories of education and social theories of cognition are also guiding the current reform effort in educational settings in schools and the workplace.

This chapter describes how a Learning Circle, a program of cross-classroom collaboration, or *telecollaboration*, embeds learning in social and educational experiences extending beyond the classroom. Students and teachers form partnerships with peers around the world to accomplish educational tasks they collectively construct. The rationale for this unique model of network learning is based on constructivist theories of education, social theories of cognition, and shifts in nature of work in our society.

RATIONALE FOR LEARNING CIRCLES

Education: From Cultural Transmission to Communities of Practice

The cultural transmission model of education is currently invoked in cultural literacy or back-to-basics programs, where *the basics* are the great ideas of Western civilization and literacy is the conceptual understanding of discipline knowledge (Bloom, 1956; Hirsch, 1987; Hirsch, Kett, & Trefil, 1993). These approaches prepare students for their future by determining a core of cultural knowledge, developing a detailed scope and sequence of the information, and motivating students to master this material by manipulating positive and negative reinforcers (Skinner, 1957; Thorndike & Gates, 1929).

Information is distributed through teacher lectures, mimeographed worksheets, and textbook chapters. Teachers are provided with a set of grade level expectancies detailing the exact content and skills to be taught. Drill and practice orchestrated by the teacher define student-teacher interactions. Students are to learn or memorize the information and demonstrate mastery by responding to a random selection of test items taken directly from the given material.

Cultural transmission models of education have been subjected to a number of criticisms, both in theory and practice. In strong contrast to cultural transmission, Piaget's (1952) investigations of the origins of intelligence outline a process in which learners operate on information to construct their view of the world. For Piaget, thinking is acting and operating on ideas, not passively storing information. His contemporary, Vygotsky (1978), emphasized the sociocultural context of knowledge construction. Interaction or social actions such as conversation, argumentation, and justification underlie intellectual development. Dewey (1916) and later Bruner (1973) have written extensively on education as experience—active manipulation and experimentation with ideas—rather than education as accumulation of static knowledge. At the beginning of this century, Dewey (1916) saw an eminent danger in organizing classroom learning as the study of texts, however well organized:

> As societies become more complex in structure and resources, the need for formal teaching and learning increases. As formal teaching and training grows, there is a danger of creating an undesirable split between the experience gained in direct association and what is acquired in school. This danger was never greater than at the present time, an account of the rapid growth in the last few centuries of knowledge and technical modes of skill. (p. 9)

Dewey wanted to involve students in experiential learning. For example, science could be taught in a more meaningful way by experimenting with growing plants, building machines, or inventing new ways of solving historical problems. Bruner (1973) extended the constructivist position, arguing that,

> the principle emphasis in education should be placed upon skills—skills in handling, in seeing and imaging, and in symbolic operations—particularly as these relate to the technologies that have made them so powerful in their human expression. (p. 497)

Criticisms of the cultural transmission approach to education also arise when school practice is examined. Science teachers worry when their students are unable to apply their textbook knowledge to phenomena in the world (Lockett, 1993). More energy is focused on the mechanics of learning to read than on the more critical skills involved in reading to learn (Brown & Campione, 1990, 1994). Applying thinking skills to the reading process is left largely up to the student. This parallels current critiques of math instruction as overly concerned with teaching math facts rather than problem-solving skills and strategies. Similarly, there are criticisms that language arts instruction is divorced from critical communication and audience considerations (Cohen & Riel, 1989). Opportunities for classroom communication are often restricted to highly scripted student–teacher exchanges (Mehan, 1979), which reduce teachers and students to having mindless exchanges of information (Freire, 1970).

In response to these criticisms, current frameworks and plans for educational reform call for a redefinition of students' work (Agee, 1992; Alexander, 1991; American Association for the Advancement of Science, 1992; Association of American Geographers, 1987; Ministry of Education, Province of British Columbia, 1991; National Commission on Excellence in Education, 1983; National Council of Teachers of Mathematics, 1991). All of these documents portray student learning as an active process of locating information, evaluating its usefulness to accomplishing tasks, solving problems, or constructing new meaning in social settings. In the constructivist view of learning embedded in current reform movements, students are encouraged to develop a rich repertoire of strategies for gaining new knowledge (Stringfield, Ross, & Smith, 1996). Critical reading enables students to focus on the meaning of texts while monitoring their level of understanding and the usefulness of information for a specific purpose (Brown & Campione, 1990). The value of an idea or understanding is closely tied to the ability to express it to others (Ball, 1993; Lampert, chap. 2, this volume). Students are encouraged to find the best way to convey their understandings to others, persuade others to follow their path of thought, or provoke others to challenge their understandings. Students are encouraged to learn how to observe, integrate, communicate their own ideas, and work with others to construct shared understandings of their world (Resnick, Levine, & Teasley, 1991).

These reform plans also redefine the role of teachers. When education is defined as transmitting bits of information to students, teachers could expect to teach from a set of materials mandated by the district or state for each grade level. If students or parents complained about what was taught, either content or process, these objectives were invoked. Defining education as knowledge construction, rather than knowledge transmission, places teachers in a different role. In most of the current educational plans, teachers are to take increased responsibility for organizing learning environments sensitive to the ethnic, linguistic, and socioeconomic characteristics of their students (Darling-Hammond, 1997; Meier, 1995). Teachers and students are encouraged to work collectively to build on expertise and interests that arise from their work as part of local and global communities (Ruopp, Gal, Drayton, & Pfister, 1993).

The model of a teacher as the primary source of content or discipline information changes to a model of the teacher as one who helps establish settings for the construction of shared understanding among students and between students and resources outside of the classroom. To assemble these communities of practice, teachers need to encourage thoughtful dialogue among students and model information-searching strategies to extend ideas beyond personal limits of the group. It is extremely difficult for teachers to accomplish this goal given their isolation in traditionally organized classrooms and schools. Teachers need ready access to both informational and social resources (Riel, 1990). The Learning Circle model described in this chapter is one way of providing these additional resources to teachers and students.

Social Cognition: Contextualizing Thought in Communities of Practice

Cognitive psychologists have characterized intellectual development as a sociocultural process (Bruner, 1973; Cole, 1988; Lave, 1988; Norman, 1980; Vygotsky, 1978; Wertsch, 1985). Vygotsky proposed that intellectual construction is first and fundamentally a social process and that individual cognitive processes result from an internalization of interaction with more competent others using cultural tools. Increasingly social scientists are exploring ways in which individuals work within systems where the actions of one person only have meaning within a larger context of shared understandings as a kind of group mind (Hutchins, 1993). Others demonstrate how learning takes place in construction zones (i.e., social settings where talk and action among people with different skills motivate intellectual development; Newman, Griffin, & Cole, 1989).

Knowledge construction is rarely done in isolation. Culture and cognition create each other (Cole, 1985). People in a field work together to build on the ideas and practices of the group. In this model, learning takes place in communities of practice (Lave & Wenger, 1991; Pea & Gomez, 1994; Ruopp, Gal, Drayton, & Pfister, 1993). A *community of practice* is a group of people who share a common interest in a topic or area, a particular way of talking about their phenomena, and tools and sense-making approaches for building their collaborative knowledge with a sense of common, collective tasks. A community of practice may be large, the task general, and the form of communication distant as in a group of mathematicians around the world developing math curriculum and publishing their work in a set of journals. Alternately, the community of practice can be small, the task specific, and the communication close as when a team of teachers and students plan the charter of their school.

One role of the school is to increase the diversity of learning experiences and provide an ordered and structured development of knowledge and skills. When the work of schools is carried in isolation, students fail to learn some of the most valuable lessons that school and culture have to offer. This shortcoming of formal education has been a topic of concern for as long as schools have been a cultural institution (Dewey, 1902, 1916; Goodman, 1964; Holt, 1964, 1967; Sizer, 1992).

Group work provides a context for the externalization of thinking. It allows for the discussion of multiple perspectives and helps all the participants realize that each person creates one of many perspectives on a topic or problem. Learning to see from the perspective of others helps create a more complex understanding of situations. Learning how to use distributed expertise as a resource and organize a team of people to accomplish a task are some of the lessons that have been missing from the cultural transmission approach to teaching and learning (Brown & Campione, 1990, 1994).

From a social cognitive perspective, the instructional strategy involves students as participants in communities of practice. They do not memorize scientific facts in isolation, but instead engage in the practice of science in context.

The Demands of the Workplace

The Department of Labor calls for school reform that gives the development of social skills a central focus in the design of learning. Using a "working backward" problem-solving strategy, the Secretary's Commission on Achieving Necessary Skills (SCANS; 1991) has asked, "What skills does the workforce want of new workers leaving school?"

The Secretary's Commission asserts that education should provide students the competence to use resources, information, and technology. They need to be able to work according to timelines, find and analyze information, and apply the best technical tools to solve specific problems. Students must be competent to work with people from diverse backgrounds in teams respecting and incorporating multiple perspectives. They need to develop flexible understanding of systemic relationships and consequences.

These competencies require a solid foundation in basic, conceptual, and personal skills. Workers must be able to read well enough to understand and interpret diagrams, directories, correspondence, manuals, records, charts, graphs, tables, and specification. Workers also need to be able to communicate ideas through written language and numerical symbols. Also important are the skills to listen and speak well enough to describe complex systems, diagnose problems, understand concerns of others, and share ideas for solutions. Workers need the personal strength and character to use their skills productively and ethically. These three foundation skills and five competencies, taken together, provide a blueprint for the design of educational programs. This blueprint supports a social constructivist approach to learning.

LEARNING CIRCLES: CREATING GLOBAL LEARNING COMMUNITIES

Constructivist theories and current prescriptions for teaching define a classroom where students and teachers are actively involved in partnerships making sense of a complex and changing world. Computer networking provides a set of cultural tools that can be used to facilitate collaboration within and between classrooms as well as encouraging students to reach out to educational opportunities in their communities and across the world. Although computer technology can support these new structures for collaboration, it is the cultural definition of the tools and not the tools themselves that define their use in schools.[1]

The educational design of the Learning Circles is based on constructivist theories of learning and social theories of cognition briefly described earlier (Riel, 1992a). Learning Circles also provide one strategy for helping students develop the skills and competencies that the Secretary's Commission identified as central to the development of a creative and productive workforce. Technology places many new tools in the hands of teachers and students; these tools make an active, constructive form of education possible even within the constraints of existing classroom organization.

The term *learning circle* is drawn from two contexts: one from school and one from the business community. Each of these contexts provides a metaphor for thinking about the electronic structure of Learning Circles. In the

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[1]This point was reinforced recently when a delegation of math and science educators from Japan were touring U.S. supercomputers and programs of educational telecommunications. During a visit to UCSD supercomputer, there was an enthusiastic description of how educational telecommunications supports collaborative learning. After listening, one of the delegates offered the following observation:

> In Japan, the teachers do a very good job of teaching in groups. This is not what inspires our interest in educational telecommunications. Instead, we are looking to telecommunications as a tool to create more opportunities for self-directed, individual work.

This observation serves as a reminder that computer technology is a tool, a practice. Likewise, the educational design and use of technology is culturally and socially defined (Mehan, 1989).

primary school, circle time is a period of the day when students in a class come together to share information with each another about themselves and their families. The goal of circle time is to develop oral communication skills in face-to-face groups, bringing family experiences into the classroom. The Learning Circle provides a setting for elementary and secondary students at different schools to come together to share information about themselves, their schools, and their communities. The goals of a Learning Circle include the development of written communication skills with distant audiences and the use of a range of local resources to explore global issues.

The term *quality circles* in the business community refers to participatory management practices. In these work situations, the hierarchical boundaries between workers and managers are replaced with distributive participatory management. In Learning Circles, teachers and students operate together as a school team. This cooperative approach to decision making and management describes the way teachers work with each other in a Learning Circle as they design educational activities to extend student knowledge and skills. Each teacher in the Learning Circle is both a learner and a part of the management team. Teachers can, and often do, extend this management role to their students. The partnership makes it possible for everyone to accept a more distributed base of knowledge and resources in each of the partners.

Learning Circle Themes and Curricular Integration

Constructivist approaches are not necessarily in conflict with structured curriculum. Teachers need to have well-defined plans for instruction and a clear sense of educational objectives. Skillful teachers are able to engage students in critical thinking about issues and draw on what students already know or believe about the subject. Ideally classroom projects are closely tied or integrated with their overall plan of study. Curricular integration is one of the problems that many teachers report when they search online networks for activities related to their classroom activities.

Learning Circles are teams of six to eight geographically diverse classrooms joined by the selection of a specific curricular theme. These themes help match teachers working in similar disciplines. However, each of the separate classrooms has its own curricular plans and constraints defined by local, regional, or national policies. This creates a paradox in terms of selection of projects. No one project will fit the needs of all the different classrooms.

The Learning Circle solution to this paradox is to have each of the classes sponsor one of the Learning Circle projects. As project sponsors, the class assumes a greater responsibility for the overall design and success of the project. The sponsors must describe the project in sufficient detail that distant students are clear on how to participate. The sponsors are responsible for analyzing and summarizing or editing and formatting the contributions from all of the participants for inclusion in the final publication. The work on their sponsored project often accounts for over two thirds of their Learning Circle interaction, and this work can be designed to extend the existing classroom curriculum.

In exchange for the work of distant students on their project related to their classroom activities, each teacher accepts the reciprocal obligation to have his or her students respond to other schools' projects. Sending information is less time-consuming than sponsoring a project. By dividing the classroom into teams, the work on all of the other projects can be done simultaneously, which greatly reduces the amount of class time required. In many cases, collecting the information involves community explorations that can be assigned as homework. Because there is another teacher and/or class directing each project, students' questions and problems can be directed to them. The classroom teacher does not become an expert on each of the projects. He or she can legitimately not know much about a given topic ongoing in classroom sponsored by another teacher. In working with students to find the information, teachers model learning rather than teaching strategies.

As the information is collected, the sponsors are each responsible for publishing their section of a *circle publication*. Completing the circle publication marks the end of the circle. If schools continue to be involved, they become members of a new Learning Circle in the next session as they might take a new class at the end of a semester or term.

The main focus in Learning Circles is on the interactive learning environment; the technology, like the acoustic properties of classrooms, facilitates the interaction. Using technology, it is possible to model for a short period of time the relationships that exist among a community of researchers. Research teams work on their own project, but they do it within a community exploring similar problems and exchanging their ideas and work through publications. Learning Circles create this sense of personal ownership of a specific issue or problem and collective exchange on a set of issues within an intellectual community.

THE STRUCTURE OF LEARNING CIRCLES

Learning Circle interaction is organized into phases, each with goals and tasks facilitating cooperative planning among the participants. To facilitate group work, teachers select a Learning Circle theme (Computer Chronicles, Mind Works, Places and Perspectives, Society's Problems, Global Issues, or Energy & the Environment) defined by a curricular focus (journalism, creative writing, geography and history, social science, and science) at a grade level grouping (elementary, middle, and high). Classroom Connections Learning Circles are shorter introductory session with a cross-curricular focus and grade level choices.

Learning Circle interaction occurs in a series of phases:

Learning Circle Phases	*Objective*
1. Opening the circle	Team-building activities
2. Planning the projects	Goal and role definitions
3. Exchanging student work	Implementation
4. Organizing the publication	Reflective writing
5. Closing the circle	Task completion and renewal

A Learning Circle is a group conversation carried over electronic mail in slow motion. Between turns of talk, a great deal takes place in the classrooms as a direct result of either the sending or receiving of information. Therefore, what takes place online is only half of the story. Learning Circles are virtual communities that exist both online and in the interaction in each of eight classrooms.

A subset of messages from an introductory Classroom Connections Learning Circle is used in this chapter to illustrate Learning Circle interaction. The focus is primarily on one classroom in Arizona that was part of this circle. This choice was made for a number of reasons. First, because it was an introductory session, the project interaction phase takes place over 6 weeks rather than 14 weeks of the theme sessions. This makes it possible to share the whole set of messages exchanged on the project sponsored by the student in Arizona. Second, this small number of messages illustrates how local perceptions can lead to different assumptions and how group dialogue across settings can provide a more systemic understanding by placing a local problem in a wider context. Third, the work on this simple project demonstrates how a class can take a topic that is of high local interest and transform it into a topic of interest for distant students. Finally, the messages index teamwork both within and between classrooms. Classroom discussions briefly described in these messages are critical for understanding the effect of this model on student learning.

Opening the Circle: Team-Building Activities

Collaborative learning depends on creating a sense of team membership and responsibility. Teachers receive their circle materials including a curriculum guide, software, and online account before the opening day of their Learning Circle. The circle opens with a message introducing the circle participants. It is at this point that teachers and students discover what cities and countries are represented in their circle. The participants begin not as individuals searching the network for something appropriate, but as a group of classes that share some common assumptions about the interactions about to take place.

Introductory activities are organized to help teachers and students learn more about one other, their schools, and their communities. These activities include electronic roll call messages, teacher profiles, class letters, and student surveys exchanged online and, during longer sessions, welcome packs sent through postal mail with school and community materials and pictures. These activities help students develop a sense of who their partners are and some basic understanding of how they are similar or different. The partial class letter from the Navajo students in Arizona (see following box) is a good example of how a class of students introduces themselves as a group.

Class Introduction:

Ya-at-eeh to our Learning Circle friends,

Ya-at-eeh means "hello" in Di-ne Bizaad or Navajo. Most of us speak our native language but most of us don't write Navajo. We have cats, dogs, cattle, and horses. We like mutton stew, roasted mutton ribs, and fry bread.

Our school mascot is a hawk and our school colors are turquoise and silver. We're members of Jr. AAGT (Arizona Association for Gifted and Talented). Our local chapter or organization is the Red Ridge Chapter. We have formal meetings each month.

We're part of Apache Country and we do have a county fair. The big attraction is the Navaho Nation Fair, which takes place in September. Rodeos, POW WOWS, and song and dances are common on the reservation.

Some of us live in Sanders, which has a population of about 300, and some of us live on other little towns (Wide Ruins, Pine Springs, Lupton, Burntwater, Hauch) but most of us live out in the country. We have to ride the bus for an hour or more because the roads are not paved. When it snows or rains, it takes longer to get to school or home.

What do people do here? They work at the school or the Port of Entry (we're near the New Mexico border) or the Red Barn Trading Post and other stores, or they work for the Tribe. Sanders is about half-way between Flagstaff, Arizona and Albuquerque, New Mexico.

[The names of 17 Navajo students]

Planning Circle Projects: Goal and Role Definition

Constructive learning takes place when there is a sense of ownership over work. Each class in a Learning Circle has the opportunity to sponsor a Learning Circle project that requires planning, requesting, collecting, analyzing, editing, and publishing the information collected from circle students. Teachers and students plan and discuss the scale of project work for the session and make commitments to their partner schools. During this planning time, circle news messages describe the individual and group responsibility of each of the classes to the Learning Circle. Teachers and students are encouraged to let the group know what to expect in terms of their participation over the session. The importance of reciprocity in teamwork is stressed. The following box is how the students in Arizona introduced their quest (a short project) in their Classroom Connections Learning Circle (6-week introductory sessions).

Planning the Circle Quest Message:

Circle Quest from Arizona,

First of all, a hearty welcome to our friends in New Zealand! We are excited to be corresponding with you.

Now for our questions:

A company that creates nuclear waste is looking at our county as a place to dump their waste. They have offered our county seat a big sum of money just to have a meeting about it. Some local people say we should at least hear what they have to say. Others ask, "Why should we listen when we already know we don't want any poisons in our environment? We have to think about our children and what kind of world they will grow up in. We don't want these brain washers to come here and try to change our no to yes."

Many of us realize that we already have serious environmental problems we need to work on: where to recycle our trash (we are hundreds of miles from cities), protecting our forests from "multiple use," ranchers killing wildlife so there's more grass for cows, and other poachers who have no respect for wild creatures.

Our county has stayed beautiful because the population is rather small. Apache County is about 50 miles wide and about 200 miles long. In the North, which is Navajo Land, there are red mesas, high grass plateaus, and forests. In the South are high weeded mountains with lakes full of fish and ponds that are home to ducks. Wild horses, bears, cougars, porcupines, skunks, eagles, hawks, deer, antelope, and many other kinds of wildlife abound in our country. We love this place and we don't want it to become America's dump.

Our question is:

1. What can we (and anybody who is facing this problem) do about companies that are trying to use "our backyard" to dump their hazardous waste? (When you think about it, the whole earth is everyone's backyard. There is probably nothing we do that doesn't affect everyone else.)

Please help us answer it in this way:

Do you have a local hazardous waste problem?

Do you believe that disposing of hazardous waste is a local problem (concerns only the people in the dump area), a national problem, or a world problem?

What laws exist to control the problem in your area?

Do they help or hinder?

If you could make a law about hazardous waste, what would it be?

What advice do you offer us in dealing with the company that wants to dump or bury their hazardous waste in our county?

Sanders Elementary School
Sanders, Arizona

The disposal of hazardous waste on the reservation was the a local issue that faced students and their community in Arizona. However, the students in Arizona framed the local issue in a more global context of pollution problems that may be faced by other communities. This project was only one of the eight quests that were explored in this Learning Circle.[2]

Exchanging Student Work: Completing Task Work

Students exchange work on sponsored projects in a reciprocal teaching and learning relationship. Students serve as reporters, authors, poets, or researchers for each other. Sometimes a class is divided into small groups and each group responds to one distant class project. Other times the whole class works as a group sending ideas. The responses sent to the students in Arizona regarding their pollution quest (see following box) are from both small and large groups of students. In some classrooms, the teachers organized whole-group discussions, whereas in other classrooms a small group of students took the responsibility of responding on this issue.

[2]Only messages related to this one quest are included in this illustration, but it is important to understand that each of the schools in this circle posed a separate quest. Here are the quests from the other schools taking part in this circle:

Class	*Circle Quest*
California	Gangs and gang violence
New York	Environmental responsibilities
Kansas	STAR and other drug abuse prevention programs
Massachusetts	History and town formation
North Dakota	Athletes and the Olympics
New Jersey	Animal habitats and rights, and commercial use of animals

Circle Responses to Arizona's Quest

From Massachusetts:

Dear Sanders Elementary School,

We think that you have done a find job so far. Nobody would have nuclear waste in their town. It causes illnesses and sometimes death.

Your problem sounds very serious but you are not the only one with problems. In Massachusetts, we have a waste problem too. Boston Harbor is so polluted that it will not be clean again for a few more years. In one of our neighboring towns (Ashland), the pollution is so bad that in some places you cannot drink the water. There are some laws from our area that we thought you might want to know:

1. To establish the compensation to be paid by the developer to abutting communities pursuant to the provisions of section fourteen. This means that company must pay the town where the waste is being dumped and also the nearby towns.
2. To encourage cooperation between a host community and abutting communities in negotiations with the developer over compensation. This means that the nearby town must also agree to the decisions about the dumping of the waste.

The laws help to some degree, but the problem has not stopped. If we could make a new law it would definitely be to ban all use of aerosol cans or sprays. We think that pollution is a world problem because everybody is affected. The only advice we have for you is keep saying "no" to them. They cannot dump nuclear waste in your town unless you agree. Good luck!!!!!

Your friends,
[Three student names}
[Teacher name}
Elmwood School, Hopkinton, MA

From California:

Dear Sanders Elementary,

We don't have industries in the area surrounding Bixby Elementary and therefore do not have a hazardous waste problem in our small local area. Nearby areas have some problems. We feel that hazardous waste should be dealt with on a worldwide basis. Since we live near the ocean, we have laws about protecting marine life and beach areas. We think that hazardous waste would be disposed of in unpopulated areas. We think you should get your whole community involved and let the company know that you are all against having nuclear waste in a populated area.

From New Zealand:

Tena koutou tamariki ma. Ten koutou kiaarko.
Greetings children. Greetings teachers.

Greeting to our Learning Circle Friends from Ohariu Model School

To Sanders Elementary on Hazardous Waste

Our city has a special tip for hazardous waste and one of our major problems is the disposal of agricultural waste. Agriculturists are being encouraged to use organic forms of pest control. Nuclear waste is not a problem in New Zealand as our laws forbid ships carrying nuclear weapons to enter our waters. The main use for nuclear products in NZ is in medicine and research. Our government has protested strongly over the testing of nuclear weapons in the Pacific.

From New Jersey:

We are lucky in that we don't really have a hazardous waste problem in our town. There is hazardous waste in N.J., however. Major cleanup efforts in the past few years have taken care of all the known dump sites. There are many laws telling you what you could dump where. Companies have gotten large fines and people have gone to jail for dumping what they shouldn't. We have mandatory recycling of glass, aluminum, and newspaper in most areas around New Jersey. The town has put out trash bins and recycling bins around town to make this easier. Littering is an offense you can be fined for. The country has a special place where you can bring things like car batteries and other hazardous garbage.

We all agree that dealing with hazardous waste is a world problem. It starts out as a local problem, then a national problem, then becomes the world's responsibility. It keeps getting larger. It is everyone's responsibility to make sure people don't dump.

Some advice to you from our class:

It is your choice what to do. We know you will make the right decision.
Think of the consequences.
If you want your town to be clean, don't take the chance.
People started this problem, people have to find a way to deal with it.
Do the right thing for our children and the next generation.
How dare they want to dump hazardous waste in your backyard!
It may effect the ozone layer.
Vote against it!

We all agree that it would not be worth the risk and a hazardous dump site is not the best thing for your community. What should be done with the waste is something we are not sure of; some students say it should be dumped in an area were there are not people,

But where??????????????????????????????????

Happy Holidays from the gang at AHSE,NJ

From North Dakota:

North Dakota to Arizona about Hazardous Waste
Greetings Arizona,

Here are some answers to your questions:

Right now, we don't have a hazardous waste problem. The laws are controlled by EPA and the state health department.

If we could make a law, it would be that you have to store hazardous waste away from populated areas. We thought the desert would be a good place. We believe that disposing waste is a worldwide problem.

Grant county in North Dakota decided to apply for a grant (over $100,000) to study nuclear waste storage. The people voted to recall the county commissioners who were in favor of this and that ended that. In effect, they were fired.

Good-by from
D. Moses School
6th Grade, Bismarck, ND

From Kansas:

At the moment we don't have a local hazardous waste problem. We took a class vote and some people in our class think it's a national and a world problem because the nation isn't trying to stop the production of hazardous waste. We don't have any local rules. We follow the rules of the E.P.A. We agree with the class from Bismarck, ND, that we should dump hazardous waste in the desert where no one is around. Our advice to you is talk to them and take the money. But don't change your mind!

Sublette School
Sublette, KS

From New York:

First of all, we want to make a strong statement supporting your stand against outside force coming into your area and using it as a dumping ground for their garbage. Hand in there!

We are also a bit shocked that some of our Circle Quest members advocate using "desert areas" as a dumping ground for hazardous waste. Hopefully it was an oversight on their part. Companies must face reality dealing with disposal of the various wastes that they produce. For years companies situated on Lake Ontario and Lake Erie simply dumped their toxic waste into the Lakes—bringing about a level of pollution that was unacceptable to both man and animal. The state and federal governments finally brought about enough pressure in bringing these practices to a halt.

> The point is industry will ignore the right thing to do if nobody is there to look over their shoulder. They need to acquire a long-range conscience in how they deal with the world in general. If the various industries are clever enough to produce the items that bring them profit, then they should also be responsible for the proper disposal of the toxic waste that they create. Do not be swayed by the companies offering you large sums of money "just to listen."
>
> Man's greed will do him under—so keep the wolf's foot completely out of your doorway. We realize that waste management is a problem that won't go away. With constant shrinking of the world, it's going to grow in intensity. We repeat, the companies must be responsible for waste management. We must stop the killing of the earth through the reckless actions of the various industries. There has to be understanding on both sides.
>
> Hopefully this will happen before it's too late.
>
> We wish you the best of fortune in protecting your land!
>
> Allen Creek School
> Pittsford, New York

In these messages, each group of students expresses a personal concern for a decision that faced the Arizona students. They discussed similarities and differences in local issues. Trying to be helpful, students from North Dakota suggest that nuclear waste be dumped in less populated areas like the desert. Students from New York are surprised by this suggestion because they know that much of the Indian Reservation is likely to be desert. They hint at the solution that the students in Arizona will use.

These messages can provide a rich context for teaching students a range of topics from geography to American history. What takes place online is only a partial glimpse of network learning in classrooms. Teachers can and do use messages like these to motivate student learning. This classroom work is not visible online, but the dialogue fostered by skilled teachers as a result of information in messages maximizes learning in this online context.

The teacher in Arizona reports extensive classroom discussions on all of the projects. The program was part of the Gifted and Talented activities of a small number of students. Interaction with many Learning Circle teachers over the years reveals extreme variation in the way in which Learning Circle work is carried out in the classroom. To some extent this is defined by curricular and time constraints. Teachers who work with the same students across different subjects find it easier to incorporate projects in classroom instruction across the curriculum. Teachers who see students for a single period devoted to a highly specific curriculum topic find it more difficult to utilize the learning potential from the full range of projects.

Many teachers are extremely interested in how their peers in other regions or countries structure learning for their students. It becomes a form of professional development to understand what is taking place in these distant classrooms, what are the important curricular objectives of their peers, and how these other teachers organized instruction to accomplish their goals. Learning Circles provide a window on the practice of teaching in multiple locations.

Organizing Circle Publication: Reflective Writing

Students review and evaluate the learning experience and organize the information received from their peers into a summary to be included in the circle publication. In Classroom Connections Circles, quest summaries are combined with class letters, planning messages, and closing messages to create the "Making Connections" Circle Publication. The following box illustrates the summary sent by the students in Arizona.

Summary from Arizona:

We asked a question about what local people can do when a government or company wants to dump hazardous waste nearby. We heard from MA, KS, ND, and NJ. Here is a summary of their ideas:

–You think you have problems! Boston Harbor is so polluted that it will take years to clean it.
–Hazardous waste should be dumped in the desert.
–Laws should be made to store hazardous waste away from people, like in the desert.
–Don't take chances! Don't let anyone dump hazardous waste in or near your town.

Our Conclusions:

We learned something from this telecommunication project. It is scary to realize that the rest of the nation thinks that because not many people live in Arizona and New Mexico this should be where the rest of the United States dumps its hazardous waste. It's like they're saying, "So what if those desert people and wildlife get cancer and die. There are just a few of the them. Who cares about the desert anyway? Nothing much can live there." Read some books by Joseph Wood Krutch and the Sonaran desert and you will realize that it is as important to the balance of life as your home is.

So what is the answer? We must find a way to recycle hazardous waste. Technology created it. Technology must find a solution. But that doesn't mean the rest of us aren't responsible. We are all the source of the illness of the our mother.

Gaters
Sanders Elementary School
Sanders, AZ

The summary message from the Arizona students encouraged others to read more about the desert to understand its role in the balance of life—in effect, an invitation to extend this exchange into a lesson about the desert. They also offered an alternate approach to the problem of nuclear waste. This final phase of a Learning Circle encourages students to reflect on what they have learned and share this knowledge with others. This process of group reflection and creation of a shared understanding is a critical dimension of learning both in online and classroom settings.

Currently the publishing is done offline in a print document. Learning Circles, sponsored by the International Education and Resource Network (I*EARN), will have access to the Internet WEB. Circle participants may decide to use shared space on the computer to publish their work. A Web frame would be created by the Circle Facilitator and each site would add their section to the Web document. Online publishing will make it possible for students to use color graphics, photographs, and short video segments in their reports. In the short run, this might make it more difficult for students to take their work home to show their parents. However, it makes the finished document available online to a much wider potential audience. Computer displays of students' work in the school library may increase parent participation in "Back to School" programs.

Closing the Circle: Task Completion

In this final week of the circle, students assemble their circle publication. These publications are often presented to the school board, sent to local newspapers, and catalogued in the school library. The last phase of Learning Circles provides students and teachers with a time to reflect on what they have accomplished and make plans for how they might improve on their next session. Teacher and student teams reflect back on their experience, share thoughts on what made it work, and discuss how they might deal with any difficulties in future circles. Then partners say good-bye (see following box) and the session ends.

Good-byes from Arizona

It hasn't been easy but it has been fun! This was our second session on the AT&T Network. My students and I wouldn't have been able to keep with the weekly projects without the technical expertise of my teaching assistant, Roselyn Francis. And, of course, none of this experience with the Frontier of Technology-telecommunication, laser disk teleconnections, CD rom, compacted information would have been possible without the brainstorm of our district's computer specialist and Chapter I Director, Doug McIntyre.

> We are busy working on our publication. Everything seems to move along so fast that I didn't feel the students had a chance to go in depth enough. For example, they each "adopted" one of the schools in our circle, intending to become an expert about that school and state. We never really had time to do that—perhaps because I only have students on alternate weeks and for only 40 minutes a day. So one week some of the kids worked on one project and the following week another group worked on that week's project. It was still VERY WORTHWHILE. You will be getting a couple of photographs from us soon in the regular U.S. mail system.
>
> Here is a poem from some of the students as a way for all of us to say "so long!"
>
> Good-bye
> It isn't easy to say good-bye
> To all of the fun things we did,
> And all of the new friends we made
> We fly like birds in our minds
> And see you afar
> Even through the mountains and states divide us
> If you try, if you really try
> We can all be one in our hearts,
> In our minds
> And in our body.
>
> The students and teachers at Sanders Elementary

Although this teacher expressed problems in keeping up, her class sent a response to each of the quests in the circle and all but one of the classes sent a final summary message. This circle was a good example of reciprocal participation.

LEARNING CIRCLES AND EDUCATIONAL REFORM

Knowledge Construction

Learning Circles have provided a structure where each school has the opportunity to construct a project. Sponsoring a project means that the students must plan and organize a learning experience for others and then evaluate and report on this activity. Designing a project places the students in the role of using information to create a project for distant students. Students and teachers are more involved in learning when they have played an active role in defining the activity. On the Learning Network, extensive expertise in the design of online learning activities is available in printed curriculum guides and through online human resources.

For the planning to be of value, there has to be some assurance that there will be students willing to participate in the project. Learning Circles support project work by establishing the expectation of reciprocity. In exchange for contributions on a chosen classroom activity, a teacher agrees to organize student participation on the projects designed by partner schools. The reciprocity of project participation in the design of Learning Circles avoids some of the difficulties experienced on open conferencing networks, where there are many more people who want to initiate projects than there are people who wish to participate.[3]

The goal of Learning Circles is to have students spend most of their time on sponsored projects integrated with the classroom curriculum. However, responding to distant projects usually involves active knowledge construction. Consider this student reflection on writing for topics sent by partner schools.

> When I start a piece, I think of a way to tie the piece in with a topic that I like and know about. For instance, in my Nordenham, Germany piece, I related a drugged person with the topic of "Should drugs be legalized?" It is important to relate it with the topic as well as it is to have an important and good title. I find this information from personal experiences, such as with my L'Aquila, Italy piece that got published! I related this piece to golf, which I enjoy. On my Ralston, Nebraska piece, I did an editorial on the importance of school sports. I love sports!!! So as you can see, I like to write about things I like and am familiar with. (Matt Brunetti; cited in Olivo, 1994)

This model of cross-classroom collaboration through networking gives students a chance to explore their world through direct experiences with others. These personal experiences often led to active searches for information. Teachers can easily extend the experience by finding films and materials to help illustrate what is learned online. A teacher in Alaska reported being delighted when her students asked her if they could invite the Elders to come to the classroom to help them answer their questions

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[3]In an effort to locate model projects on one of the more successful freenets, Free Education Mail (FrEdMail), the initiators of 900 projects, were asked to report on the outcome of their project. These are projects initiated by teachers with no technical or curricular support. Only a hundred or so teachers responded and from this group only a few dozen projects received active participation from partners. The authors identified 13 projects as good models of online learning (Stapleton, 1992). In contrast, on the Learning Network, as many as 80% of the teachers and students complete their sponsored projects. The quality of projects is impressive and many of the teachers have won awards and honors for their creative project designs. (See TIE Newsletter of the ISTE Special Interest Group in Telecommunications, Vols. 4 and 5, for some examples of contest winning telecommunication project ideas from Learning Network teachers.)

prompted by requests from their distant peers about their past. This contrasted with previous years, when the teacher would ask the Elders to come to the school to teach the kids about their culture.

Communication through computers in Learning Circles encourages students to read and write purposefully. They write to express their ideas and they read to see how their peers respond to issues they care about.

> During this past year in English class, I have written more essays than in my three previous years of school, combined. I think these essays have helped me develop as a writer. (Christopher Swiszcz; cited in Olivo, 1994)

In this activity, language is not a school subject, but the medium of communication and expression. It is this blend of student interest and experience with others that leads to the active, shared construction of knowledge rather than a one-way transmission.

Learning Circle Communities for Students

Learning Circles place students in a special relationship with peers from distant schools. They become local experts on their communities. In many cases, the community of learners extended beyond the classrooms to include people with a range of skills. Consider the following:

1. Clare Devine (NJ) invited Senior Citizens to work with her students in writing newspaper stories for their Computer Chronicles Learning Circle. The students taught the seniors how to use the technology and the Seniors were a rich source of information for responding to the project requests.

2. Bill Burrall (WV) provided a direct yet anonymous way for felon inmates to join his Society's Problems Learning Circle. Students were able to send and receive messages from prisoners serving life terms finding out their views on a range of social problems. The prisoners gave exceptional insights into the consequences of specific patterns of behavior.

3. In Susan Hess' (NY) class, special education students became partners with students in regular classes to participate in circle activities. The students in regular instruction learned about adaptive technology and the range of skills as well as handicaps of their partners. The special education students had the opportunity to work with their near and distant peers in a setting where their writing, and not their personal appearance, would be the center of interaction.

Teamwork among students with very different skills is facilitated by the invisibility of systems of social support on the network. Advanced students may be able to locate information and compose their messages on the computer. Less skilled students may have to work in groups and edit many drafts to create a report of similar quality. However, the amount of time spent or the social supports used to create the writing is not evident online. Only the final product represents the student or group of students. A teacher who works with teenagers who are in a lockup school program because of crimes they have committed says this program is one of the few times when her students pay attention to their work. They ask for help because, they say, they do not want to be seen as dumb kids. The network makes it possible for students from privileged backgrounds to interact with students who have faced the problems of poverty and prejudice without visual markers of ethnicity and class (e.g., brand name clothing, tattoos, or spiked hair) immediately defining the interaction.

Team-building activities at the beginning of the Learning Circle help students to think critically about who they are and how they are similar and different from their peers. Students are surprised to find that sometimes the most extreme differences occur between regions within, rather than between, countries. For example, students in the continental United States quickly discovered that they have more in common with students in European cities—where teenagers played similar sports, had the same computer games, and enjoyed fast food, shopping, telephones, and movies—than they did with students from remote U.S. villages in Alaska, where snowmobiles and planes are the primary means of transportation, where the only phone is in the school, where the only paid job is the teacher, and where mail arrives weekly by plane.

One of the tensions in Learning Circles is creating a strong sense of team or community without devoting too much valuable teaching or learning time to personal exchanges. This requires a strong commitment from the circle teachers to balance the amount of informal messages with those that are more task related. This same tension appears in the classroom during group work (Goldman, 1992) and in the workplace. Informal norms develop about the amount of online background noise that is acceptable while students work on their network projects. These norms vary by teacher and by years of experience in Learning Circles. Students also have a normative sense of what it means to work on a topic. Consider these student observations on circle participation at the end of their session.

> I don't think that some of the other schools really took this project seriously. For example, I read some of the papers that were sent to us, and a lot of them had some spelling mistakes, or they were too short for their intended purpose. (Christopher Swiszcz; cited in Olivo, 1994)

> The other members of the circle didn't take the project as seriously as we did. It seems like they sent first-draft pieces to us, and often they really weren't that good. Some schools didn't even send all assignments. This last fact really bothered me! (Matt Brunetti; cited in Olivo, 1994)

The quality of interaction in Learning Circles depends on the quality of teaching in each of the classrooms. Where there is good teacher guidance and supervision, motivated students use a range of community, library, and social resources to think with their partners. Some teachers send student work after extensive peer editing and revisions. Other teachers have students send their first drafts and look for distant peers to provide feedback or comments. Some teachers chart work and require students to meet editorial deadlines. Overcommitted teachers sometimes fall behind schedule. Some of these teachers work hard to catch up, whereas others are content to finish when they do with less concern for deadlines. In cases where the teacher has turned the project completely over to students, there tends to be more chatty messages from students and less quality work on projects.

These differences in student work habits, teaching styles, and meeting deadlines provide a real-world experience in both the positive and negative aspects of team work. Because each Circle is different, over time teachers develop a range of skills for negotiating these issues and can share this learning with their students. Team work in Learning Circles can also positively affect the relationship that develops between teacher and students.

> Learning Circles provide students with a real purpose and a real audience rather than contrived situations. Students are in on the planning, teachers and students work together as learners, and they work with interesting people from exciting places around the world. I have noticed they learned more about me, and I learned more about them. Together we built better relationships, and certainly we developed a terrific positive class spirit that impacted very favorably on everything we did as a class. I found students and teacher take real ownership of the process and develop a sincere desire to ensure that "work is done" . . . properly!
>
> Phillip Noel (1993)
> Newfoundland, Canada

Communities of Practice for Teachers

Teachers share a special language and a set of tools, have similar goals, and engage in shared activities. Still, community development among teachers is difficult to facilitate because so much of their time is spent with students. Teaching is an art form that cannot be displayed in a museum. The sharing of sponsored projects gives teachers the opportunity to showcase their innovative educational ideas. In Learning Circles, teachers have time during the school day to team teach with teachers from distant places. The relationships among teachers in Learning Circles provide an opportunity to share both the content and art of teaching, building on the ideas that they have seen sponsored by their peers or exchanged in circle discussions. Consider these ideas:

> A class in The Netherlands expressed their concern over commercial waste of limited resources by sponsoring a project on overpackaging; students were asked to collect and compare examples from each community. The teacher shared a sample letter for sending companies the results of their survey.
>
> To help students understand the relationships between local geography and human adaptations, a class in Saudi Arabia asked students to describe the best and worst consequences of their local land formations. This information suggested a much different way for teachers to approach the study of geography in the classroom.
>
> A fourth-grade class in Montana collected information from their peers on the "cost of being a kid" in different Learning Circle locations. The teacher, Aubrey Miller, demonstrated how students can learn a range of math skills by working with numerical data they collect.
>
> A high school class in California sponsored a "Stock Market Project" in which each class was given the same amount of money to invest in the stock of one or more local companies. Students tracked and reported business news stories that affected their stock and discussed their investment portfolios.
>
> Marilyn Wall (VA) started a trend of "exchange mascots" when her class sent their school mascot, "J. Bear," to distant schools to extend student understanding of cultural and regional differences. Students at each distant school helped J. Bear write "travel logs" and letters home explaining his experiences.
>
> A German high school class sponsored a circle project on "immigration problems." Using U.S. television programs as evidence that students from different races sit and work together in classrooms without conflict, they wanted to hear more about how this was accomplished. This project helped students discuss the source of information, the diversity within a country the size of the United States, and the issue of race relationships from multiple perspectives.
>
> During the Persian Gulf War, one circle decided to create a simulation of international diplomacy. Each school took the role of a different nation.

These examples are included to demonstrate the range of ideas that develop when teachers and students are asked to create, rather than implement, curriculum. The circle is a small global community that often draws students into world events because these events affect their partners. It is harder to ignore a distant war when you have network partners who write about crocheted backpacks made by their mothers for carrying their gas masks.

The best network projects are those that are extensions of the classroom curriculum; projects are more meaningful when they are embedded in a larger system of work. The collaborative nature of Learning Circles makes it possible for teachers to restructure the Learning Circle to suit evolving educational needs. Circle teachers have had students design quilts, exchange food, and participate in a range of humanitarian projects.

LEARNING CIRCLES AND WORKFORCE SKILLS

The SCANS report identified three foundational skills that are essential in the workplace:

- Basic Skills: Workers need to be able to read, write, compute, express their ideas, and listen to others.
- Thinking Skills: Workers need to think creatively, make decisions, solve problems, visualize, and learn how to learn and reason.
- Personal Qualities: Workers need to have individual responsibility, self-esteem, sociability, self-management, and integrity.

The way is which Learning Circles address the first two sets of skills was discussed earlier. There are continual debates defining the overlap of the role of schools and families in fostering the third set of skills. Participation in Learning Circles may provide a strategy for addressing these skills in a school context that is less conflictual with the family's role. Parents object to school tests or writing that address family values or seem invasive, as was evident in the controversy over the 1995 "CLAS" testing in California.[4] In Learning Circles, distant peers, not the teacher, create the assignments and students are often given more responsibility in creating their responses. Their ability to work with distant peers to accomplish a shared goal can have positive effects on their confidence and self-sufficiency. Consider the following student reflections and teacher comments from Montana:

> It teaches me how to write real-audience, multiple-revision pieces and make them due for a deadline. It makes students work under pressure, and teaches them to share resources (3 Macs). The project also teaches responsibility, I like the increased workload and responsibility. (Arthur Chamberland; cited in Olivo, 1994)

> We have worked hard enjoying our work and feeling a greater commitment than in normal class activities. We realize that our English is good enough for communication with people around the world. (e-mail message from students from Liceo Scientificao "G. Marconi" Via Cosntitenete Parma, Italy, 1993)

[4]For more information on the CLAS test see California State Auditors http:www.bsa.gov/bsa/summeries/94109sum.html.

> In the four Learning Circles that we have participated in, each one progressively helped our students with (especially) their self-esteem and responsibility, ability to work in a team, and effective use of technology. Some students otherwise shy about expressing opinions and feelings have really come out of their shells and openly, willingly discussed cultural differences and traditions with other students in far-removed places, an opportunity they would not have otherwise had. Since they are graduating seniors, I really believe this experience will be especially valuable when they go on to college. (Gale, 1993)

Not all students respond in this way, but there are many examples from teachers (Riel, 1992b), supported by a controlled research study (Spaulding & Lake, 1991), that work in Learning Circles has a positive effect on students' conception of themselves as writers. A strong effect on student self-esteem comes from having work published by students in distant schools where publishing decisions are made based on the written work rather than on personal ties to the writer. These student reactions to having their work published are common on the network:

> It is an exciting and wonderful feeling to think that your paper may be published. Then, when you walk into the class and hear the teacher say, "Published!", you feel like you're a good writer. At that exact moment, I felt like I could write as many stories as I want and they would keep getting published. (Stacey Litz; cited in Olivo, 1994)

> The best part was when my teacher yelled out "PUBLISHED!!!!" and said my name. I was published among San Antonio's "best in the world." That made me very happy (Julie Arrison; cited in Olivo, 1994)

The SCANS report also identified a set of competencies for skilled workers:

- Resources: Workers need to know how to allocate time, money, materials, space, and staff.
- Interpersonal Skills: Workers need to be able to work on teams, teaching others; serving customers; and leading, negotiating, and working well with people from culturally diverse backgrounds.
- Information-Handling Skills: Workers need to be able to acquire and evaluate data, organize and maintain files, interpret and communicate, and process information.
- Systems: Workers need a clear understanding of social, organizational, and technological systems and be able to monitor performance and design and improve systems.
- Technology: Workers need to select appropriate technology, applying the most effective tools for the task, and be able to using good problem-solving skills when technology does not work.

These skills are not easy to teach in a knowledge-transition model. They require an active learner who is organizing and working with information in group settings with deadlines and goals. Students in Learning Circles make a commitment to their peers to work cooperatively on a task that requires students to manage time and resources so that all work is completed in time for publication deadlines.

> I think that participation in the AT&T project helped me become a better writer. It certainly helped me learn to budget my time. It also taught me that when you have a deadline, you shouldn't fool around with your assignments. (Nicholas Dion; cited in Olivo, 1994)

Just as in the workplace, team work and good interpersonal skills are crucial ingredients for the success of Learning Circle projects. Teachers and students cannot control the behavior of partners at a distance, but they do learn that there are better and worse strategies for encouraging participation. Learning Circles place students in the role of trying to encourage their peers to complete their work on time. They learn which strategies are effective ways of encouraging those who have not completed their work from their teacher and from success and failures in circles.

Students in different countries approach similar problems in different ways. Real-world involvement and comparison of local information and data with students in distant locations help students begin to think in more global and systemic ways. Students use a range of technical tools—computers, modems, fax machines, scanners, desktop publishing tools, and printers—to facilitate their work in Learning Circles. Moving between and among these tools to accomplish a task is a much more powerful way to learn about technology than looking inside the "box" in more traditional computer literacy courses.

CONCLUSIONS

The diffusion and evolution of project ideas among a community of teachers provides for professional development within the context of classroom teaching. Each circle has a task to complete that will involve sharing information and presenting a finished report according to a production deadline. Learning Circles provide a community that encourages the development of interpersonal skills that come from working with many different groups of people and the continual evolution of ideas that come from creating shared knowledge within different groups.

Participation in these learning communities encourages students to take an active role in the construction of knowledge. They request information from their peers and then incur a responsibility to use this information to construct new knowledge for themselves and others. It is a social setting where students depend on one another and are asked to incorporate different world views into their frame of perception. When skilled teachers work together effectively, they create a mechanism for developing students' school experience in the spirit of Dewey's fundamental principle of direct experience. School experience should not merely teach about processes and tools, but should weave into its very fabric the values, social order, and processes it seeks to impart (Dewey, 1916). Technology has the potential to increase our ability to work and learn from others who are distant in time and location (Riel & Harasim, 1994). Schools need to help students develop the interpersonal and intellectual skills necessary to use new technologies to construct shared understandings of their world. Learning Circles provide one way to develop an instructional system that can help students learn to work with each other to shape their collective destiny in a shrinking world.

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CHAPTER

16

LEARNING COMMUNITIES: A COMMENTARY ON CHAPTERS BY BROWN, ELLERY, AND CAMPIONE, AND BY RIEL

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The thesis of this chapter is: The notions *Community of Learners* (Brown, Ellery, & Campione, chap. 14, this volume) and *Learning Circles* (Riel, chap. 15, this volume) capture a fundamental aspect of learning that has been missing from the current design of schooling. If we are to redesign schools so that they function more effectively, we need to understand what is missing from the current design and how best to incorporate the missing elements into a new design of schools. This chapter shows how the two chapters point the way to a fundamental redesign of schooling.

To explain the argument, I need to make two critical distinctions. The first distinction is between individual and collective knowledge. Individual knowledge is what a particular individual learns and what is measured by most tests. The public at large, including most educators, thinks that the purpose of schooling is to increase each student's individual knowledge. Collective knowledge is what a community believes. For example, when I write that, "the public at large thinks . . . ," I am making a claim about collective knowledge. Similarly, the statement "the earth is a sphere" is one of the beliefs within the collective knowledge of our society. Thus, facts, laws, principles, and so on are all part of collective knowledge. It is important to note that not all members of a community believe each piece of collective knowledge. In the case of Einstein's theory of relativity, few people understand it, although it can still be counted as part of our collective knowledge. When someone makes a distinction, such as "My family thinks alcoholism is a sin, whereas I think it is a disease," they are making the distinction between collective and individual knowledge.

The second distinction is between a community whose goal is to increase its collective knowledge (which I label a *learning community*) and a community whose goal is to maintain its current beliefs (which I label a *conserving community*). In a conserving community, a lot of learning must go on, but it is by individuals who are acquiring the community's beliefs and practices. In a learning community, the focus is not on acquisition of individual knowledge, but on acquisition of collective knowledge. In fact, all communities are both learning and conserving communities to some degree. However, as I try to exemplify, some communities are designed to change themselves and their beliefs, whereas others are designed to preserve the status quo.

LEARNING COMMUNITIES VERSUS CONSERVING COMMUNITIES

This section attempts to induce the characteristics that distinguish learning communities from conserving communities by considering a prototypical example of each. My example of a conserving community is the medieval church in Europe and my example of a learning community is the modern scientific community. I choose these examples because they are the examples that are most discussed in the literature with respect to the distinction in question. As I try to make clear, both communities have elements that they try to conserve and elements they are willing to change. However, the focus of the medieval church was on preserving a core body of beliefs about the world, whereas the focus of the scientific community is on discovering new beliefs about the world. The goal of the comparison is not to make judgments about these two institutions, but rather to use them to develop a set of design issues for analyzing current schooling.

The church in medieval Europe had a number of mechanisms designed to preserve a central belief system about the nature of God and humankind; it is an excellent example of a conserving community. The church was centralized in Rome and power and authority were exercised through a command hierarchy, which instilled respect for authority in people from an early age. The church developed an agreed-on body of doctrine (their collective knowledge) and it acted to prevent anyone from challenging the doctrine either in print or speech. In fact, access to original sources was very restricted and most people's only knowledge of doctrine came down to them orally through the hierarchy. One of the most profound effects of the printing press was to give people access to the Bible, which enabled them to question the teaching of the church hierarchy, leading eventually to the Protestant Reformation (Eisenstein, 1979). This structure was effective in maintaining a core body of belief among the general public for close to 1,000 years, although there were some changes in the doctrine over that time span.

In many ways, the modern scientific community is the antithesis of the medieval church and is the best example, to date, of a learning community. It does have a core body of beliefs that it maintains, such as belief in empirical testing to settle scientific arguments, but its core beliefs are about methods rather than content. The structure of the scientific community is decentralized with power and authority spread widely among scientific practitioners. In fact, the lowliest graduate student may publicly challenge the beliefs of the most eminent scientist and gain an audience (although many scientists will dismiss the challenge as coming from someone without credentials). Of course eminence and authority often win out in a scientific argument for a time, as in the case of Wegener's theory of continental drift. However, a core belief of the scientific community is that evidence and logic, rather than authority, should be used to settle all arguments. Dissemination through the scientific media is open to all, with the mechanisms of peer reviewing and multiple outlets under different scientists' control to ensure that a compelling argument will have a chance to be heard. Similarly, access to the ideas being debated in the scientific community is open to all, although of course people in elite institutions typically gain earlier access. The fact that there are often controversies about the denial of access to particular individuals shows that access is held as a core value in the community. The scientific community is constantly refining its collective knowledge and its mechanisms are designed to foster growth in knowledge.

These two examples highlight a number of dimensions that influence whether a community will be a conserving versus a learning community:

- Centralized versus decentralized authority
- Command hierarchy versus egalitarian structure
- Repression of argumentation versus fostering of argumentation
- Arguments resolved by authority versus logic and evidence
- Restricted access in disseminating beliefs versus open access
- Restricted access to hearing new beliefs versus open access

THE DESIGN OF SCHOOLING

In the school design that emerged early in the century (Callahan, 1962; Cremin, 1961; Cuban, 1984; Tyack, 1974), there are a number of indications that the goal was solely to foster growth of individual rather than collective knowledge. For example, tests are administered to individuals rather than groups of students and the measure of success of a teacher or school is the gain in individual test scores. Students are discouraged from working or even studying together and their access to resources is often restricted on the grounds that each student must know and be able to do everything on their own without any help.

This focus on the growth of individual knowledge has inadvertently been at the expense of the growth of collective knowledge. If we consider that the dimensions listed earlier are required to support a learning community, it is clear that schools fall far short. There is a fairly rigid command structure for ideas, which is maintained through teacher education, textbooks, and uniform tests. Many teachers circumvent the structure by closing their doors and ignoring the texts, but the system is designed to discourage such behavior. The texts embody the wisdom of domain experts, and most teachers, students, and parents assume that the knowledge is not to be questioned or debated. This is less true in the humanities than in math and science, but it is a pervasive tendency in schools. Finally, the ability to express or hear ideas not endorsed by the textbook or teacher is severely restricted in most classrooms. Teachers do not like to have their authority or the textbook challenged; they suppress argumentation and even sharing of ideas between students. Students learn only what the teachers and books know a priori. Hence, schools are not learning communities in most cases; rather, they are communities designed to transmit the cultural knowledge embodied in textbooks and teachers.

As I said earlier, most people believe that schools do not need to be learning communities; in fact, their function is to transmit knowledge to students. Why should we redesign schools to be learning communities? Riel (chap. 15) and Brown, Ellery, and Campione (chap. 14) make essentially two arguments for why we should do so: One is referred to as the *constructivist* argument (Riel) and the other is referred to as the *learning to learn* argument (Brown, Ellery, and Campione). Both chapters endorse the two arguments.

The constructivist argument is that the theory of individual learning underlying the cultural transmission model is flawed. The constructivist view is that individuals learn not by assimilating what is given, but rather by a knowledge-construction process much like the process that goes on in a learning community. On this view, the knowledge-construction process is modeled and supported in the individual, when it also occurs in the learning community. It is not necessary to adopt the constructivist view of learning entirely for the argument to carry weight. Even if most individual learning occurs by assimilation of transmitted knowledge, as long as substantial aspects of learning occur in a constructivist mode, it would follow that creating a model learning community would foster individual learning.

The learning-to-learn argument is related, but I think separable. Smith (1988) argued that children will learn to read and write if the people they admire read and write. That is, they will want to join the *literacy club* and will work hard to become members. Brown, Ellery, and Campione argue that there has been a change in the demand on schools; they now need to produce expert learners or intelligent novices. This change has been brought on by (a) increasing knowledge, such that no one can absorb in school everything they need to know in life; and (b) the changing demands of work, where technology can carry out low-level tasks requiring workers who can think and learn. Given that schools need to produce people who know how to learn, it follows from Smith's argument that children will learn to be learners by joining a learning club.

If these arguments are correct, we need to figure out how to design schools so that they are effective learning communities. As is elaborated in the next section, Riel and Brown, Ellery, and Campione provide complementary models for doing so. A major impediment to such a redesign of school is the opposition of those who do not want schools to be learning communities. As in medieval times, many people want schools to transmit the received wisdom of our culture without questioning it. Hence, a major battle is looming around the learning community view of schooling.

THE REDESIGN OF SCHOOLING

If we want schools to become effective learning communities, what does this imply for the redesign of schools? My argument is that Brown, Ellery, and Campione have come up with an effective design for the classroom community and that Riel has come up with an effective way of bringing outside knowledge into the classroom community.

The Community of Learners model borrows heavily from the model of the scientific community. Students take on the role of investigators using available resources to answer their questions. Everyone in the community is on an equal footing and all have equal access to presenting their ideas in spoken and written form to the community. The institution of *crosstalk* forces students to address other students' questions and challenges. The fact that students use books as sources probably means that they treat them as authoritative knowledge, at least at first. However, as they explore topics more deeply, they will come up against contradictions and unanswered questions, which will eventually lead them to view sources in the same way that scientists do: as something that can be challenged if counterevidence can be mustered. This is a community designed to increase its collective knowledge.

In a typical classroom, what each student learns depends on the activities in which he or she engages. In these classrooms, what one learns depends on what is in the air—that is, community knowledge is widely shared. The design calls for individual students to become experts in some area, such as camouflage mechanisms. Through writing and explaining, they are responsible for other students learning the essentials of their topic area. This *jigsaw* approach (Aronson, 1978) resolves the dilemma of common versus special knowledge that pervades schooling. The typical curriculum attempts to teach all students the same things and emphasizes breadth of learning. Project-based curricula counter this emphasis by having students investigate topics in depth. The Community of Learners classrooms, by using the jigsaw technique, support students acquiring individual knowledge that they bring into the collective knowledge of the classroom.

Brown, Ellery, and Campione have not yet solved the problem of using electronic media to bring in expertise from outside. They have been most successful when the experts they used did not function as experts, but more as facilitators making suggestions and raising issues. Riel has developed a format–the Learning Circle–that successfully brings knowledge from the wider community into the classroom. By posing problems to other students around the world, the students elicit new views and knowledge about the issues on which they are working. Like Community of Learners classrooms, Learning Circles put all the students on an equal footing; thus, the discussion proceeds on the basis of evidence and logic, rather than authority. All students have equal access to the medium and so can hear and promulgate their ideas. By giving the problem posers control over the final statement, the design undermines, in part, the egalitarian structure of the Learning Circle. It would be better to force a negotiation across all the parties of the final statement. Nevertheless, the Learning Circle format succeeds in creating a distributed learning community.

The synthesis of these two models could be very powerful. A synthesis would electronically bring together students working on a related set of issues, as in the Community of Learners classrooms. One can imagine different classrooms around the world–where the Community of Learners model has been implemented–posing and discussing problems that they have identified in their research. Their common research focus would act to increase the expertise of distant student groups in addressing issues that a particular classroom is investigating. Similarly, adding a jigsaw component to the Learning Circles model would foster efforts by each group to extend the collective knowledge of the other groups. There is potentially a huge payoff in extending knowledge seeking to a common set of problems across different schools around the world, just as the scientific community benefits from having scientists all over the world working on common problems.

It is important–in the zeal to create communities that are effective in acquiring collective knowledge–that we not inadvertently create communities that stifle the growth of individual knowledge. This could happen if a few students take over the knowledge-acquisition task and other students rely on them to do all the learning and thinking. This sometimes happens in project-based classrooms, but the jigsaw method is explicitly designed to prevent it and I do not think it is a problem for either model presented here. Both models address a significant flaw in the design of schooling; they foster the growth of collective as well as individual knowledge. The synthesis of the two models might be the optimal design for a student learning community.

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