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EMERGING DISCOURSES IN MIDDLE SCHOOL: A STUDY OF INDIVIDUAL UNDERSTANDING AND GROUP CONSTRUCTION OF THE CONCEPTS OF MASS, VOLUME, AND DENSITY

By

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ABSTRACT

EMERGING DISCOURSES IN MIDDLE SCHOOL: A STUDY OF INDIVIDUAL UNDERSTANDING AND GROUP CONSTRUCTION OF THE CONCEPTS OF MASS, VOLUME, AND DENSITY

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This study examines interactions in a sixth grade urban science classroom in which students were learning about describing substances. It tells the story of the development of a discourse community in the classroom as students worked on the concepts of mass, volume, and density. At the same time, it depicts the interactions in which two target groups of four students each involved themselves. In telling these two stories together, the study gives a sense of how language, thought, and action move across different social arrangements in the class, as well as the interplay between developing private and public knowledge.

Students in the class worked individually, in pairs, in groups of four, and as a whole class. The students who were the subjects of the study came to the instructional setting with a variety of backgrounds in terms of home culture, past success in school subjects, and academic skills. The teacher in this study employed a discourse-based instructional approach in which engaging students in a wide range of language, thought, and action was seen as a productive way to teach conceptually difficult material. While they were learning to about substances, students also learned about the activities of scientists, characterized by the acronym TOPE, which stands for techniques, observations, patterns, and explanations. The TOPE acronym then served as an organizing framework for their investigations.

Drawing on the conceptual change and sociolinguistic research traditions, this study examined classroom discourse in terms of four dimensions: goals, mediational

means, standards, and connectedness. Over the course of instruction, the teacher expected that the range of intellectual and physical tools which students would employ in describing substances would narrow and become more scientific. The principal mechanism at work in this narrowing was the privileging of some forms of mediated action over others in a variety of social settings in the classroom. The study found that when privileging occurred, students who were less academically adept were likely to withdraw from significant roles in interactions. In like fashion, students who were able to incorporate the privileged forms were more prepared for later instruction. The author suggests further study of this teaching approach and these concepts in pursuit of science for all students.

Dedication

To my family,

Karen, Matthew, Katie, and Emily,

who love and laugh each day

and remind me what's important.

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To Karen, my beloved wife, I owe a debt I cannot find words to describe. You have lived through the hardest part, and have sustained me in body, soul, and mind. Your love and care have made this work possible.

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My brothers and sisters, Dan, Tim, Beth, and Dot have each taught me as we have lived and grown together. Here, in my own family, I learned to love learning. I am grateful beyond words to my parents, Deacons Skip and Anne Vellom, for this lifelong attitude. You show by your example how good life can be when one accepts new challenges and is willing to learn from them, and grow.

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CHAPTER 1

Introduction

Among the many goals of science education reform over the last thirty years, two stand out as having been central to virtually every significant effort. One has been the quest to make school science *both meaningful for students and truly scientific*, a goal engendered by curricula and teaching that in many cases has been characterized by lists of facts and process skills. These have made it hard for students to understand how science is applied, or to take from it anything that might be useful in their lives thereafter, since much of the science they learn is not presented in meaningful contexts. The second goal has been *to teach science in ways that make it accessible to all students*. Traditional science teaching, and even the teaching of late that is hands-on and real-world based, generally serves only a portion of the student population. Typically, students who are least successful in school science classes include those who are marginalized in other school settings, those who lack basic academic skills and attitudes, and those whose home cultures differ significantly from the mainstream culture of the school.

The quest for these goals has been a long-standing one. Three decades of effort on each of these counts has engendered reform efforts that have, in many ways, altered many of the underlying assumptions and practices associated with school science. Even today, however, the full achievement of these goals remains out of reach. We have not yet found the answer to meaningfully represented school science that is accessible to all. Over this span of time, analyses of classroom situations have given us better curricula, and better and more fruitful approaches to teaching. Yet, in some sense these analyses have been only as good as the results they have engendered. These goals beg an analysis that both helps us to better understand and tease out the problems inherent in teaching meaningful science to all students, and one that leads us to indications for better practice as well.

This dissertation is based on two forms of analysis that have been brought to bear on this problem, each with its own set of underlying assumptions and its own recommendations for teaching. One of these is the *conceptual change* perspective, which focuses on individuals' cognitive and sensory-motor activity. This perspective promotes a focus on science concepts, and the kinds of activities that students do with them, in reforming classroom teaching. Proponents of this perspective claim that students' theories and conceptions are often not recognized or dealt with in meaningful ways in traditional science classrooms. For example, sixth grade students learning about the concepts of mass, volume, and density often do not distinguish between mass and density, using the word "heavy" to describe both massive objects (such as logs) and those that are very dense (such as lead). Teaching that focuses on definitions and formulas, even if it involves hands-on applications, often fails to connect with the students' conceptions or to help them through the process of conceptual change. Thus, this perspective suggests teaching in ways that put student ideas and conceptions in the center of the instructional arena, in order to assist students in coming to more complete and complex understandings of concepts in meaningful contexts.

Research on conceptual change suggests that teachers should use specific strategies to assist students in the process of modifying and expanding their own conceptions. Among these are the presentation of phenomena or events that cause cognitive conflict with personally held theories, the elaboration of alternative ways of conceptualizing the phenomena or event, giving students time and reason to "try on" alternate conceptions, and assisting students in making connections that elucidate important links between new conceptions and related ideas that the students are likely to know and appreciate as part of their own webs of understanding. Again, conceptual change teaching takes as its starting point the ideas and conceptions that students bring to the instructional setting, and thus it is often called 'student-centered teaching'. Yet, alternate conceptions must be carefully selected and presented in ways that encourage the transformation of personal theories towards those that more closely reflect the scientific canon. This drive towards accepted scientific ideas is the crux of the conceptual change model of instruction, and as such forms the basis for success or failure for students.

Two common teaching strategies that many teachers employ in conceptual change (and traditional) classrooms are to link important canonical ideas to the persons who formulated or discovered them, and to direct students' attention to increasingly fine details in attempting to make sense of observed phenomena. The first of these often leads teachers to use historical debates among scientists both as a way of teaching the concepts or ideas, and as a model for classroom discourse. Both of these approaches in teaching -- modeling historical debates, and redirecting students' attention to smaller and smaller details of observation -- work best for students who already see the value in articulating and debating theories about observed phenomena.

As a research perspective, conceptual change tells a limited story of the classroom. It fails to account for the many aspects of classroom life that are not analyzable as conceptions about the world. These aspects, which include individual attributes of students and teachers, physical setting, social norms and expectations, and institutional arrangements, include critical factors that weigh heavily on the educational process. This shortfall limits the usefulness of the conceptual change approach as a source of recommendations for teaching. It doesn't address issues such as motivation and language, which may be critical for engaging students (especially lower-achieving ones) in discussions of their conceptions.

A second analytical approach, often called the *sociolinguistic* perspective, focuses on students' participation in collectively (and therefore culturally) valued social practices. This perspective suggests that language use in authentic situations should be the goal of teaching in any subject area, and that engaging students in language and social practices that approximate those of the scientific community is one way to achieve success in teaching and learning science. Sociolinguists examining teaching about mass, volume, and density would be most interested in the cultural practices surrounding their use in the classroom, including the kinds of opportunities for meaningful discourse and action that students encounter.

In classrooms in which the teachers subscribe to this approach, students might initially be encouraged to use formulations for these concepts that make sense to them, such as "heavy", and to negotiate meanings with other students in instances where disagreements or confusion occurs. Moves to include more scientific language (which may be suggested by any member of the community, and drawn from virtually any source) then hinge on the needs of students as they try to make sense of their own work and the work of their peers. Sociolinguists contrast this kind of teaching with the IRE interaction pattern found in many traditional classrooms, classrooms (Wells, undated), focusing their efforts instead on opportunities for involvement in scientific discourse around describing substances. They point out that in some classrooms the opportunities to appropriate scientific discourse do not exist, while in other classrooms (like those in which conceptual change teaching occurs), social and cultural patterns exclude some students from meaningful participation. Their focus on action in social settings removes barriers that limit access for many students in traditional settings, and endorses teaching methods that support a rich set of classroom interactions in which students' formulations play a central role.

The sociolinguistic perspective supports teaching that engenders meaningful uses of scientific discourse in classroom settings. Teachers are encouraged to structure situations that challenge students to seek answers to questions that they find interesting and worthy of investigation. They then assist students in their quests by helping them to understand the culturally relevant practices of the scientific community that may help the students to answer their questions. In this process, they provide many varied opportunities for written and spoken discourse, all bearing the hallmark of authenticity in terms of the students' quests for understanding. At the same time, connections between the actions of the students and those that practicing scientists might take in similar situations are made explicit to students. In these ways, students are scaffolded into meaningful discourse that reflects increasingly scientific approaches to solving problems that are real to them.

Criticisms of the sociolinguistic approach to teaching science have reflected concern over the limited tools it presents for dealing with what Lemke (1990) refers to as the 'thematics' of classroom discourse, or what science teachers usually call the 'content'. With emphasis on forms of language and patterns of participation, how conceptual elements are treated in discourse becomes a critical factor that has much to do with what students learn. When the focus is generally on forms of language and participation first, many worry that concepts and ideas are not fully treated or developed, especially in light of the time constraints that define much of what students experience in science classes.

In analysis of classroom teaching and learning, the sociolinguistic approach bears the same criticism. Those concerned with improving school science often seek a richer analysis of conceptions, and relationships among them, as a baseline for understanding teaching and learning situations. For the most part, sociolinguistic studies do not focus on conceptual issues *per se*, but rather elaborate contextual factors that together determine the paths that many students take in these situations. In choosing this focus, these analyses fall short in the eyes of many science educators, missing what they see as the important part of teaching science.

These two forms of analysis have been viewed in most circles as competing, since they make different claims about what is important, and thus how science should be taught. However, Cobb (1994) suggests that these two perspectives might better be viewed as complementary, since in the former, the individual is studied against the backdrop of the collective, and in the latter, the collective is the focus while individuals within it shape the contextual space. In essence, his argument suggests that, rather than limiting oneself to one form of analysis or another, the two forms share substantial ground. The only real difference between these two approaches is in what is foregrounded and what forms the backdrop. Each perspective informs the other, and taking them as separate, distinct, and irreconcilable means losing much of the analytical power of each. Taken together, he suggests, they may help us to learn more about what works and what doesn't in classrooms.

While Cobb suggested this synthesis in terms of *analyses* of classroom teaching and learning, I see his complementary view as holding considerable promise as a *teaching* approach, as well. In discussing his own rationale for the complementary view he suggests, Cobb cites Ball's (1993) analysis of her own teaching of mathematics, in which she elaborates three dilemmas of teaching. In Cobb's words,

> "...dilemmas of content, discourse, and community 'arise reasonably from competing and worthwhile aims and from the uncertainties inherent in striving to attain them' (p. 373). It would therefore seem that the aims of which she speaks and thus the pedagogical dilemmas reflect the tension between mathematical learning viewed as enculturation and as individual construction." (p. 14)

Just what a teacher believes about the way students learn shapes assumptions that undergird his or her design of instructional situations. Thus, one teacher might take a conceptual change approach in which conceptual activity is of primary importance; even in doing so, however, issues of cultural practice form important contexts in which conceptual material must be understood if the student is to be able to make meaningful use of it. In like manner, another teacher might focus on the cultural practices of a group of students as they investigate phenomena; in this setting, concepts and the practices around them are inextricably linked as well. So when students get together to negotiate meaning, whether they are seen as actively interpreting individuals who constitute processes individually and collectively, or whether they are seen as parts of a collective that together constitutes cultural and social practices makes a difference in how the teacher might structure tasks and roles, and what outcomes might be expected. And, teachers may hold both views, just foregrounding one now and the other later (depending on the goals they hold as important at any moment), much as researchers might do in structuring analyses of teaching and learning situations.

Research Questions

This is a study of a classroom in which I, as the teacher, was trying to enact the kinds of recommendations that Cobb would make. In my role as a researcher, I have attempted to tell this story in a way that makes substantial use of analytical perspectives and frameworks from both of these research traditions. I attempted to meld these two perspectives in order to more fully address the challenge of the two goals discussed above, in an observational study of an urban sixth grade science classroom in which students were learning about matter and molecules. In this effort, I chose to foreground the sociolinguistic approach, while landmarking the analysis with views of individuals' conceptual work. The study was guided by the following research questions:

1. How did the construction of the concepts of Mass, Volume, and Density proceed in the discourse system of the classroom community as a whole? In what ways did teacher and student privileging of mediated action influence the development of these concepts?
2. In what ways did eight individual students in this class take on the "identity kit" of science, as demonstrated by participation in classroom and collaborative group discourse and investigations about mass, volume, and density? How was the emerging discourse system of the classroom community and collaborative groups facilitative (or not facilitative) of their participation in the activity of describing substances, and especially their understanding of Mass, Volume and Density?

Note that the first question focuses mainly on the story of the collective. It suggests that concepts can be socially generated and held, and that *privileging* is a social mechanism that has important bearing on this process. Yet, the emergence of concepts in a collective always, out of necessity, begins and is landmarked by individuals' statements and efforts in the public domain. Thus, tracing the public construction of these concepts foregrounded the public actions of individuals within the collective in order to get a fix on just what the public form or understanding was at a given time. Rather than comparing individual differences in understanding, these differences were taken as indicative of a *range* of conceptual command at a given time. Over time, this range was expected to change, as elaborated below (see section II. 'A Sociocultural View of Teaching and Learning').

The second question focuses more on individuals as they operated within the collective. Here, I examined how each of these individuals functioned within the class. I attempted to characterize the ways in which they were aided by their participation in the social practices valued in the class, and the points at which they moved the class to a new level of social activity. In doing this, the actions of these individuals were examined within the contexts of task and social setting in order to develop a sense of the effects of this two-way relationship.

A Sociocultural View of Teaching and Learning

The teaching that occurred in the classroom under study was quite different from the traditional lecture-and-demonstration model. My goals of instruction centered on assisting students in their attempts to appropriate powerful new discourses in a variety of contexts. Creating these contexts to challenge students to take on the many facets of the "identity kit" represented by these discourses occurred over time, as I facilitated classroom interactions in the role of a leader of the classroom community of learners. In this role, I was a learner too, but also an expert in the field; as such, I became the "knowledgeable other" that Vygotsky (1967) saw as crucial to the processes of learning in social settings. I sometimes provided knowledge of the scientific canon (both procedural and conceptual) at the times and in the contexts in which I judged it was needed. At other times, I purposely stood back as students reasoned through problems of meaning and procedure. Students as peers sometimes served in the role of "knowledgeable other", too, as interactions proceeded and they worked to describe and explain phenomena that in this case had to do with describing substances.

In this classroom, I attempted to assist students in moving from the vernacular terms and usages (and relatively general concepts) that they brought from their own experiences, toward more precise scientific constructions that, for instance, would give them increasing power to describe and explain observed phenomena. This meant that as the classroom community encountered situations in which more precise or powerful language was needed, some forms were necessarily *privileged* (Wertsch, 1991) over others. Over time, I expected that the evolving discourse of the community would demand (and reflect) increasingly powerful attempts to describe and explain observed phenomena, and would give insights into the growing understandings of the membership. I conceptualized this goal in a simple graphic (see figure 1 below).

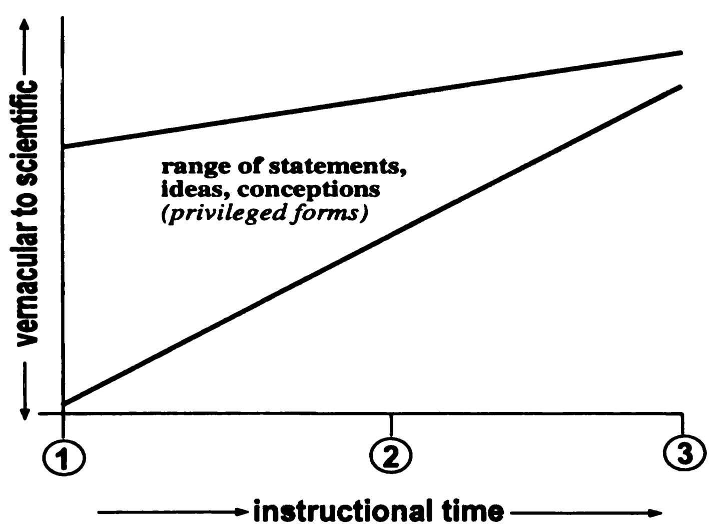


Figure 1: One representation of the goals of discourse-based science instruction

Just as this graphic represents the goals of science instruction in this kind of setting, so too is it descriptive of the discourse-based activities of the classroom community over time. In this representation, the bottom boundary line of the range of statements, actions, and conceptions reflects the development of standards for adequacy in the discourse of the students. Hand in hand with the development of standards is the privileging of some forms over others. It is not inconceivable that some students who do not take on new forms as they become valued in the community may find themselves outside of the range as represented here. These students, by virtue of the discourse they control, are excluded from negotiations of meaning because they don't "speak the language" that is valued by their peers in the community.

Between the lines that define the range, students who are practicing the forms of discourse that are valued in the classroom at that particular time can be found. In locating these students within the range, we recall that discourses are acquired gradually over time and interactions; we hold a dynamic view of students herein (and elsewhere on the graphic!) as actively constructing new forms, attending to various features and details of the phenomena and the communications around them, and taking these interactions as the basis for rethinking, reworking, and reordering their understandings in unevenly paced and unevenly productive ways. Within this range we will find students who are struggling hard with certain aspects while holding apparently divergent conversations in which they adroitly persuade their peers or elaborate a position. The dynamic and personal nature of this process, interwoven as it is with the social aspects of communication and mediated action, cannot be understated here.

The line at the top of the range represents the building of new, more powerful and scientific forms of discourse. Here students apprehend and integrate new information and strategies into their discourse, taking on the "identity kit" of the scientist in thought, action, and communication. This, too, is a messy process that occurs over the course of a range of interactions in time. Thus, at any given point in the instructional sequence, one might conceive of a range of accepted forms, realizing that among the membership of the community, students place themselves in this range by the forms of thought, action, and language that they use. This placement is in relation to the thoughts, actions, and language of the community at that time. For instance, at the outset of instruction (number 1 above) the range of students' ideas, language, and actions (in the class taken as a whole) in relation to the task of describing substances is conceived as relatively wide. It includes a range of vernacular constructions and ways of acting and thinking, as well as some more scientific ones, since there will likely be, as in most heterogeneous classrooms, those few students who have had extensive and enriching experiences around science topics. It is also likely that, in such a classroom, there will be a few for whom science is anathema. For the majority of students, it is likely that the discourse of choice will be the vernacular, common usages and terms that have served them well at home and in other school situations. Given the range of experiences with which students come to the instructional situation, then, the initial range of statements, actions, and conceptions would be relatively large.

As students work on describing substances in significant ways, we would expect most to move along this continuum (number 2 above), as their repertoires of language-in-use, action, and thought come to include forms that are more useful in relation to their endeavors. We also hope that these students concomitantly broaden and sharpen their understandings of the related concepts and their applications in scientific terms. We assume here that students are both willing and able to alter the webs of understanding that they hold at the outset of instruction, and that the kinds and conditions of instruction are enabling in this quest.

I see the process of *privileging* some forms of talk, action, and thought over others as ensuring this kind of movement. Necessarily, scientists value certain ways of talking, acting, and thinking around the activity of describing substances more than others. Generally speaking, those that are most productive and efficient, or those that are deeply culturally ingrained (and still relatively efficient) are valued over those that are less so. In a similar way, as the students experience the need for more precise and efficient ways of acting, thinking, and speaking in their work with substances, they and the teacher come to value certain of these that help them to make important distinctions or work more efficiently. When this happens, the range of acceptability is narrowed as standards for adequate terminology, use, and action are established. These standards emerge from the struggles of the students and teacher to make sense of what they have done in the classroom. Students who do not pick up the newer and more accepted forms may, over time, be excluded from participation in future interactions, by virtue of their efforts being perceived as unhelpful, as inadequate, or as wide of the mark.

When this happens, the dissonance that results can be like someone doing a polka in a room full of waltzers. While the dancers may not collide for some time (or at all), the two sets of movements are hardly complimentary; neither does much for the other. The music that is playing clearly favors and supports one of the two steps, and while the other may be accomplished by adaptation, it is not valued by potential partners doing the other step. In the classroom described herein, we shall see instances when the students actively privileged certain forms of language, thought, and action over others, as well as some instances in which I (the teacher) provided the impetus for privileging some forms.

Over the span of instruction, I expected that the range of language, thought, and action would narrow. I also expected that this narrowing was as a result of these two processes, and that the resulting narrower range would reflect more of the scientific canon (number 3 above), by which I mean the generally accepted ways of talking, writing, and acting that scientists use when they set out to describe substances. This canon includes scientific terminology in specific uses, concepts related to the description of substances (described by some of the terminology!), and strategies and courses of action that are regarded as productive.

One of the challenges of instruction, then, was to engage students in activities that would have the potential for meaning-building, and to further scaffold them along the continuum. While current thinking in science curricular reform generally recognizes the value of activities that approximate many of those that scientists undertake in scientific inquiry, a recently growing body of literature suggests that this value is optimized in situations in which students are involved in authentic inquiry that involves meta-views of themselves that make explicit the connections between their activity and their learning (Ball

1993, Lampert 1990, Ballenger 1994, Michaels & O'Connor 1990). These meta-views are typically developed by a variety of strategies and activities, including introductory instruction and discussion with the teacher and peers, periodic tasks which require students to attend to these connections, and reflection leading to discussion or writing about the activity and learning.

This view of curriculum fits well with Gee's (1989) conception of discourses as multifaceted (hence his characterization of discourses as an "identity kit"). To Gee, discourses encompass all forms of textual interaction (where 'text" can be any form of language expression, or non-language expressions such as art or costume), and are thus complex and interwoven with the personae of the players. These players act with mediational means in the contexts of tasks within a classroom, situated in a school setting in a given community. They constitute discourses as they jointly construct understanding through social interaction.

This is a study of students and their teacher acting in various social contexts within the larger sociocultural context of a science class in a public school. This classroom was studied as the students and teacher engaged in a particular kind of activity, that of scientific description of substances. My first purpose in conducting this study was to conduct a careful analysis of this classroom from a sociolinguistic point of view, to try to better understand the students' interactions and their developing understandings. To further this goal, I selected eight target students (comprising two collaborative groups of four students each) as points of focus for studying the dynamic interplay between public forms of discourse, more private forms, and emerging command of the "tool kit" of scientific discourse, including thought, language, and action.

Learning About Mass, Volume, and Density as Enculturation

Scientists continually seek to describe more fully the natural world in which we live. One part of this quest involves scientists who attempt to describe substances in precise ways. Over many years, scientists have accumulated a vast array of information related to substances they have encountered. And, as this base of information has grown, so have the means by which scientists learn about substances. Today, many complex and specialized instruments are available to scientists seeking to describe substances ever more precisely. Yet, all attempts at describing substances, whether simple or complex, focus on characterizing the properties of the substance. And, each substance is still characterized in terms of concepts that represent measurable properties, including mass, volume, and density. These particular properties have been a part of the repertoire of scientists who engage in this activity for many years.

One product of many generations of work on describing substances are the numerous practices and ways of thinking that have to do with determining the mass, volume, and density of substances in efficient ways. These practices are a product of the social and historical settings in which they operate, and as such represent a kind of *scientific culture*. So, we might think of scientists today as living and working in (and daily creating and representing) a culture that includes ways of describing substances that are efficient and powerful to them and to other members of the community. These ways of describing substances are a mixture of relatively older practices that are still recognized in the community as the best ways to solve particular problems or answer certain questions, and newer practices that have been found more powerful, accurate, or efficient by the community. These practices are not limited to laboratory investigations and manipulations;

they include language practices which are a central feature of nearly every activity of the community. Douglas Barnes (1990) notes that

> Any group that meets frequently for work or play develops a language style of its own. This will only partly be comprised of technical terms needed for the shared activity; there is likely to be an 'in-group' way of putting things, cryptic because of shared assumptions and experience, comfortable for insiders but likely to rebuff and discourage outsiders. (54)

While Barnes made these comments in reference to small groups who work together, I believe there is a kernel of truth here for those who work in larger communities comprised of smaller working groups like those Barnes considered. They, too, by virtue of shared assumptions, and common purposes and experiences, are likely to develop their own specialized language practices that reflect the values and priorities of the membership. This means that among scientists who investigate substances, close description along commonly agreed-upon parameters may be the norm, and that the language practices, ways of thinking, and central ideas and purposes that comprise these activities are likely to become specialized, include technical terms, and in some ways be less meaningful or accessible to those who do not share the experiences and assumptions of the community that created them.

A primary difficulty for students attempting to learn science concepts in school settings is created when students must move from the set(s) of cultural norms for speech, thought, and action to which they are accustomed in other parts of their lives (particularly the home environment) into the ways of speaking, thinking, and acting that are characteristic of those who "do" science. These cultural differences are what makes much of science seem difficult or uninteresting to students, since the language and activities of the scientific community are different in form, purpose, and content from most of those that students encounter at home, in school, and around their neighborhoods. Teaching strategies like involving students in direct manipulation of science materials may draw many students in and actively engage them in the content to be taught. When the focus changes to conceptual concerns, however, most students may still have difficulty making connections that would enable them to see the activity as important and worthy of effort.

As noted above, involving students in discourse about scientific investigations or observed phenomena seems to hold promise for enabling many students to become familiar with the new set of social, cultural, and language practices of the scientist. This is especially true in settings in which the ideas of the students are valued and become central to classroom negotiations aimed at understanding. Talk, writing, and working together with models and real phenomena have, when taken together, the potential to engender and scaffold new understandings, as noted in a growing body of literature describing discourse-based instruction in science. Case materials and other studies (that look at students) so far have been largely aimed at characterizing the nature of classroom discourse, exploring the effectiveness of specific discourse strategies in instruction, telling the story of an individual student, or examining the effectiveness of a particular curriculum with a particular type or number of students. (Warren et al 1989, Michaels & O'Connor 1990, Driver et al 1985, Roth & Rosaen 1990).

The approach that this study takes may best be described in terms recently used by Wells (1991), Wertsch (1991), and others. Within the structure and purposes of given tasks, discourses are considered tools that facilitate cultural practices. A story may serve to illustrate. When I bought my first car, I quickly discovered that the engine was hungry for oil at every fill-up. After a day of diagnosis, the need for rebuilding the engine became evident. My exposure to engine repair and maintenance to this point had only consisted of a few brief encounters with spark plugs and fan belts, but with the encouragement of a friend who offered his tools, garage, and expertise, I set out to get the job done. Prior to this series of events, I had used a screwdriver numerous times, to insert and remove screws and bolts of various kinds in various settings, and also as a chisel and pry tool. In hindsight, I would characterize these uses as rather inexpert, but good enough to get these tasks done most of the time. I used the tool when I had to, but did not seek out activities where this was the case, feeling that there were others in our family who were better suited to this kind of activity than I was.

Among the set of all those who use screwdrivers, those who rebuild engines and do similarly specialized and complex engine repairs are a small subset. Those who do these kinds of repairs often (we call them mechanics) generally have substantial experience, and often specialized training, to be able to perform these repairs well and efficiently, and with reasonable certainty of the desired result (an engine that works). In the course of learning about and repeatedly performing these repairs, mechanics develop a sense of the ways to use a screwdriver that yield the most satisfactory results. While there is some variation among mechanics in the ways they hold, align, and twist the tool in order to apply or remove fasteners, there are also a number of actions for which screwdrivers are not considered the right tool, among them prying and chiseling. The concerns here are that the tool, when used for these purposes, may yield unsatisfactory results in those activities; these concerns are founded on the design of the tool itself, and the kinds of forces for which this design is made. Forces other than those for which the screwdriver is made may result in a broken or bent tool, an unfinished task, or even injury to the user.

Outside of the field of mechanics, however, are a vast number of people who pick up and use screwdrivers as tools to enable them to accomplish something in their particular situations. Some of these actions are tightly proscribed, as in electronics repair, while others are less so, as in boarding up a doorway. In all cases, however, the setting, task, and user determine the appropriate range of uses for the tool, as well as the particular kind of screwdriver (tool) that might be used. Different communities of users will encounter different demands to which they will apply a tool in different ways. Many of these ways may only be valued in one community, and seem foreign or even incorrect in others.

In similar fashion, the language and practices of science, including relevant concepts, terms, actions, and habits of mind, may be considered tools that scientists use in their attempts to describe, explain, and predict the natural world around them. When a scientist sets out to describe a substance, she or he uses a set of tools that are valued among those in the scientific community who describe substances. These culturally valued tools include ways of using language, acting, and thinking. Among these tools are the concepts of Mass, Volume, and Density. Scientists whose work is to describe substances have developed relatively consistent ways of using these terms. These begin with well-defined ideas of the ways in which Mass, Volume, and Density are descriptive of a substance, including what property of the substance is represented by each, distinctions between them, how each might be determined, and an understanding of relationships between these concepts. While there are certainly many other concepts and methods that scientists use to describe substances, mass, volume, and density are central to scientific description. Many other descriptive measures depend on a full or partial description in these terms.

Tracking these concepts in a study that foregrounded mediated action in the social milieu of the classroom necessitated some methodological innovation. Primarily, this involved the selection of eleven 'episodes' of classroom interaction that spanned the first seven weeks of the eleven-week instructional sequence. These episodes represent snapshots of each of several social configurations in the classroom, and the kinds of discourse and action that accompanied each, as the students worked on problems and concepts related to describing substances. Each of the episodes includes a significant piece of data from the discourse system of the classroom, in the form of transcripts and artifacts from the public arena of the whole class, and from relatively more private settings like groups of four, working pairs of students, or individuals' logbooks. In selecting episodes, my primary goal was to trace the emergence and evolution of language, thought, and action in each of these settings within the classroom.

Pre- and post-instruction conceptual tests and clinical interviews were administered during the first and last weeks of the sequence. These two sets of data had some importance in tracking conceptual understandings of individuals, but the episodes themselves were most instrumental in my efforts to trace collective and individual understandings during the course of instruction. While analysis focused on these data, none were analyzed in isolation. Often, written artifacts generated during the course of dialogue were examined as tapes of the dialogue were viewed. In like manner, the actions of individuals were often noted in reconstructing sequences of interaction, in order to verify and elaborate my understanding of the import of these sequences.

The full extent of methodological considerations is described in Chapter 3 and further elaborated in examination of the data in Chapter 4.

Description of the Study and the Unit of Analysis

This study examines teaching and learning in a middle school science classroom. I examined video and audio tapes of classroom sessions, student logbook entries and other written work, group products like posters and presentations, and teacher reflections taped after each class session in order to develop rich and contextualized descriptions of the teacher and students as they thought, spoke, wrote, and acted their ways through the instructional sequence.

In such a rich set of data characterized by many kinds of evidence about a sizable range of kinds of interactions (individual/ logbook, working pairs, groups of four, whole-class, group/poster, group/whole-class, group/written text, and others), a primary concern for the researcher is selection of a unit of analysis that enables a systematic examination of a representative sample in order to formulate a picture of the interactions that is true (with high degrees of certainty) to the larger set. In the data collected for this study, the range of interactions was of particular concern.

In Voices of the Mind, J. V. Wertsch (1991) suggests that the appropriate unit of analysis for the study of human interaction (which he terms 'mediated action', and includes language, thought, and action) is *individual(s) acting in social context(s) with mediational means*. In proposing this unit of analysis, Wertsch points out that this is the smallest unit that accounts for all of the things that are essential for the study of interaction. Smaller or less inclusive units, such as the individual, discount interactions which are by nature social. Contexts as a unit fail to account adequately for individuals and their actions. A study of actions in isolation likewise denies the context and individual considerations. Wertsch notes that the sociocultural model of mind that he proposes represents a synthesis and extension of the work of Vygotsky and Bakhtin, theorists whose work rests firmly on convictions about the social nature of thought and action, including interactions in which learning takes place.

Using this unit of analysis, this study aims at telling the rich and engaging story of what happened in one sixth grade science classroom. The story will be told as a series of episodes, each of which represents mediated action. Episodes were selected to cross the many different social configurations (and thus learning contexts) in the classroom. In each setting, I will examine four different aspects of mediated action.

- the nature of the group or individual engaged in the action and
- what he or she (or they) were doing, using
- what kinds of mediational means, including all manner of language, intellectual tools and concepts, and classroom equipment or props, in
- what social context, including immediate task, authority, and role structures, as well as larger group, classroom and school contexts.

In this classroom, the goal of instruction was to assist students in moving from their common ways of talking, thinking, and acting in relation to the natural world towards interactions more representative of a scientific world view and approach. In short, classroom activities were designed to help students command new and more powerful scientific discourses by involving them in collaborative activity in which their own ideas about observed phenomena played a central role. In attempting to scaffold this transition, the teacher worked to create an environment which reflected some aspects of working groups of scientists. Specifically, four kinds of activities that reflected the work of scientists who are describing substances were presented by the teacher, and became a framework within which the discourse-based interactions in the classroom were structured. These activities included

- developing Techniques
- making and recording Observations
- looking for Patterns in recorded data
- developing Explanations for observed phenomena

My analysis of the many kinds of interactions that ensued in the course of the unit was also contextualized within this framework. Thus, in this analysis, I attempted to focus on the kind and nature of interactions in which students and teacher were engaged, and to characterize these interactions in relation to each other and the evolving discourse of the classroom. This discourse was often shaped by my own action and language, as I attempted to scaffold students in their negotiations of meaning and their attempts to build new understandings around the activity of the classroom. Systematic examination of evidence, included repeated viewing of videotapes in conjunction with students' individual and group written work, was undertaken in order to characterize the nature of the interactions in the classroom context.

One of my purposes in targeting interactions in this classroom was to gather evidence about (and subsequently characterize) the development of *intersubjective* understandings of the nature and purposes of the activities in which the students and teacher were involved. Intersubjective interactions are those interactions in which the interacting individuals share attention, recognize a common purpose or goal, and develop shared understanding of the subject in context (Rommetveit, 1990). Rommetveit notes that intersubjective relationships are truly dialogical in nature, meaning that they assume two or more players attending to the same idea or purpose in the interaction.

In the instructional sequence under study, I tell the story of my own teaching, as well as the stories of students learning in my classroom. Included in this story are my representations of each of a series of activities which comprised school versions of science that were representative (in some ways) of the work that scientists would do in describing substances. In telling this story, I used classroom vignettes, materials, and teacher reflections to reconstruct snapshots which reflected my own (teacher's) understandings of the nature and purposes of the activity over time. Against this backdrop, I placed student enactments of a series of activities. Using transcripted evidence from talk, individual students' logbook entries, and group products, I constructed pictures that reflected the students' sense of what these activities are about (their goals). In holding these two kinds of pictures (teacher and student) in tension, I examined the evolving senses of purpose over the span of the instructional sequence, in all cases seeking corroboration across the range of data types in order to reduce uncertainty in my analysis.

The Analytical Frame: Four Dimensions of Discourse

Four dimensions of classroom discourse were selected for study, in order to characterize the emergent individual and group understandings. Each is discussed in some detail below. The dimensions studied were:

- goals and purposes the students and teacher brought to the activity
- standards they applied in language use, validation of data, and other activities
- mediational means (including all manner of tools) they used
- the connectedness of their language and action over time.

The portrait that emerged from this particular examination was one of the teacher establishing (and subsequently modifying as needed) initial **goals and purposes** for classroom activity that were intended to scaffold the students into deep engagement with the phenomena observed. As the instructional sequence progressed, and as the students engaged, the teacher's purposes moved beyond engagement to include careful and directed study of the observed system, and eventually to characterizing that system in terms of patterns that emerged from the collected observations of all of the groups in the class. In making these transitions, he focused on consensus as the basis for decisions that were made in the class about the veracity of claims that students made about the system, based on observational data.

Just as students encountered the teacher's representations of purpose in each of the many tasks and activities in this unit, they owned these activities by populating them with their own goals and purposes (Bakhtin, in Ballenger). This meant that the students (individually, as well as in pairs or larger groups) made sense of each activity by figuring out what to do; what actions, language events, and thoughts would get them "done" with the activity. In situations where students worked in pairs or groups, pictures emerged that showed the different goals and purposes that students held in working on classroom tasks, and some of the ways in which these multiple purposes interacted in groups working on a common task. In some of these groups, an intersubjective understanding emerged among some of the members, but commonly the task was completed with multiple purposes and goals held in tension.

A second aspect of this instructional sequence that I wanted to characterize was the students' evolving use of **mediational means** in their attempts to describe substances. As the sequence unfolded and the students' and teacher's activities focused more intently on describing the system under study, I wanted to examine the students' developing control over skills, experimental tools, techniques, scientific concepts and related terminology, believing that their use and command of these and other mediational means reflected some of their emerging understandings about the system, and about the activity of describing substances. In particular, in situations in which students were working together in pairs or groups of four, I tried to examine instances in which the players attempted to scaffold or challenge each other on one or more of these grounds. In doing this, I repeatedly examined sets of evidence together (including language and action from video tapes, as well as individual written work and group products), to closely characterize student action and thought while maintaining a rich picture of the overall interactions and the larger contexts of classroom, task, and sequence of tasks.

A further aspect of this instructional sequence that I examined related directly to the scientific nature of the activities in which the teacher and the students were involved. When scientists set out to describe substances, much of what they do reflects an understanding of the need to describe substances in ways that are consistent with current scientific practice (as defined by the larger scientific community of which they are a part), and in ways that build on what is known or readily observed about the substance. Essentially, there is a **connectedness** and logic to their actions, so that each strategy or procedure that the scientist employs builds synergistically on previous ones to define and describe the substance(s) in meaningful ways.

Students who have not had experience in the set of cultural practices that comprise the scientists' approach to describing substances generally do not command enough of the scientists' "tool kit" to link activities in this way. As a result, many of the courses of action and concomitant uses of language vary substantially, and some are less productive than others in describing substances. In this instructional sequence, the teacher's goals and purposes were transformed by the students into their own senses of what they were about. The teacher walked a line between restricting the activity to ensure productive results (at the risk of "losing" in terms of student engagement), and allowing a wide range of activity that ensured engagement (at the risk of not seeing any productive results in the set). Generally, the teacher sought to reconcile these extremes by structuring tasks that focused on a specific area of endeavor and required a specific kind of product, but allowed students considerable latitude in creating their own paths to these products. This kind of task structure has been termed an *open problem space* (Palincsar et al, 1993). One of the typical results of the open problem spaces that I observed was that different groups of students often presented results that reflected the kinds of processes that they had enacted in the course of completing the task. In a classroom with many groups, presentation of these results often highlighted differences in underlying assumptions about the activities from whence they came.

In examining the unfolding instructional sequence, I was interested in trying to characterize the attempts of the students in terms of a kind of internal logic, or consistency across different aspects of a task or set of tasks. I looked for evidence that individuals or groups held understandings about the connectedness of new efforts to previous ones, and the relationships that existed between these efforts in building accurate and powerful descriptions of substances. As I examined these classroom interactions, I was also interested in how the students, as individuals, in pairs, or in groups of four, developed and applied **standards** for scientific work. Just as the teacher scaffolded the class by privileging certain thought, language, and action over others, I was interested in the ways that students might privilege interactions in similar ways. In particular, I was interested in the ways in which particular mediational means and their uses might become accepted and privileged over time, establishing new thresholds for acceptance of interactions as productive in group and whole-class situations.

These aspects (developing standards, use of mediational means, internal logical consistency between actions, and an understanding of the nature and purposes of the activity) became a series of filters through which I examined some of the many interactions that comprised this instructional sequence. Each tells something about the actions of the students and teacher, and gives an incomplete picture of the students' developing ownership of the identity kit of science. Together, they paint pictures that are, in my estimation, compelling portraits of some students who succeed in taking on this new identity kit, and others who have far less success. In the latter case, these pictures give us strong evidence to explain the continued marginalization of some students, even in discourse-based instructional settings. But, they also give us hope, by helping us to understand why school science is so difficult for some of these students.

CHAPTER 2

Knowing and Learning: A Conceptual Change Perspective:

The conceptual change perspective follows the tradition of Piaget in regarding knowledge as individually held and socially validated. In this view, knowledge itself is information of various kinds, including cognitive organizing structures, that are appropriated through various kinds of effort. Thus, in learning, the sorts of mental activities and demands that a learner encounters are determiners of what is learned and how well. Yet, learning is not seen solely as an individual, cerebral process. In order for new information to be truly learned, it must be integrated into what the learner already knows, and this happens when it is validated in social interaction. To some, this means that it must be 'applied', although others frame this process in terms that are less mechanistic and restrictive. They might say that the learner 'makes sense' of the information in social interaction with text, peers, or adults. This sensemaking is often characterized as incorporating new information into existing webs of understanding and connectedness, and making necessary adjustments in old knowledge as well.

In this view of learning, conceptual processes take primary importance. While context and interaction are noted as important factors, the primary focus of conceptual change research has been on the cognitive demands that students face. For instance, in the instructional unit examined in this study, the central concepts were mass, volume, and density. Conceptual change researchers would see the kinds and qualities of the challenges that students faced in relation to these concepts as having much to do with whether they learn these concepts, and if they do, how well. The concepts themselves are conceived as interacting with other concepts and ideas that each of the students already holds, what Posner and colleagues term the 'conceptual ecology' of the learner (Posner *et al,* 1982).

This ecology, or structured understanding, is similar in some ways to the idea of *schema* , the mental structures, like templates or maps, into which new information is fit (Anderson, 1977); these map-like structures change (and thus the relationships between established ideas changes as well), sometimes radically, as new information is added and old reordered or discarded.

Even though social validation is recognized as important, learning is first seen as "a process of active individual construction" (Cobb, 1994). Posner *et al* (1982) describe a distinction between two kinds of learning, which they term *assimilation* and *accommodation.* Assimilation occurs when "students use existing concepts to deal with new phenomena" (212). In this kind of situation, new information either adds breadth or depth to existing structures, by supplying new examples or information that fills in or fills out an existing world-view. They noted that

> Often, however, the students' current concepts are inadequate to allow him to grasp some new phenomenon successfully. Then the student must replace or reorganize his central concepts. This more radical form of conceptual change we call *accommodation* (212).

Strike and Posner later (1992) argued that, "People do not accommodate when assimilation is still reasonable" (149). They characterized a decade of research in this tradition as indicating that four conditions (which they and their colleagues had suggested in 1982) are commonly accepted as necessary for radical conceptual change to occur (for a more complete discussion of these conditions and the research tradition that supports them, see Strike & Posner, 1992). They are:

1. There must be dissatisfaction with current conceptions.
2. A new conception must be intelligible.
3. A new conception must appear initially plausible.
4. A new conception should suggest the possibility of a fruitful research program.

So, in order for this more radical transformative kind of learning to occur, certain conditions are desirable. Central to these are situations in which students encounter observed phenomena or accumulated data that directly conflict with ideas and concepts that they hold to be true, in order to create dissatisfaction with their conceptions.

In classrooms, this kind of *conceptual conflict* (Hewson & Hewson, 1984; Nussbaum & Novick, 1982) typically occurs in carefully orchestrated situations created specifically for the situation by the teacher. However, the design of these situations is critical. A class of students may present literally dozens of different conceptual arrangements for a given concept situated among related ones. Instructional design that hinges on directly confronting the relationships between concepts becomes difficult, because of the difficulty in tailoring instruction to individuals' configurations. So, while conceptual conflict is seen as essential for radical reordering of webs of understanding, it is a condition that is difficult to create for an entire classroom of students, or even the typical smaller working group of three or four students. Doing so depends on the teacher's accurate reading of the students' conceptual ecologies, some strong commonalities in these for students working together, and the design of a well-defined and engaging experience to confront the naive conceptions.

With the focus on the individual students that is assumed in a conceptual change perspective, students' understandings and ideas about the topics under study are important in two ways. First, they are the place that instruction should start. A significant body of research documenting common conceptions held by students has emerged over the last two decades, with heaviest emphasis on the physical sciences (Driver 1985, as well as teacher guides from the Institute for Research on Teaching at Michigan State University, cited in a later portion of this chapter). This research can form a significant resource for teachers as they think about and begin to design classroom curricula and instructional situations around their students' ideas and conceptions. Having a notion of common ideas and approaches, as well as common difficulties that students encounter, has enabled some teachers to more adequately plan for instruction and to meet institutional demands for advanced ordering of materials or coordinating instruction among a team of teachers.

A second way in which students' ideas and conceptions are important in conceptual change concerns the way in which they influence students' developing understandings of science-related topics. Research has indicated that these ideas often form a kind of "filter" through which students view phenomena and instructional events. Included herein are classroom studies that reveal how students' conceptions of particular subjects like chemical change (Hesse & Anderson 1992), and students' ideas in introductory-level physics (Clement, 1982) interact with instruction designed to directly confront these conceptions. In a similar way, Eaton (1984) and colleagues studied how students' ideas about light interfered with the ideas presented in instruction, even though teachers were aware of their ideas and designed instruction to enable conceptual change.

One lesson that emerges from this work is that students do not come to a state of dissatisfaction with their own theories and explanatory frameworks easily (Watson & Konicek 1990, Clement 1982). Students' naive conceptions are quite durable and persistent, even in the face of repeated observable evidence that contradicts them. Hence, conceptual conflict must be much more than momentary and fleeting, but rather of such magnitude and duration as to cause the student to see his or her own ideas or theories as dysfunctional or inadequate over a significant span of time and experience. Thus, creating sufficient dissatisfaction with the students' own conceptions is one major challenge in teaching for conceptual change. And, conceptual conflict must be coupled with other conditions that support radical reordering of webs of understanding if conceptual change is to occur.

Teaching: A Conceptual Change Approach

In classrooms, then, conceptual change instruction usually focuses on creating and sustaining these conditions in such a way as to support students' attempts to reason out, or make sense of, the sources of conceptual conflict. Again, this means that conceptual change instruction necessarily begins where the students are. Finding out what students believe, and how they explain or make sense of observed phenomena, is always an early step.

Once the students' ideas have been elicited and fleshed out, events or phenomena that cannot be easily explained using the students' understandings become a part of the instructional sequence. Students are given cause to reflect on their own ideas and the observed phenomena, and often are encouraged to propose alternative explanations or ideas. Finally, with guidance from the teacher, students select and work with plausible new ideas in order to better understand and explain the observed phenomena. This process takes time, and does not fit well with traditional school science curricula that demand that students and teacher "cover" vast amounts of factual material in limited amounts of time. Thus, the kinds of curricular priorities that the teacher reflects are essential components in conceptual change instruction.

Many of the individual strategies and approaches that are valued in creating conditions for conceptual change fit well with Collins' notion of *cognitive apprenticeship* (Collins et al 1989). This is distinguished from traditional apprenticeship:

> ...our term, cognitive apprenticeship, refers to the focus of the learning-through-guided-experience on cognitive and metacognitive, rather than physical, skills, and processes. (457)

Specific features of this kind of situation, according to Collins and colleagues, include "the externalization of processes that are usually carried out internally" (ibid.), including problem-solving processes used by experts. Of significance in this externalization are "the development of self-correction and -monitoring skills" (458). In classrooms, this means that reflection includes more than just the ideas and concepts under study, but also the physical and cognitive processes employed in studying them This is one of two general attributes of cognitive apprenticeships cited by Daiute & Dalton (1993), which they call *reflectivity*.

The authors (Collins et al, 1989) propose a goal of this kind of apprenticeship:

> We propose that cognitive apprenticeship should extend situated learning to diverse settings so that students learn how to apply their skills in varied contexts. (459)

Thus the concepts, as well as the strategies and processes employed in using them, are applied across multiple contexts, so that students develop a greater sense of the possibilities and limits of their application (Michaels & O'Connor 1990). It is this kind of greater sense that supports radical reordering of conceptual networks, and the building of broad and robust new ones, that is central to the conceptual change model. Daiute & Dalton (1993) cite this as a second general attribute of cognitive apprenticeship, which they call *generativity.* Notice that the focus here is on conceptual content and cognitive processes; social settings and interactions are important contextual factors in this picture.

Recommendations for Teaching from Conceptual Change Research

Specific teacher guides and instructional units (mentioned above) were developed across a wide range of topics by researchers and teachers in the Institute for Research on Teaching at Michigan State University, to assist teachers in designing instruction for conceptual change. In biology, these included respiration (Anderson et al 1987), photosynthesis (Roth 1985, Roth & Anderson 1987), and respiration and photosynthesis together (Bishop et al 1986), as well as ecology (Brehm et al 1986). In the physical sciences, teacher guides for light (Anderson & Smith 1983, Eaton et al 1986), heat (Hollon & Anderson 1986), and the kinetic molecular theory (Berkheimer et al 1988a, 1988b) were produced. In each of the guides, ideas about common student conceptions formed the basis for specific recommendations for teaching the particular topic(s). These recommendations were then supported with classroom-ready materials designed to support teaching on a conceptual change model.

Some researchers undertook cataloguing and probing students' ideas as a starting point for conceptual change instruction and curriculum development (Carramazza et al 1981, Stewart 1982, Driver et al 1985, Hewson 1986). From these catalogues, they were able to suggest fruitful entrypoints and avenues for instruction on specific topics. Significant contributions along this line of work continue to be made, as researchers and teachers work together to catalogue common student conceptions in many other areas of science (for example, Hynd et al 1994, Gallegos et al 1994, Galili et al 1993, Benson et al 1993, Kesidou & Duit 1993). These studies support conceptual change instruction as they enable the creation of instructional materials designed to address common conceptions held by students. The provision of such materials is regarded as critical support for teachers attempting to implement conceptual change strategies in their classrooms (Smith et al 1993).

A second body of classroom research from the conceptual change perspective has revealed a number of teaching strategies associated with conceptual change instruction (Smith et al 1993, Roth et al 1987) and conceptual learning in science (Anderson & Smith 1983). Some of these strategies are (from Smith et al 1993):

- eliciting and responding to students' misconceptions
- focusing on explanations
- probing after student responses
- balancing open-ended and closed discussions
- providing practice and application

Smith & Anderson (1987) had earlier found that teachers' use of these strategies was most strongly supported by the availability of specially designed instructional materials for conceptual change. Case studies that focused on particular topics have supported this finding, as well as indicating specific conceptual areas that present difficulties for students and for teachers (Smith & Anderson 1984, Minstrell 1984, Hesse & Anderson 1990).

In addition, Kathleen Roth's 1985 dissertation study examined how science texts, central to most traditional science instruction, influenced students' ideas about food for plants. Knowing that texts are a central feature in most science classrooms, she and Anderson (Roth & Anderson 1988) later suggested specific strategies for using texts in promoting conceptual change learning. In these studies, as in others noted above, contextual factors formed the background against which specific instructional strategies were studied. While choices in design and approach were seen as critical in all of the resulting recommendations and materials, an underlying assumption in this body of research was that when the right conditions were present, students would be enabled (and willing) to do the cognitive work required to radically alter their conceptions, as well as the webs of understanding that they constituted. This cognitive approach has clearly moved us to science instruction that serves many students well.

Even so, some recent researchers have claimed that while conceptual change research up to this time has been helpful, it is based on an oversimplified view of students, teaching, and learning. Pintrich et al (1993), point to the necessity of considering motivational beliefs of students, and other contextual factors, in addition to the cognitive aspects of student understanding in promoting conceptual change. Lee & Anderson (1993) examined conceptual change in relation with task engagement and motivational issues. Each of these studies supports revisions in the original theory of conceptual change suggested by two of the authors, Strike and Posner (1992), which essentially focus on the need to consider 'motives and goals and the institutional and social sources of them' (148) both in studying conceptual change classrooms, and in designing instruction to promote conceptual change.

Sociolinguistic critiques of conceptual change include the need to examine motivational issues, but also history, social justice, and culture. Ogbu (1992), for instance, studied issues of differential access and motivation in multicultural settings. Gee (1994) examined how enculturation proceeds as students learn to 'talk science' in discourse-based instruction, and what this means in terms of students' understanding. This last approach, which focuses on students' appropriation and use of cultural tools in developing their own conceptual understandings in science, makes recommendations that most closely fit our own goals in designing the science instruction studied and reported here.

The curriculum for the larger 4-year project, of which this study is a subset was based on Matter and Molecules (Berkheimer et al 1988a, 1988b), and substantially followed the recommendations therein for teaching about the kinetic molecular theory. The modifications we chose to make centered around our conviction that *social negotiation of meaning among peers* was a powerful tool that we wanted to explore in our instruction. This choice, essentially, reflects our commitments to a sociolinguistic view of teaching and learning.

Knowing and Learning: A Sociolinguistic Perspective:

Sociolinguistic researchers regard knowledge as socially constituted and then internalized, a formulation that is credited to Vygotsky (1967) and elaborated by colleagues and followers in this tradition (Rogoff & Lave 1984, Wertsch 1985). In this view, what counts as knowledge is determined by the culture and social milieu in which it is situated. Thus, interaction-- which includes thought, language, and action, all taken together-- is essential for learning, and is the determiner of what can be learned in any situation. Central to this view is the role of language in social contexts; the nature, breadth, and depth of language-intensive explorations are seen as indicators of potential and opportunity in teaching and learning situations in classrooms, and elsewhere (Wells 1991).

James Wertsch (1991) introduced the idea of *mediational means* as the intellectual and physical tools that a person or group uses in acting in a social setting. By Wertsch's account, the range of tools available to an individual or group at any given time in a setting can be enormous; the bounds would seem to be determined only by imagination. But, the use of mediational tools is generally culturally influenced, both in terms of which tool is valued in a setting, and in terms of the ways in which it is employed, as well. The more appropriate, valuable, and efficient uses of tools for accomplishing specific tasks or working towards shared goals are valued over less efficient or productive ones.

Thus, learning involves the use of new and old tools in a particular setting (such as a classroom). These tools necessarily include language, concepts, larger themes, as well strategies, habits of mind, and specific techniques or routines that are functional and efficient within the setting and range of interactions. They also include the kind of physical tools that one might also call 'equipment' (or, in education, 'manipulatives'). The tools that are available, and the tools that are seen as appropriate, are often determined by the setting, the identities of the actors in the setting, and the kinds of interactions that are likely to ensue in the setting.

An overarching instructional goal in this view of classroom teaching is involving students in *reasoning in multiple discourses* (Michaels & O'Connor 1990) in learning any subject. Gee (1991a) defines a discourse as:

> a socially accepted association among ways of using language, of thinking, and of acting that can be used to identify oneself as a member of a socially meaningful group or "social network"...Think of discourse an "identity kit" which comes complete with the appropriate costume and instructions on how to act and talk so as to take a particular role that others will recognize. (Gee, 1991a, p. 3)

Thus, as students reason in multiple discourses, they try on the identity kits, including language, thought, and action, that come with that discourse.

In this study I examined students' language, thought and action as they worked individually or in groups on problems having to do with describing substances. In each of these settings, interactions of students with other students, students with text, students with teacher, and students with equipment and materials was examined. In each of these settings, what the students had the opportunity to learn was seen as intimately connected to their interactions, particularly those in which they used new mediational means, connected or extended ideas from one segment to another, explicitly argued from logic, or held themselves or each other accountable to particular standards.

In examining these interactions, a principal issue was the creation of a 'dialogic context' (Bakhtin 1981, Nystrand 1992) in which meaning was co-constructed by teacher and students together. In this kind of classroom setting, students were challenged to build fluency and power across cultural settings-- across the cultural norms of home, school, school subjects, and the disciplines associated with them. They were challenged to do this as they negotiate, first in their own words, and in progressively more purposeful and sophisticated ways, the meanings and rules for solving problems of understanding in the classroom. This meant that, in the case of school science, their learning is seen in terms of their abilities to appropriate and use the intellectual, linguistic, and physical tools associated with the scientific enterprise.

Teaching: A Sociolinguistic Approach:

Lemke (1990) proposed that scientists, by virtue of their world view and shared habits of mind and intellectual tools, might be seen as constituting their own *culture*. In science, the ways of going about solving problems, the kinds of problems that are valued, and the common shared assumptions about what counts as a solution to a problem, are quite different from the like dimensions of interaction and endeavor that are common in the homes, neighborhoods, and work environments of most people who are not scientists. Thus, one might say that the problem facing science educators is one of assisting students in moving from the common ways of talking, thinking, and acting that they bring with them to the school setting, into the ways of doing these things that are common to the scientific community and endeavor.

In attempting to scaffold these students into greater scientific literacy, our task was to assist students in taking on the *identity kit* (Gee 1991a) of the scientist. This meant creating situations in which they were engaged in meaningful discourse, and helping them to take on the midst and world view of science and scientists. In this way, students were encouraged to learn about, experience, value, and take on for themselves some of the ways that scientists operate in the world. This was a process of *enculturation* into some of the practices of science, as well as into a scientific world view.

The activities that one would be likely to observe in classrooms in which this kind of teaching is the goal necessarily look different from the activities one might see in a traditional classroom. While there is considerable variation in the ways that sociolinguistically based teaching plays out, and thus in the underlying rules and assumptions in play in these classrooms, by looking at studies that describe instructional events and settings I have identified five commitments that these classrooms and teaching situations seem to share. What differs between them is the priority given to each commitment, as well as the identities of the players, the subject at hand, and the larger social settings within which the classroom is nested. The five common commitments are:

1. A commitment to the central role of language in learning.
2. A commitment to the importance of students' own discourses in learning.
3. A commitment to an active facilitator/mentor role for the teacher.
4. A commitment to a learning community classroom.
5. A commitment to reflection for teacher and for students.

While I have listed these commitments as separate and distinct, there are many ways in which each depends on others. It may be fully possible to institute one of these commitments in a classroom without committing to any of the others, but this seems to me to be rare; I have not seen examples of these commitments being parsed out from one another in the broader research literature of descriptive classroom studies. And, because these commitments are interwoven with one another and somewhat interdependent, in sociolinguistically based classrooms one is more likely to see three or four of these strongly evident, if not all five.

Just as these commitments are important to those who teach from a sociolinguistic perspective, they also frame important perspectives from which these classrooms are often observed. Said another way, these commitments lay out some of the major arenas within which research is conducted in sociolinguistic classrooms. As I will elaborate below, when one or more of these commitments becomes the central focus of classroom research, often several others must also be amply described as a part of the research report.

Thus, placing issues against contexts in reporting can present substantial challenges to the researcher; what often results are rich and compelling descriptions of classroom interactions, replete with transcribed talk, student writing, and annotations that indicate important actions and players. As a result of this dynamic, most sociolinguistic studies of classrooms describe many aspects of the daily life therein. It is often a combination of these aspects that come to the fore in the description, as the observer attempts to convey a rich sense of the situation to the reader. Still, the centrality of these commitments to language- and interaction-based instruction and research lends focus and orientation to each. Further consideration of each of these commitments, together with some examples of the ways in which researchers have examined classrooms in light of each, follows.

1. A commitment to the central role of language in learning.

Many researchers have examined the critical role that language, and the process of enculturation into particular ways of writing, speaking, acting, and thinking, play in learning in various classroom settings. In our own research group, for instance, Holland (1994) examined the discourse opportunities available to a Hispanic male student operating within a collaborative group of four students in a sixth grade science classroom. These opportunities were seen as critical in developing conceptual understanding, which was conceived to depend on his participation in significant group interactions about the meaning of phenomena related to states of matter and the arrangement of molecules.

In a related study, Kurth et al (1994) noted the ways in which differences between conversational styles prevalent in home cultures of some students and those that are common in the classroom may be important factors in influencing the degree to which minority students are empowered or disempowered in collaborative group settings. 'The case of Carla' tells a compelling story of a good student who often had good ideas that would move her group forward, and backed them with solid evidence and reasoning. Her groupmates, however, did not value them because she played by a different set of linguistic and interactional rules than they. Even so, Carla maintained deep engagement with science content, despite being silenced by the dissonance between her language use and that of her groupmates.

Michaels & O'Connor (1990) studied Haitian Creole students in a bilingual program, as they learned about the concept of balance by investigating relationships between various lengths of the balance arm, and various weights placed in the pans of the balance. The researchers paint vivid pictures of the students' approaches to the problem, characterization of it, and the negotiations that ensued-- often in Creole as well as English. They further examined the ways in which the interplay of these languages influenced what the students took as important, and the ways in which claims they made in the context of the classroom were culturally nested. By understanding much of the students' own home culture, they were able to examine enculturation into social practices of the scientific community from a unique and fruitful perspective.

Significant among studies that examine language in the classroom is Lemke's (1990) Talking Science. A social semiotic study of the role of language in maintaining power and authority differentials in classrooms, Lemke's detailed move-by-move analysis gives us insight into how common patterns of language use determine much of what is learned in classrooms. While Lemke's study was not limited to classrooms in which discourse-based instruction was the rule, it does give us important insights into the ways that the language of instruction can influence what messages students get about the nature of subject matter.

While Lemke studied teacher-student interchanges and some student-student interchanges in more traditional settings, Gordon Wells (1991) examined talk in a collaborative group of nine- and ten-year-olds as they negotiated about refraction and reflection during a unit on light. Wells' analysis first provides a detailed picture of how the group's talk and interaction unfolded, as they developed common ways of speaking about these concepts. Then he considered what was learned, and how the context of the talk influenced its productivity for the students. Noting that the talk was conversational in nature, Wells proposed

> two main ways in which the context of preceding talk influences what follows: first, by providing a pool of words and phrases that can be drawn upon in subsequent turns, and secondly by creating a conversational framework that, at each point, sets up strong expectations for both the form and the content of immediately succeeding moves (15).

This kind of analysis, coupled with the elaborated pictures of classroom discourse that accompany it, gives us some insight into a few of the ways that talk in classrooms may support the developing understandings of students. At the same time, we see pictures of developing discourse systems, as negotiated by the participants.

Daiute & Dalton (1993) elaborated our understanding of the role of talk in important ways in their study of third graders learning to write. By examining interactions in pairs of students working together on stories, they characterized collaborative interaction as dependent upon three important elements: playing, cognitive conflict, and explaining as a strategy (285). In this examination, they demonstrate the importance of talk in these students' internalization of both structural and conceptual information, furthering our understandings of the importance of a range of verbal interactions in maintaining intense student engagement in classroom tasks.

<u>2. A commitment to the importance of students' own discourses in learning.</u>

In work related to that of Michaels & O'Connor on the Cheche Konnen Project, Ballenger (1994) focused on 'science talks', a regular classroom event in which students worked together to formulate questions to investigate, beginning with their own ideas and experiences, and their own ways of approaching the questions they posed. Taken together, these ideas, experiences, and approaches constituted the students' own *discourses*. The choice to build instruction around students' discourses was seen as central to the deep *engagement* (Newmann 1992) and interest that the students showed in the problems they studied. Their investigations often led to other questions as they studied topics like mold, spontaneous generation, and water quality. Ballenger provides us pictures of how these students approached these problems, and how science content could be learned in support of the students' quests to answer the questions they had posed.

Complementary pictures emerge from work in the Collaborative Problem Solving Project (Vellom et al 1994), set in multicultural urban sixth grade classrooms (the same setting and project as Holland and Kurth, noted above). As students worked in collaborative groups and later as a whole class on problems having to do with mass, volume, and density, their claims about data were seen as a strong basis for their engagement in argumentation and negotiation about the veracity of those claims. With sustained effort based on ownership of these claims, the students validated a set of claims consistent with replicable observations. In the course of these negotiations, the students and teacher together developed efficient and standardized ways of describing the substances under study.

In Ways With Words, Shirley Brice Heath's (1983) landmark study of the southern communities of Roadville and Trackton, the author describes the ways that she involved students in an ethnographic study of gardening, a topic that was a daily fact of life for her students. Beginning with the students' own questions about what constituted good vegetable gardening, Heath's study takes the reader through many of the negotiations and investigations in which students engaged each other and their families and friends in the community.

In Heath's study, the students involved others as they created a community of interested learners much wider than the classroom or the school. In doing so, they found that knowledge was embedded in many different kinds of discourses. In order to get the information they wanted about gardening, they had to learn to operate inside a number of particular discourses, as they interviewed people in the community who were recognized as good gardeners. They also had to learn to work across these discourses as they compiled data from individuals into larger sets, and sought consistency and coherence across their samples. Finally, as they reported their findings verbally and in writing, the students' own discourse reflected a growing sense of the value of the research process. As they worked, they reflected on the work they were doing in order to establish for themselves some standards and some common and fruitful ways of operating. The vision of community-based science learning that Heath gives us stands in striking contrast to the experiences that many students encounter in more traditional classrooms, especially in terms of the motivation and involvement of the students, and in the pictures they get of the scientific enterprise.

3. A commitment to an active facilitator/mentor role for the teacher.

In juxtaposition to the traditional teacher's role of dispenser of and authority for knowledge, as well as central player in most classroom interactions, Schoenfeld (1985, 1990) described the teacher as active facilitator and mentor. In striving to involve students in the kinds of interactions and quests that are valued among those who practice the discipline of mathematics, Schoenfeld's vignettes from his own classrooms show how he stepped aside to enable his students to openly probe and question classmates about their understandings of relationships and meaning. In these studies, the students' ideas and the role of language in negotiations of meaning were seen as central to the teacher taking this role. Schoenfeld noted that those who are in the discipline work this way, proposing ideas publicly and attempting to validate them as they negotiate issues of language and meaning.

In a similar body of work, Lampert (1985, 1990) and Ball (1990) studied classrooms in which the teachers supported students as they made conjectures and then justified them to their peers. Ball called this 'respecting students as mathematical thinkers'(13). In her classroom, she often posed problems that challenged students to work across 'representational contexts', and then facilitated student interaction, making reasoning and decisions public in order to move the interactions in positive directions.

Lampert, examining a similar classroom, proposed a 'continuum of justification' along which students move, from private to public justifications, as they learn. In seeing justification of ideas as a part of learning, Lampert assumes that the ideas that students bring to a situation are important, and also assumes that the teacher will take roles that encourage students to propose and justify their ideas, rather than working solely on a predetermined set of ideas or algorithms. Lampert's and Ball's classrooms show (with much younger students) many of the aspects that Schoenfeld noted as reflective of *doing* mathematics as those in the discipline do.

In a similar way, Vellom and colleagues(1993) report on a classroom in which the teacher attempted to scaffold students into reasoned decisions about the veracity of conflicting observational data that had been reported from various collaborative groups working with a system of liquids with differing densities. Holding consensus as the model for decisionmaking in scientific communities, the teacher valued the claims of all students while assisting the class in setting up and conducting verification procedures. His willingness to accept all claims initially, and then to give students a degree of self-determination as they suggested ways to resolve conflicting claims, allowed the class to establish it's own working *standards* for what counted as data. Eventually, with the teacher actively working to assist them, the students successfully distinguished replicable data from the "noise" of irreproducible claims.

4. <u>A commitment to a learning community classroom</u>.

The kind of classroom situation envisioned here, where the teacher takes the role of co-learner, mentor, and coach, has been called a *learning community* (Schwab 1976, Ball 1990, Lampert 1985, Roth & Rosaen 1990). In these classrooms, when students' ideas are being negotiated, the teacher may propose or modify the focus of negotiations, or may instruct students in fruitful ways of thinking about or solving problems (Schoenfeld, 1985). The teacher also shares the rationales for choices he or she makes in order to move the negotiations ahead with students.

Another important feature of a learning community is a growing sense of shared purpose in joint activity. In several of the studies cited above (notably Schoenfeld 1990, Ball 1990, Vellom et al 1993, Heath 1983), this shared sense of purpose enabled students to build on the ideas of others in classroom settings that worked very differently from some of the more traditionally structured classrooms that Lemke (1990) described. Thus, in these classrooms, the kind of true *collaboration* described by Wells (1991) was possible.

> "students are able to offer their interpretations for consideration by others without fear of ridicule and, in the process of discussion, to calibrate their interpretations with those of other members of the group, including those of the teacher" (13-14)

The kind of collaboration illustrated in Wells' study, which described heterogeneous groups of four middle school students working together on refraction, requires shared responsibility for maintenance of the learning environment. Both teacher and students worked together to develop explanations, and to monitor their contributions and progress.

The Collaborative Problem Solving Project (previously mentioned) examined heterogeneous groups of four middle school students working together during units of instruction designed to assist them in developing understandings of the kinetic molecular theory. Eichinger et al (1991) characterized the social norms and conceptual nature of collaborative groupwork as students worked to reason out the 'Water on the Spaceship Problem'. In this problem, the group was asked to produce a poster on which they proposed which state of water (solid, liquid, or gas) was the best way to store and transport the water that a group of astronauts would need. As the students in the group worked to solve the problem, alliances between students developed, based on shared conceptual grounds, or on shared social norms. These alliances appeared to support some students developing understanding, while being less promising for students that were not a part of them.

Kollar et al (1994) and Kurth et al (1994) also studied collaborative groups in this same project. Kollar's study examined relationships between personal identity and students' agendas in group settings. She noted that students with better records of past academic performance, who tended to be most engaged in group activities and discourse, also tended to develop the wider senses of purpose necessary to move the group towards well-defined and elaborated explanations of the observed phenomena. Other students who were recognized by group members as less academically able tended to assume roles that supported the aims of these select few. Kurth and colleagues delivered a compelling case study (previously mentioned) which also elaborated some of the complexities of this kind of instruction. Issues of equity and justice often arose when groups of students were given opportunities to develop their own ways of operating, and to evolve standards for collective validation of ideas (Roth & Rosaen 1990, Miller 1987).

<u>5. A commitment to the critical role of reflection in learning.</u>

While reflection is not always noted as a significant commitment in sociolinguistic studies of teaching and learning, it may be found implicit in classroom practices or may be framed explicitly in different terms. The essence of reflection is taking a stance outside one's present actions to consider what one has done and might do in relation to one's present condition. Reflection includes the meta-level strategies that help us to make sense of what we have done, and to look ahead and plan strategic action. In teaching and learning, they often result in better understanding of the significance of particular events and ideas, for teachers and for students.

One way in which reflection appears in a range of studies is as a 'self-monitoring' aspect of the work of a group or discipline. This representation is common to the mathematics studies cited above (Schoenfeld 1985, 1990; Ball 1990, Lampert 1985, 1990). In a later study, Ball (1992) described a situation in which her students were trying to reason out how fractions work. Given the challenge to figure out 3/4 of 12, they proposed solutions, explained how they figured each out, argued about meaning, and eventually validated a number of ways of thinking about fractions that were fruitful for solving this kind of problem. In the validation process, reflection led to critical examination of ideas and algorithms together with the situation, resulting in students arguing about the meaning of the fraction 3/4 in ways that supported their reasoning.

A second way that of framing reflection is in terms of metacognitive strategies, such as explicit talk about talk. Michaels & Bruce (undated) interviewed urban fourth-graders about the earth's motion and seasonal changes in climate after the students had participated in a text-based unit of instruction. Analysis of the interviews revealed that most of the students developed plausible-sounding explanations without understanding underlying theoretical constructs such as relative distances, time, and relational motion. The interviews themselves were occasions for students to recall what they had learned. But they allowed the interviewers, during analysis, to reflect on what had worked and not worked in the instruction. This reflection led to their suggestion that instruction include

> opportunities for students to commit to a particular theory and to reflect as a community of learners on the variety of discourses of explanation, a chance to record, analyze, and critique competing modes of explanation, and to practice them, orally, and in writing (27)

Note that reflection can occur as a feature of classroom activities involving oral and written practice of discourse, especially those that assume a critical review of ideas and their applications to problems.

Likewise, Michaels & O'Connor (1990) gave examples of third and fourth grade students learning about balance. In this and three other studies that they reviewed (Heath 1983, Palincsar & Brown 1984, Moses et al 1989) they noted the importance of talk about talk in developing discourse strategies among students. In each case, explicit teacher scaffolding of talk was also noted as significant in the gains that students made. By discussing new terminology and modeling appropriate usage, and by making discourse strategies such as agreement, disagreement, giving evidence or reasons, and proposing new ideas or explanations explicit in the conversation of the classroom, teachers supported students' understandings of the developing discourse on conceptual and structural grounds.

Recommendations for Teaching from Sociolinguistic Research:

Many of the recommendations that sociolinguistic researchers have proposed for teaching appear as implicit or explicit aspects of the discourse-based classrooms they chose to examine. In other words, rather than saying that we haven't quite gotten 'the formula' for good teaching right, these researchers have taken each classroom and context as unique, and therefore different from others in significant ways. For them, there is no single formula for teaching science (or any other subject matter) that will ensure successful learning for all students. Instead, the recommendations that emerge from this research have much more to do with the ways in which classroom interactions are structured and valued, as reflected in the five commitments in the previous section. These recommendations are tempered by their presentation as a set of reasonably detailed examples of classrooms that work for some students. The researchers' work is concerned with figuring out what dynamics are operating in these educational settings, in order to better understand why the instruction and setting work for some students and not for others.

Still, out of the many studies reported here and elsewhere, there are a few that stand as visionary examples of meaningful contexts that engaged students deeply in learning that they obviously cared about. I suggest that a significant part of the success in each of these particular situations was that in each, a *discourse community* was created. Swales (1990, 24-27) identified six criteria for this kind of community, which I have listed below, together with my own sense of how these criteria relate to the dimensions of discourse I have selected for this study.

- *A discourse community shares a broadly agreed set of* ***common public goals***. In the classroom, this means that the teacher shares the goals and purposes of the activity, but it also means that students have some freedom to make sense of the activities in their own ways (cf Ballenger 1994) within the guidelines set by the teacher. I examined episodes of student interaction to try to characterize the *goals or purposes* that students established for their activities, and those that the teacher established.

- *A discourse community has* ***mechanisms of intercommunication*** *among its members.* In every working group, common terms and usage evolve as the group works together. The patterns of speech, ways of recording data, and terminology all constituted forms of *mediational means* in use. This study traced the use and development of mediational means across many social arrangements in the classroom.

- *A discourse community uses its participatory mechanisms primarily to provide* ***information and feedback***. The students and teacher in this study were attempting to describe substances as fully and accurately as they could. In doing so, they communicated through verbal interaction, writings in individual logbooks, making and presenting posters, gathering class data and verifying it, and many other activities. The currency in all of these activities was the information about the substances themselves, and how to best describe them. In examining the ways in which information and feedback were used and shared, this study traced the *connectedness* of action, speech, and thought.

- *A discourse community utilizes and hence possesses one or more* ***genres in the*** *communicative* ***furtherance of its aims***. In this study, students learned some of the genres that are common to science (like tables with data), but they also worked on developing their own genres (like arguments of support for particular claims). Each of these genres constituted *mediational means* that students and teacher used.

- *A discourse community has acquired some* ***specific lexis***. Over the course of the instructional sequence, students developed more scientific ways of communicating about substances. Some of the specialized terminology and ways of using language were developed by the students themselves, while other language (such as mass, volume, and density) came directly from the accepted scientific canon via the teacher. Both *standards* and *mediational means* were in play as new language was acquired and tested.

- *A discourse community has a* ***threshold level of*** *members with a suitable degree of relevant content and discoursal* ***expertise***. In this classroom, each student came to the instructional setting with his or her own set of understandings and skills. As students worked to describe substances, they established *standards* for good description and productive work and communication. Over time, these standards ensured progress towards the ultimate goal of describing substances in terms of mass, volume, and density.

Swales' criteria, while appropriate for discourse communities of all kinds, was somewhat more detailed in the areas related to genre, lexis, and communication than was appropriate for this study. The four dimensions of discourse around which this study was constructed formed an important analytical frame within which to examine the students' and teacher's actions in this instructional sequence, without the redundancy of Swales' six criteria. In essence, the dimensions I selected focused on aspects of classroom interaction and context that most powerfully capture what happened in terms of the emerging social and individual understandings of difficult and complex subject matter. The research questions that guided this study, which follow, illustrate the focus of this study, which was characterizing developing individual understandings as well as the emergent public understandings as these students attempted to describe substances in ways that were both meaningful to them, and scientific.

CHAPTER 3

Purposes of the Study

This study was guided by the following questions:

1. How did the construction of the concepts of Mass, Volume, and Density proceed in the discourse system of the classroom community as a whole over the seven week instructional period? In what ways did teacher and student privileging of mediated action influence the development of these concepts?
2. In what ways did eight individual students in this class take on the "identity kit" of science, as demonstrated by participation in classroom and collaborative group discourse and investigations about mass, volume, and density? How was the emerging discourse system of the classroom community and collaborative groups facilitative (or not facilitative) of their participation in the activity of describing substances, and especially their understanding of Mass, Volume and Density?

In general terms, my aim in this study was to develop a rich description of interactions in a learning community classroom in which students were negotiating meanings of scientific concepts. I wanted to study the classroom development of concepts that are typically difficult or foreign to many students; I also wanted to select concepts that represented abstractions from examples, rather than simple descriptors used in observations. These criteria led me to select the activity of describing substances, and the concepts of Mass, Volume, and Density. These concepts are often taught using a multiple-representations approach, wherein initial conceptions are refined and sharpened through repeated application in a succession of situations which each differ in some way from previous ones. In this kind of teaching sequence, one would expect some conceptual development or refinement over time. I wanted to see what this looked like by examining the mediated actions (thought, language, and action) of members of the class and the teacher as they worked these concepts out in the public discourse system of the classroom. I was particularly interested in characterizing the interplay between public and more private forms of discourse, and in tracing concept development through them.

Thus, a second purpose in this study involves looking at individuals and how they participated in the developing discourse system of the class. As instruction proceeded, some forms of mediated action were privileged over other forms; I wanted to trace how each of eight target students fared in terms of these privileging actions, which in some cases established new standards for accepted action. I wanted to see what happened--whether these students took on newly privileged forms, or whether they were marginalized by virtue of not doing so. I worked to develop descriptions of these students that included instances in which they challenged, or were challenged by, the privileging of certain forms of action over others. I sought connections between their developing understandings, their use of mediational means, and their participation in discourse-based events in the classroom.

With these two purposes, I hoped to gain some understanding of the flow of ideas and information in a classroom that included a variety of working contexts for discourse, such as individuals writing in logbooks, pairs of students working together, students working in collaborative groups of four on open problems, and whole-class discussions and inquiries in which consensus was the basis for decision-making. While not looking for a definitive model or mechanism, I felt that characterizing this feature of the social milieu of the classroom would add immeasurably to my descriptions of the collective discourse system and the individuals within it.

Description of Setting

The School and Community

This study took place in a middle school situated in a midwestern city of perhaps a quarter of a million people. The city is the state capitol and an industrial center for manufacturing durable consumer goods, and is served by one large school district, as well as several smaller suburban districts. Adjacent to the city is a smaller town which includes a major land-grant university.

The middle school serves a population that is noticeably diverse in terms of ethnicity and socio-economic status. The class studied herein included mainly European-American and African-American students, but also included Asian-American and Latin-American students. Parents' occupations included professional, para-professional, and blue collar and service industries. Slightly more than fifty percent of the students at this school received free or reduced-price lunch assistance. While no statistical analyses were conducted as a part of this study, I saw this particular class as fairly representative of the larger school population.

I studied a sixth grade science class in a grades 6-8 middle school. The students in this school were arranged in "teams" of three classes, or approximately 110 students, who shared the same teachers. Each team of four teachers worked together to establish consistent guidelines for homework, classroom behavior, and personal organization and management for their students. In this way, students from varying backgrounds were provided a unified set of expectations and policies, at a time in their lives when many of them experienced increased independence, and were expected to make wise choices and begin to manage their own affairs. This system had been developed several years earlier by the teachers at this school, in response to a felt need to help many students learn how to succeed in the areas of personal responsibility and organization.

I entered the classroom in January of the school year, as the students were finishing a state-mandated unit on health and hygiene. By agreement with the regular classroom teacher, I took over complete responsibility for planning and teaching this class, which was the first class in the morning. The regular teacher observed most of these lessons, recording information for her own use. She then taught two other classes the same material, often staying a day or two behind my class. On occasion we co-taught this class, especially at times when she had ideas about scaffolding whole-class discussions. Rarely were these occasions planned in any detail, as it was common for her to interject comments at any time during the instructional sequence. She also retained responsibility for grading the students' work; in all cases, we agreed on grading criteria during weekly planning conferences in which we mapped and modified our curricula for the ensuing weeks.

This study was conducted during the fourth (and last) year of a federally-funded classroom research project which focused on relationships between collaborative activity and understanding in sixth grade urban science classrooms. Research was conducted at this site, and another similar middle school site in another city in the same state. Over the lifespan of the project, significant attention was focused on social and cultural factors and their part in determining students' success in these classrooms. (see Eichinger et al 1991, Holland et al 1994, Kollar et al 1994, Kurth et al 1994, Vellom et al 1993, 1994, 1995)

This particular teacher had been a part of this research project for the entire duration; each year she welcomed a researcher as a teacher in one of her classes, and consented to other researchers videotaping one of the classes she taught. She participated in weekly meetings after school to plan curriculum, and actively relished the opportunity to see what ideas and concepts the university researchers thought important, and to share strategies and insights in the planning process. In this way, a mutually beneficial relationship between the researchers and this teacher was maintained.

In taking on the role of teacher during this instructional sequence (eleven weeks in duration), I made a choice to defer my role as researcher until the sequence was over. This choice was made possible by the availability and work of two other university researchers, and the resources of the larger project. At the outset, these researchers conducted pre-instructional clinical interviews with each of the eight target students. One of these researchers videotaped and recorded field notes each day. In addition, assistance with procuring, setting up, and cleaning up lab materials was provided to me and the cooperating teacher. And, post-instructional clinical interviews were conducted by the researcher as well. This enabled me to distinguish, in practice, between those activities that were research-based, and those that were based on teaching. I was able to make this distinction completely, on a practical basis, because others were collecting the data. I was also familiar with how large and rich a typical data set gathered in this way would be, and this enabled me to focus on the teaching rather than having to worry about the kinds and quality of data that would be gathered.

My decision was based on a firm conviction that teaching demands full attention, and worries about ethical considerations and compromises that might arise from my confusing these two roles. I wanted to make sure that I did a good job of teaching, for the sake of the students involved. I had set ambitious goals for myself in teaching this unit; these had to do with daily use of logbooks as significant learning tools in the classroom, and in attempting to provide interaction-rich instruction that would hold high potential for learning for all students. In other words, I had formulated my goals for teaching this sequence around interactions between students and texts, and I wanted to push myself and my students to see what could be accomplished. I was focused on the potential payoffs for me as a teacher, and for my students as learners of science.

Features of the Classroom

I believe that significant interactions involving student ideas about the natural world are best accomplished in a setting in which students and teacher share responsibility for maintenance of the learning environment. In such an environment, often called a learning community, (Ball, 1990; Lampert, 1985) the teacher takes the position of co-learner (rather than absolute authority for what is right or wrong), and student ideas often undergo a process of collective validation. Miller (1987) described collective validation as a process in which members of a group either accept, reject, or argue about ideas generated within the group, until some group position is achieved.

In this classroom, student ideas were often generated and recorded first in individuals' logbooks, and thereafter shared with partners, small groups, or the whole class. Students often worked in pairs to investigate phenomena or share ideas. Regularly, two pairs met (students in groups of four) to negotiate ideas or process data. The groups of four in this class were stable over the eleven weeks of instruction, with the only adjustments resulting from a single student moving into the class. The groups were originally formed by the regular classroom teacher, using the following criteria (in rank order of precedence):

- One student from each quartile of the class, based on academic performance in this science class prior to the beginning of the instructional sequence
- Mixed ethnicity
- Mixed gender

The cooperating teacher had formed these groups at the outset of the academic year, but the students had not worked in groups for some time before the we arrived. The students had, however, been exposed to some social norms for group work. This included instruction based on three key words:

- Responsibility- for my own work and the work of my group
- Understanding- trying to understand others and be understood
- Tolerance- for others who may act differently or have different ideas

She referred to these by the acronym RUT. In the previous year, these words had been used as a part of the formal instruction during the curriculum unit she shared with the research team. This year, however, the cooperating teacher had set up the groups herself, and had worked with students on social norms; thus, further instruction in group norms was tabled until a need for it arose.

The Curriculum

The curriculum for this instructional unit was a modified version of Matter and Molecules (Berkheimer et al, 1988). This curriculum was designed to teach students about the kinetic molecular theory from an alternative frameworks perspective, making explicit use of student conceptions in instruction that is aimed at assisting students in reordering their webs of understanding about the nature of matter. Beginning with macro-level (observable) phenomena, students observe carefully and develop theories to explain their observations. Eventually, they employ models of micro-level structures (atoms and molecules) to establish consistent and coherent explanations for the behavior and properties of substances.

One modification to this curriculum was the addition of a version of the ESS Colored Solutions problem, which forms a large part of the instructional sequence reported here. In this problem, students were given three solutions of differing density; red, clear, and green (in order of increasing density). However, all were completely miscible, and thus could only be layered one atop another with great care. Most students, on their first few attempts at layering the liquids, ended up with mixtures instead.

The problem was presented by the teacher as a challenge to see how many different ways the solutions would "stack". The teacher showed a stack of red over clear to show that stacks could be made, and then students were provided with materials (vials, droppers, soda straws, and plenty of each of the solutions), with a tray of materials provided to each pair of students. Work on this problem initially took two days, and led to a process of collective validation and then reporting via group posters. Discrepancies in posters led to further validation, this time focused on explanations for the observed phenomena, with the whole sequence spanning three weeks.

From this sequence, many students arrived at "heavyness" as the salient feature of the liquids that determined stacking order. Building on this idea, the teacher initiated a series of test-design tasks and subsequent investigations designed to clarify which properties were responsible for the liquids' behavior. At the same time, he initiated some discussion and reference work on terminology aimed at helping students to understand important distinctions between some of the vernacular terms that they were using in science contexts. These instructional activities spanned another two weeks, eventually evolving into directed instruction in Mass, Volume, and Density, as well as a series of demonstrations that elucidated distinctions between these properties and how they are measured and used (the Colored Solutions problem and ensuing instruction is described in detail in Chapter 4). Finally, students took a written test covering the Colored Solutions and Mass, Volume, and Density. Instruction for the five remaining weeks, beyond the scope of this study, included states of matter, and employed molecular models in developing coherent explanations to explain observed phenomena.

Data Collection:

The data collected and used in this study were a subset of the data collected for the larger project previously mentioned. However, I made use of a vast array of data collected in one class; for this reason, I describe the project data collection and analysis procedures here, as well as my own efforts and choices in analysis. I make clear distinctions about choices I made which defined the data I used within the larger set. While analysis involved continuous cross-checking and corroborative searches, I have chosen to begin this description by listing my data sources below, and discussing each in turn. Critical issues and frames for analysis follow these descriptions.

Conceptual pre-tests and post-tests were administered to all students in the class before and after instruction, respectively (See Appendix B). These tests were long, and thus were divided into parts A and B, given on successive days. Students were informed that these tests would have no bearing on their grades, but instead were to give the researchers and teacher some ideas about how they understood some science concepts and ideas. They were encouraged to write ideas down, even if they were not sure. Students who missed one or more of the days of testing were encouraged to make the test up during homeroom or spare time in class. Pre- and post-tests were identical. They were used as corroborating evidence to track students' initial and final understandings, as well as to gauge the students' approach to problems involving description of substances at both times. This study made use of the pretests and posttests of the eight target students. I used these in conjunction with clinical interviews and logbooks to gain insight into early conceptual understanding and approaches, and then later to establish the same at the end of the instructional sequence.

Pre-instruction and post-instruction clinical Interviews were conducted with each of the eight target students in the class (See Appendix B for protocol). Interviews asked students conceptual questions, questions aimed at understandings of scientific approaches to problem-solving, and questions about attitudes and experiences in collaborative group work. Many of the interview questions were prompted with materials. This study made use of one question in particular*, which asked students to compare two cubes of equal dimensions but made of different materials (one Lucite and one aluminum). Responses to salient questions and probes were transcribed, and examined for conceptual content and sophistication. These were compared across the instructional span, and used as corroborative evidence with the conceptual tests to establish pictures of each student's understandings before and after instruction. Post-interview transcripts were also used to verify my hunches about which students had benefited from certain aspects of instruction, as far as this was possible (*Note: Unfortunately, because the interview protocol was lengthy, none of the eight target students was asked this question during the pre-instruction interview. All were asked the question in post-instruction interviews. Since the interview data was used in concert with other sources to determine conceptual understanding and typical approaches to problems for which the concepts of Mass, Volume, and Density would be useful, this data was derived from examination of student logbooks, conceptual pretests, and videotapes of group interactions during the Colored Solutions activity.).

Videotapes were recorded each day of class, using two cameras mounted on tripods. One camera sat in a front corner of the classroom, and captured images of the students at work in whole-class settings. The other camera sat in a back corner of the classroom, and captured images of the teacher (See map below). When students worked in small groups, each of these cameras was aimed at a target group of four students, and was augmented by a PZM microphone placed on a desk of a group member. In this way, a nearly continuous and complete video record of whole-class and small group interactions (for the two target groups) was made. This record allowed me to examine each of these social contexts closely, to establish what kinds of action were occurring, and who the actors were.

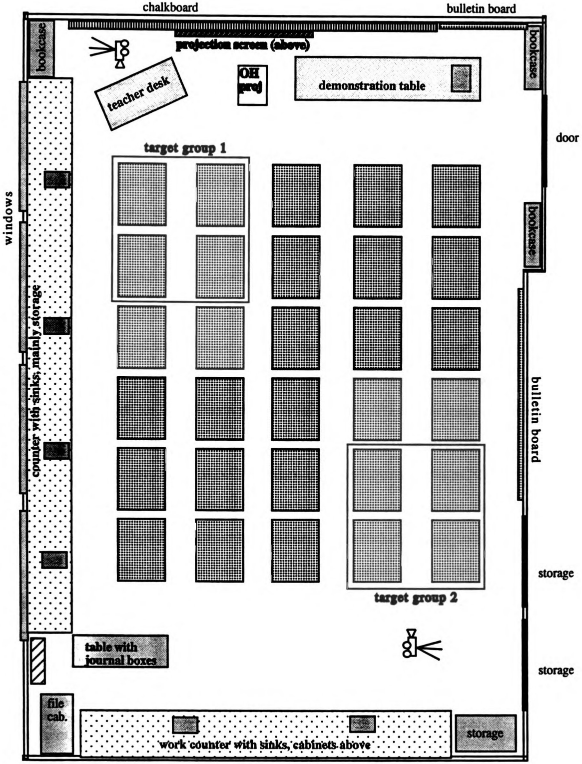


Figure 2: Map of classroom showing locations of cameras and target groups.

These records were augmented by fieldnotes, which were recorded by a researcher using a standard Classroom Observation form developed by the project. During transitions, the researcher moved from one camera to the next in order to redirect the camera towards the appropriate range of subjects. Students became accustomed to the presence of the camera and researcher quickly, and in most cases the redirecting occurred quickly and without disturbance (although transitions often represented the only significant "holes" in our data collection, since aiming the cameras took a few minutes, and eliminated the possibility of fieldnotes for a short time). Tapes were stamped with date and continuous time markings, so that real-time analyses could be conducted.

When students worked in pairs, microphones were placed on the desks of the pair closest to the camera (these pairs remained constant in makeup and position). Audio cassette recorders were placed on the desks of the other pairs. These audio tapes became supplemental records for verbal interactions in these pairs. They were transcribed in conjunction with viewing the video tapes of these sessions, in order to establish the identities of the speakers and to view the actions that accompanied speech. This study made close analysis of approximately seven weeks' videotapes, fieldnotes, and audio tapes; this time span represented the instructional sequence in which describing substances was a substantial part of the curriculum. As mentioned above, taken together, these data sources gave me windows into small groups and pairs of students working together on many of the tasks and activities that comprised the unit. Analysis focused on using as many of these resources as possible to establish what was going on in these various collective settings.

Tapes were secured in the classroom daily, and carried to the university in batches. Once there, working copies were dubbed immediately and the originals stored in a locked cabinet. Fieldnotes were entered into a computer database (FileMaker Pro v. 2.0) in which a new record was created each time a transition occurred in the classroom (this followed a pattern already established in the fieldnotes themselves, which emphasized recording transitions in activity or arrangement of students in the classroom). Thus, records were based roughly on kinds of interactional settings and activities within the classroom. These records were used as an initial catalogue for selection and analysis of video tape segments. The sorting and cataloguing capabilities of the database allowed us to select successive group sessions, or a series by subject, or a chronological series for analysis. As video tapes were viewed, video annotation software (CVideo) was used to develop real-time catalogues and transcripts of classroom events and interactions. These were then simply pasted into the correct records of the database, for further analysis. In similar fashion, transcripts of audio tapes were added to the database as well.

Video tapes and audio tapes give the impression of a 'real image' of interactional settings. As real as these images may seem, however, they are limited by the point of view of the camera, technical limitations of image quality, and by the complexity and dynamic nature of human speech and interaction. In essence, when one records video or audio images in a classroom or elsewhere, one gets an incomplete or limited view of what transpired. This kind of data, then, is best used in conjunction with other data sources rather than as stand-alone records. For this reason, we designed some redundancy into the collection system. With fieldnotes as well as taped images, we reduced the chances that we might miss, or misconstrue, important events in the classroom.

A further caution in analysis of these taped images, which again have their limitations, derives from potential bias in viewing and interpreting them. Essentially, each analyst reviews the images and interprets what he or she finds there. While these analyses are usually undertaken with due care and diligence, one must be continually aware of one's own biases in formulating and researching hypotheses about what is represented on the tapes. This is difficult, especially when a theoretical or explanatory frame seems to "fit" a small fragment of the recorded data. Large enough samples must be surveyed carefully to reduce the chances of a misconstrual. Thorough analysis of taped evidence is rarely enough, in these cases. Corroboration must also be sought in other data sources; cross-checking and then re-viewing (or re-hearing) taped interchanges is a must. This is incredibly time-consuming, but the only responsible way to proceed. Reducing uncertainty in analysis is the name of the game, and it must be done well in every case.

Copies of written work from the entire class were made intermittently during the course of the instructional unit. These included student logbooks, tests, written worksheets, and poster planning documents. In this study, these formed the largest corpus of corroborative information for my work analyzing video and audio tapes, but also comprised a rich and intriguing collection of student efforts from a variety of settings and activities. Much like albums of photographs, the student logbooks gave momentary images of students' understanding and negotiation of ideas. Particularly powerful analyses included viewing students' written work in conjunction with video tapes of the work being done. In these analyses, I was able to watch as dramas of composition and evolution of ideas occurred, often in group settings. Just as written work was important in conjunction with analysis of tapes, it was a vital source of information about individuals-- their ideas, approaches, and understandings. For the study reported here, I closely examined the logbooks of each of the target students; I also used the remaining logbooks in the class to verify hunches about the range of ideas and approaches present in the larger discourse system. On occasion, individuals' logbooks were examined to certify my best guesses about occurrences that were unclear on the tapes of classroom sessions.

Audio tapes of teacher reflections were made after each class session, and were used only for this study. These were free-form recollections (there were no specific prompts to which the teacher responded each day) of problems encountered in teaching, reminders of things to be done for the next day, and exciting or interesting events that occurred during the course of instruction. On occasion, the teacher "reasoned through" happenings in order to make sense of them. The norm for these recollections ran between five and ten minutes per day. These recollections were transcribed in the course of reviewing and collecting materials to write the teacher's story. They rarely provided a clear catalogue of events for a particular day, but rather helped (in conjunction with video images, lesson plans, and classroom materials) to reconstruct a story that includes much about the teacher's goals and purposes in instruction.

Data Analysis:

The data set collected during the six week* span of this study is truly enormous, especially in terms of the taped media. Humans talk and act at will, and the sheer numbers of interactions occurring in a classroom at one time, or over the course of a forty five minute lesson, is often boggling as well. For this reason, I found it important to select segments of time (and thus classroom interaction) for close analysis. However, I first reviewed field notes in order to identify larger sequences of several days' duration that held promise for telling the stories of individuals and groups within the context of the whole class. Then, video tapes from these days were viewed and annotations made to supplement the existing field notes and to catalogue major transitions and promising interactions. (*Instructional sequence for this study was six weeks, but conceptual post-tests were not administered until four weeks later, which was the end of the unit and the larger project study).

The research questions (see 'Purposes of the Study' above) guided selection of smaller segments within the larger sequences that had been catalogued. The first research question concerns qualities or features of mediated action in the public discourse of the classroom. In attempting to create a picture of this developing discourse system, I examined the catalogue, lesson plans, and classroom materials for landmarks, or pieces of interaction that reflected particular aspects or features of mediated action that I wanted to examine more fully. This kind of analysis (one in which a developing system would be characterized) required an understanding of the complete sequence of classroom events; those events not reported in detail would have to be summarized in ways that represented the features under consideration fully enough to create a coherent picture of the system over time.

Mediated Action in the Developing Discourse System of the Classroom

Wertsch's unit of analysis, mediated action (always created by actor(s) in specific context(s)), is fitting for examining the variety of data sources included in my data set, because it assumes that in every case, the data is an artifact or representation of some form of mediated action. I was not interested in simply examining classroom interactions with an open question like, "What are they doing?" to guide me; rather, I wanted to examine the actions themselves (language, action, and thought) for specific qualities or aspects representative of the mediated actions of scientists in describing substances. Another way of phrasing this kind of analysis might be, "In what ways does the action I am observing reflect the qualities in which I am interested?" Using this question as a guide, I reconstructed the story of the public discourse system of the classroom, based first on the actions and purposes of the teacher. This story would later be fleshed out and grounded with episodes from individuals, working pairs, and groups of four.

Thus, the analysis reported here was often the story of the collective-- all of the actors in the classroom, including students and teacher--as well as individuals, pairs, and groups of four within the collective. As I analyzed from these two perspectives, a relatively consistent structure emerged as episodes were selected and the story pieced together. First, the backbone of the narrative was told from the teacher's perspective. In many ways, this story was the story of the collective (although the very personal nature of teaching is evident, as are the personal choices and preferences of this teacher). At times, he held goals and standards that the other members of the community did not value; at others, he scaffolded members of the community into action that reflected his vision; at still others, he adjusted his vision to their actions and goals.

Chapter 4 begins with an episode that includes a brief description of the teacher's instructions for an investigation in which the students would be working in pairs. Next, it includes student logbook entries and transcripts of working pairs from that investigation. Following this, I focus on an artifact, a table of claims from a whole-class data gathering exercise in which each of the working pairs reported out their results and they were compiled. This three-part structure (whole-class description, small group transcript, whole-class artifact) which is a repeating feature of this analysis, also reflects a cyclical nature of the instruction in the classroom.

In selecting and portraying episodes in this fashion, I was able to establish and value the links between each of the pieces of an episode. In short, the teacher's "set" for an activity often provided explicit evidence for goals, standards, use of mediational means, and expectations of connectedness in the activity. Then, looking at the students' language and action as represented in the transcripts allowed me to see what sense they were making of the activity. Specifically, I was able to look for:

- goals and purposes they brought to the activity
- standards they applied
- mediational means they used
- the connectedness of their actions.

These individual, working pair, and group of four vignettes often illustrated the wide range of purposes, standards, and mediational means that students brought to bear on classroom tasks and processes. Ending the episode with artifacts from whole-class sessions then gave me a view of how the teacher and students valued or transformed the products of small-group interactions, again with attention to the four aspects mentioned above. These four specific analytical frames for mediated action are discussed in more detail below

Types of Mediated Actions

The activities and artifacts included in the analysis are varied with respect to the actions of the participants, their language, the tools that they used, and their conceptual content. It was therefore necessary to develop an analytical system that described how these actions were related to each other and to the overall goal of helping students describe substances in terms of Mass, Volume, and Density.

The scientific description of substances is not a single, unified activity. Rather, it is a complex interconnected set of activities requiring different tools, techniques, and language. Within scientific communities, these activities are connected by shared understandings of the nature and purposes of scientific description, properties of substances, and appropriate tools and techniques for describing each property. In laying out these activities and the connections among them, I begin with a discussion of the nature of scientific activity in general. This discussion is followed by a scheme for analyzing the specific activities associated with describing substances.

1. General nature of scientific activity

In the teaching reported here, much emphasis was placed on developing realistic pictures of the activities of scientists for and with the students in the classroom. To further this goal, at the outset of instruction, the activities of scientists seeking to build new knowledge about substances were characterized in a simple framework, identified by the acronym TOPE. As a representation of the activities of scientists, this framework is elegant in several ways. Perhaps the most immediately appealing is its simplicity; yet, it retains an internal consistency that reflects accurately a hierarchical approach that a scientist might take. Between the lines, however, lie a set of qualities of mediated action that characterize and distinguish scientific inquiry from the kinds of inquiry that students might undertake on their own.

Letter	Activity	Examples
T	Developing and learning **techniques**	trying to figure out how to make interesting things happen with substances, like stacking different liquids or dissolving something fast or slowly.
O	**Observing** carefully and recording what they see	using one's senses (and instruments) to notice details as well as the obvious things when you compare substances and changes in them. Making careful notes and drawings so that you can tell or show others what you observe.
P	Finding **patterns**	looking for patterns in the data from your observations. Sometimes, testing your ideas about patterns to see if they always work is important.
E	Developing **explanations** about substances	explaining the patterns you found, and matching patterns with reasons why they happen. Often, scientists develop ideas to explain something, and then later change their explanations when they see new patterns. So, your ideas can change, and you can write new explanations to replace old ones.

Figure 3: TOPE activities and examples

As an example, when a scientist encounters an unknown substance that he or she wants to learn more about (describe), the scientist begins with the T and O actions (see Examples column) to develop an initial characterization of the substance, and then to further describe it. Then the initial characterization is elaborated and refined as the scientist examines the data for patterns (P) and develops explanations (E) for them.

Scientific description does not follow a uniform path (that is, all scientists would not necessarily perform the same acts; order and reasoning might differ as well). But all of their actions are directed at essentially the same larger goal, that of describing the substance in ways that are valued in the community of scientists. To do this, scientists often act with mediational means-- tools of various sorts, including lab equipment and measuring devices, as well as intellectual tools like concepts and understandings about the nature of matter. In these actions, they observe standards for acceptability of their actions established and maintained by the community. One of these standards has to do with careful observation and recording of data. And, each of the scientists' actions adds to the understanding he or she holds of the substance. This is because the scientist focuses on the connections between new attempts to describe and what has been learned in previous ones. To the outside observer, then, these actions appear to have a consistency and logic that are reflected in the evolving description of the substance.

In teaching my students about scientists who describe substances, I sought to make explicit my understanding of the nature and purposes of the classroom activities that we undertook (goals). In doing this, I hoped that my characterizations of these activities would represent modal (or perhaps idealized) actions that all of the members of the learning community could understand as reference points for their own actions. Realizing that my own actions as teacher, and the actions of my students, would vary from this mode, I still thought it important to make this characterization explicit, and to give students some freedom in determining how to translate and interpret these characterizations and the tasks into their own actions.

2. The activities of describing substances

The scientific description of substances begins with some specific goals and values that are shared within the scientific community, but not necessarily within other communities or contexts. In particular, scientific description values denotative precision over nuance, poetic value, beauty, or connotative power. As scientists pursue this goal of precise description of substances, they rely on variables as conceptual tools or mediational means. Each variable is clearly defined and related to other variables that are used to describe substances in clearly specified ways. Among these variables are mass, volume, and density. Thus scientific description of substances encompasses shared understandings about:

- Acceptable techniques for comparing or measuring mass, volume, and density of substances
- Acceptable ways of reporting observations, such as comparisons or measurements of mass, volume, and density
- Patterns that are consistent for observations of mass, volume, and density for many different substances in different circumstances
- Explanations of why these patterns hold.

These techniques, observations, patterns, and explanations are summarized in Table 2, below.

	MASS	VOLUME	DENSITY
T	• Weighing substances using a balance. • Comparisons of mass can be made using a double pan balance.	• Measuring liquid volume using volumetric containers. • Measuring volume by linear or displacement means. • Comparisons of volume can be made by height of liquids in identical containers.	• Comparing density of substances by floating and sinking • Calculating density from measures of mass and volume
O	• Measured in units, gram is standard unit • We say that objects with more mass are heavier, while objects with less mass are lighter.	• Measured in units, liter is standard unit • Comparing volume of liquids leads us to say we have more or less of one. • Comparing volume of solids leads us to say one is bigger or smaller than another.	• Relative density determined by introducing one substance into another to see which floats and which sinks. • Calculated and referenced to standard (water = 1g/ml) • Comparisons can result in stacking, floating and sinking, or lead us to say one is more dense or less dense than another.
P	• Mass is dependent on sample size. • Mass is independent of gravity	• Volume is dependent on sample size for solids and liquids.	• More dense liquids sink, less dense liquids float • Floating and sinking is independent of sample size • Floating and sinking is independent of shape or size of container • Floating and sinking is independent of order of introduction into container
E	• Mass is a measure of how much matter is in a sample	• Volume is a measure of how much space a sample takes up	• Density is a measure of how closely packed matter is. • Measures of density assume samples are uniform

Figure 4: The TOPE x MVD grid

Figure 4 unites the general goal of describing substances in terms of mass, volume, and density, with the specific activities of the classroom. Each of the episodes in the analysis describes members of the classroom community working on one of the specific activities described in Table 1 or on the connections among them.

3. Dimensions of each activity

The analysis of each episode characterizes its place within the general set of activities associated with describing substances outlined in Figure 4. Each episode can also be analyzed in terms of four dimensions that are implicitly present for all activities and explicitly apparent in some. These dimensions are:

- Goals - the nature and purposes of the activity
- Mediational means - the physical, intellectual, and social tools used in the activity
- Logic - the connections between each action and other actions in describing substances
- Standards - determine the acceptability of language and action in describing substances.

Ways in which the language and action associated with each dimension were identified and analyzed are described below.

Analysis of the mediated actions that resulted tell much about the students and their understandings of science concepts, as well as the nature of the scientific enterprise. As I examined each episode, I sought to focus on the four critical characteristics of action underlined above. So, for instance, in the introduction of the Colored Solutions problem, I tried to characterize the teacher's understanding of the nature and purposes (goals) of the activity. In doing this, I asked the question, "What do(es) the actor(s) understand the nature and purposes of the activity to be?"

1. GOALS

When students are working on goals, or concerned about the nature and purposes of the activities in which they are involved, they may argue about what they are supposed to be doing. In most cases, this argument may have to do with the academic features of the task, like disagreements about what products are supposed to look like or include. At other times, students may disagree about the conceptual aspects of a task. This may come from different inter- pretations of the task, which can have to do with approaches and prior knowledge. In these cases, we would see different approaches; the differences in these approaches may involve differences in the status of knowledge, or differences in the kinds and frequency of conceptual work that students are accustomed to doing. An example from poster creation involves some students who are most concerned with the actual creation and production of the poster, and others that are concerned with having good ideas that fit together well on the poster.

At the same time, the teacher is often explicit about the nature and purpose of what he is doing, or what the class is undertaking. We see this in writing in handouts and task-structuring documents. We see this also in his public pronouncements and in the decisions he makes in shaping whole-class discourse events. There are times when he explains the goals in relation to what he knows about the way scientists operate in working groups.

The teacher's goals are the framing goals for looking at the students' understandings of the nature and purpose of what they do. One could consider that there are several frames in which to consider purposes in any situation; these have to do with the nested contexts represented here. For instance, a particular student may feel a lack of confidence in science, or feel disenfranchised by other members of the collaborative group. Either of these personal feelings have the potential for transforming the ensuing interactions, by becoming an overriding frame in the service of which the interactions play out. Likewise, larger goals of learning about the solutions tend to be diminished in the face of more immediate ones having to do with the demands of the task.

As an example of how this played out in the instructional setting, my own characterizations of the TOPE activities were transformed by the school and classroom settings, and the context of the Colored Solutions problem. Actions related to T and O began with an initial phase of exploration with the Colored Solutions, during which there were few constraints placed on the kind of data that each working pair gathered or the kinds of tests they ran. That is, initially, I did not impose standards for acceptable data (other than that it should be recorded as each trial was completed). Nor did I hint that I wanted students to try to approach the problem systematically; I did not model or mention building a more complete picture, and I did not limit (beyond the limits imposed by the equipment provided) the order or manner in which they conducted these tests (I did not require that they establish logical connections between tests).

On the second day of exploring with the solutions, however, I began the class with a short question-and-answer session that changed the nature of much of the exploration that ensued. This change resulted from my asking what "stacks" of solutions had been made. When the vast majority of the class reported making no stacks, but only mixtures, my directions to be careful and to try to get layers redefined the goal of the activity from open-ended exploration to investigating the floating and sinking behavior of the solutions. In my analysis, the application of this question (What do(es) the actor(s) understand the nature and purposes of the activity to be?) helped me to determine the purposes the teacher and students held in actions they effected during the course of the unit. Subsequent shifts in purpose led the teacher and students to focus on finding patterns in the Colored Solutions data, and then to developing explanations for the observed patterns using the concepts of Mass, Volume, and Density.

2. <u>STANDARDS</u>

Just as goals influenced my selection of episodes, so too did each of the other aspects I wanted to study in telling the story of the collective actions of this class. This meant that I examined the teacher's story, and the whole-class discussions and activities, for evidence of emerging standards for acceptance of claims about data, patterns, and explanations. In some instances, I found that the teacher privileged certain kinds of data or reasoning over others. In these instances, I regarded the privileged forms of language or action as the new standard. To trace the development of standards, I asked the questions, "What is the basis for acceptability of data or reasoning in this episode?", and "Is this different from the previous standard?". I wanted to examine, in particular, instances in which the standards appeared to change. I was interested in where these new standards originated, and in the interplay between new standards, goals, and the shared responsibility for maintaining the learning environment that is characteristic of a learning community.

Standards are a dimension of discourse and mediated action that reflect growing awareness and understanding of the productiveness of particular actions in light of the goals and purposes of specific tasks, and larger activities within which they may be embedded. Essentially, I think of standards as momentary (that is, they are often specific to the immediate situation) in classroom interactions; they hinge on judgments made by one or more actors about the efficacy and appropriateness of particular actions or moves. However, I also see them as having an enduring quality; when a standard becomes privileged and the commonly used form, it often delineates a "bottom line" for acceptability. In some of the vignettes included in this study, standards for backing claims with data emerged in conjunction with the need for replicability in experimental results. Both of these standards represent a threshold above which future claims and reports had to climb. They did this by exhibiting the desired qualities with which the standards were concerned.

Both teacher and students share responsibility, in a learning community, for setting and maintaining standards. Some standards were jointly held, and others originated with one situation and were generalized across others. Thus, I expected to see evidence of these across a variety of contexts, which included teacher-centered instruction before and after investigations, data-gathering sessions (whole-class and small-group) after investigations, pairs interactions during investigations, and in individual records and reports of investigations, as well as in whole-class discussion about the patterns and explanations for them.

Teacher-initiated standards were found in whole-class sessions and written materials, where the teacher set guidelines for action and speech. Generally, I looked for emergent standards by looking at the actions of the teacher over time, and asking "What are the criteria for acceptable work in this situation?" , and "How have these changed from those extant in previous interactions?".

Similar questions having to do with the nature of standards in student interactions were asked. I also looked for situations in which students privileged certain actions over others in group settings. These were often evidenced by uptake on particular ideas or forms, lack of uptake on repeated forms, or insistence on a particular format or formulation in creating group products such as posters or data tables.

There are a lot of different kinds of standards that one might look for, and perhaps detect, in the discourse system of a classroom over time, especially as the participants develop common ways of getting things done. I was particularly interested in standards that reflected some of the values of science, which include careful inquiry and record keeping, attention to the TOPE framework and the activity of describing substances, and collaborative activity in which the ideas and claims of all members are valued.

3. MEDIATIONAL MEANS

These standards apply, in many ways, to the other two aspects of mediated action that I wanted to examine. These are the use of mediational means, and the development of connections between actions undertaken in describing substances. In a real sense, I expected to see growing use of a set of mediational means valued in scientific circles as students and teacher moved from the T and O activities towards finding Patterns and developing Explanations. As certain mediational means were used, I expected that they would become privileged forms, and constitute standards for action in a variety of settings. In order to trace the use of mediational means, (which include intellectual tools like concepts, organizational matrices, and terminology, as well as physical tools like lab equipment and measuring devices), I asked the question "With what is (are) action(s) being effected in this episode?" Episodes were selected that show significant shifts in both the means that were used, and the actions in which they were employed. I attempted in this sequence to landmark significant shifts; this led to the selection of several of the episodes included in the study.

When students take action of any sort, they do so with mediational means. These means include physical tools (which might include the materials they need to do school tasks, as well as specific science equipment), skills and aptitudes that a student might have, and intellectual tools. All of these kinds of tools are context-related; there are those that come with school, like ideas about what students do, and what teachers do, and what school is for. There are others that relate more directly to the specific course and classroom; these include attitudes about science, knowledge about science content, skills having to do with the practical side of doing science, and ways of thinking that have

Mediational means are present in every context. But, there are contexts in which the use of particular mediational means (including terms, important approaches and distinctions, and usages of the same) give us indications of students' developing understandings of science concepts and the "identity kit". Especially in terms of describing substances, these mediational-means-in-use include:

- describing substances in comparative terms by using a single feature across both
- focusing on the salient property of the substances in explanations for observed phenomena instead of issues of technique (including care, order) or properties that are independent of the phenomena, like sample size
- exploring in order to understand the system, rather than to try to get it to do something or to get neat results.

- making important distinctions, or using terms that include these distinctions, in negotiations about what is possible in groups.

4. LOGIC AND CONNECTEDNESS

The last of the features of mediated action that I wanted to examine was the development of connections, or logical consistency, across sets of actions in describing substances. One way to describe this quality involves considering the actions of scientists versus those typical of students (or other novices to describing substances). The scientist, having worked at describing substances as a member of a community that does the same, would be likely to demonstrate a set of practices and ways of thinking that get the job of describing done in relatively efficient ways, and with results that would be valued in that community. The approach that the student or novice would take, however, might be much less efficient and produce results that would not be as valued in the scientific community. This is because the community has developed standards for describing substances, and these standards reflect the common practices (including concepts, common understandings, ways of investigating, and ways of thinking) of that community. In looking for connectedness and logical consistency, I asked the questions, "In what ways does this action build on previous actions or information in describing substances?" and, "Does this action reflect an understanding of common scientific practices in describing substances?"

When students are working on describing substances within the context of school tasks in a classroom community, their mediated actions are most often context-specific. Yet, they are involved in what I have termed multiple nested contexts, or a kind of play-within-a-play situation. They are doing science in school, which changes the nature and purposes sometimes. They are also working as members of pairs, groups of four, and the larger classroom community, each of which has incumbent on it certain socially-determined roles and expectations. Meanwhile, in all of these multiple contexts, the students are working to move from the vernacular to the more scientific.

The questions that are important here have a lot to do with the ways in which their actions support their understanding of the activity of describing substances. In a lot of ways, this is the crux of the "identity kit".

In looking for evidence of logic and connectedness, situations in which individuals make and defend choices for action are important, but may be rare. In other words, the choices may not be explicitly discussed, but instead just made on the basis of assumptions about the nature and purposes of the activity. Examination of individuals acting in a variety of contexts on a variety of tasks should give an indication of the logic or connections they see in what they are doing, and the connections that they may not see.

Further examination depends on questions like, "In what ways do these actions build on previous ones and further the activity of describing substances?" in examining individual segments. Yet, the larger estimation on this count comes with examination across segments. Evidence of this kind of understanding would emerge in examination of a series of snapshots of the same individual or group across several contexts or tasks. Evidence across the series might include situations in which students examine recorded data to determine patterns; or in which students look carefully at techniques to try to eliminate systematic errors in testing procedure that might be related to results, or in which students re-examine and retest claims or propose alternate tests which validate a claim.

Summary

Each of the aspects of mediated action reported above became an analytical frame through which videotapes of the teacher and class, lesson plans, and teacher reflections were examined. As noted above, episodes were often selected because they represented landmarks in one or more of these qualities. As far as possible, the development of each of these qualities was traced through the instructional sequence in order to form a "big picture" of how the actions played out in the evolving contexts of the classroom. Constantly interacting with these evolving actions in the public discourse system, and in fact often engendering or qualifying them, were an equally complex and important set of mediated actions in more private settings-- individuals writing in logbooks and on other written work, and working pairs and groups of four negotiating ideas and meaning as they worked to describe substances.

CHAPTER 4

Introduction

This chapter is comprised of ten episodes that represent a larger story that evolved over a seven week period in the classroom. As noted in the previous chapter, episodes were selected that would give a sense of the ongoing story, while allowing closer analysis of some of the many interactions that this story entailed. In particular, I sought episodes that represented the rich nature of classroom speech and action. I wanted a collection that would be true to the larger story and still give views of the range of interactions in which students were involved.

My first purpose as I wrote this chapter was to tell the story of what went on in the classroom. Clearly, I could not include it all; however, in selecting episodes I did seek to balance the story by using a variety of data sources as different views of it. Thus, the teacher's story, reconstructed from video tapes of classroom sessions, lesson plans, materials handed out in class, and audio taped reflections, forms the background against which the various student episodes are displayed. And these student episodes give us views of students working singly, in pairs, in groups of four, and as members of the larger classroom community-- with “snapshots” of each of these configurations situated within the progression of the larger story. Transcripts drawn from video and audio tape illuminated students working in pairs and groups, and also reflected the character of whole-class interactions. These transcripts are complemented by individual students' writing in logbooks, by posters created within the groups, and by excerpts of interviews conducted after the instructional sequence. Each of the episodes reported here depended heavily on one or two of these data sources, but analysis relied on corroboration and cross-checking between sources and across episodes, in order to develop the character of each episode and phase in responsible ways.

I created a timeline (see next page) in order to visualize how each of these episodes supported the larger story, and to examine the kinds of data included in each of the episodes in relation to others. Each of the specific activities around which episodes were depicted are located on a chronological timeline by day, and briefly described. The episodes are sorted into two groups: those that represent discourse events in the whole-class arena, and those that represent events occurring in more private settings (groups of four, working pairs, or individual writing in logbooks). The major pieces of data for each episode are listed to the right of the diagram, and these are boxed and numbered by the *phases* they represent (explained below). This timeline is intended to give the reader a sense of the overall organization of the episodes, as well as some insight into the ways that this structure played out in the analysis.

The story told below is divided into four *phases*, each representing a different view of the nature and purposes of the activities in which the teacher and students were involved within a particular timeframe. While my initial intent was to create one continuous story, in my efforts to do so I found landmark events, around which the nature of the story changed dramatically. These landmarks had most to do with changes in public understandings about the goals of activity in the classroom. For example, Phase I is called "Getting and Recording Data in Colored Solutions", and represents a general characterization of what the students and teacher were doing in the included episodes. A general focus on generating and recording data was characteristic of the episodes included in this phase. The next phase, called "Getting Good Data in Colored Solutions", represents a shift in goals toward a focus on the quality of the data that was being generated and recorded. Similarly, a large shift occurs to delineate the beginning of Phase III, "Looking for Patterns and Developing Explanations in Colored Solutions". Phase IV, called "Developing the Concepts of Mass, Volume, and Density", deals with the ways in which the teacher and students built understandings of these concepts after the Colored Solutions unit, including making important distinctions between them in discourse-based classroom interactions. While this

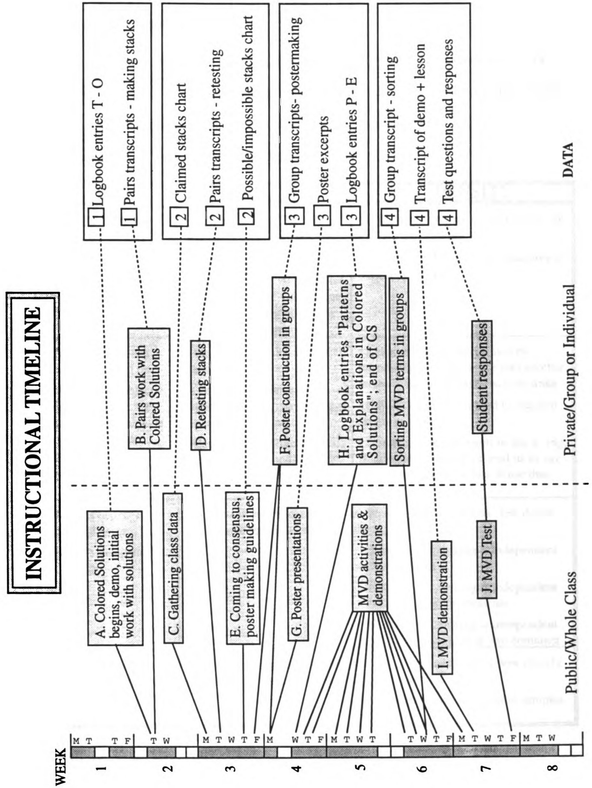


Figure 4: Instructional Timeline

initial introduction to these four phases is quite brief, it is presented here as a telegraphic reference to the sections that follow, in which the nature and texture of each of these phases will be elaborated in greater detail.

One way of viewing the goals and purposes of the teacher's and students' work in this instructional sequence that I found useful involved indexing their actions to the TOPE activity scheme (Techniques, Observations, Patterns, Explanations) for describing substances using Mass, Volume, and Density.

	MASS	VOLUME	DENSITY
T	• Weighing substan-ces using a balance. • Comparisons of mass can be made using a double pan balance.	• Measuring liquid volume using volumetric containers. • Measuring volume by linear or displacement means. • Comparisons of volume can be made by height of liquids in identical containers.	• Comparing density of substances by floating and sinking • Calculating density from measures of mass and volume
O	• Measured in units, gram is standard unit • We say that objects with more mass are heavier, while objects with less mass are lighter.	• Measured in units, liter is standard unit • Comparing volume of liquids leads us to say we have more or less of one. • Comparing volume of solids leads us to say one is bigger or smaller than another.	• Relative density determined by introducing one substance into another to see which floats and which sinks. • Calculated and referenced to standard (water = 1g/ml) • Comparisons can result in stack- ing, floating and sinking, or lead us to say one is more dense or less dense than another.
P	• Mass is depen- dent on sample size. • Mass is independent of gravity	• Volume is dependent on sample size for solids and liquids.	• More dense liquids sink, less dense liquids float • Floating and sinking is independent of sample size • Floating and sinking is independent of shape or size of container • Floating and sinking is independent of order of introduction into container
E	• Mass is a measure of how much matter is in a sample	• Volume is a measure of how much space a sample takes up	• Density is a measure of how closely packed matter is • Measures of density assume samples are uniform

Figure 5: The TOPE x MVD grid

Table 2 above provides a wider view of activities associated with describing substances using these mediational means (hereafter, I refer to this table as the "TOPE x MVD" grid or scheme). Using it as a referential grid within which to situate the students' actions allowed me to track the students' and teacher's understandings of the nature and purposes of their activities, and to locate significant junctures where shifts occurred. These shifts, as noted above, were significant in determining the bounds of each of the analytical phases.

Structural overview of this chapter

In the story that follows, I begin Phase I with a description of classroom events leading up to student work in pairs or groups of four. This description includes information about the teacher's intentions and strategies. Somewhat summative in nature, this description gives initial impressions for analysis of the four dimensions of discourse previously discussed (see Chapter 3 for complete elaboration) and listed here:

- the nature and purposes of activities in the classroom
- the mediational means in use as a part of these activities
- the standards that are in play during these activities
- connections between this and other activities, or between different parts of a single activity

This summary is then followed by transcript data from the small group interactions that ensued-- students working in pairs and later in groups of four. Each of these transcripts is briefly discussed in terms of it's most obvious features, and then examined in light of the four dimensions of discourse presented above. Generally, this examination begins with a discussion of the nature and purposes of the activity as understood by the students; these purposes are examined in light of the teacher's goals, and their relative position on the TOPE x MVD grid. Other dimensions (emergent standards, connectedness, and the use of mediational means) are discussed, as well as patterns of status and participation. Rather than attempting an exhaustive discussion of each of these four dimensions in relation to each piece of data, I tried instead to focus on developing characterizations of each dimension at points where it seemed to play a role in shaping the emerging discourse. Phase I ends with an examination of the entries two pairs of students made in their logbooks. These individual records help to establish a relationship between discourse and action in the working pairs and the understandings of the individuals in them.

Finally, trends in each of the four dimensions are highlighted for the phase. I attempt to maintain a contextualized view of the different social arrangements from which discourse was examined, and through which students made sense of their actions. (In each of the first three phases, this characterization results in a focused transition into the next phase. In the final phase, development of each of the four dimensions is discussed in terms of the entire instructional sequence, using landmarks from each phase to paint a picture of different students' participation in each of the phases, and the resulting consequences for their understanding and engagement in future instruction.)

Phase II begins with a reporting-out of observational data, in the form of claims about stacks that students made or were unable to make. In support of this process, an artifact (a table on which class data was compiled) is presented from the whole-class session that followed the groupwork. The whole-class episode gives us a sense of the developing discourse community in the classroom, and the privileging of certain forms of discourse over others across time. Evidence from transcripts is used in conjunction with the artifact, in order to give the reader a snapshot of the discourse, and the four dimensions reflected in it. The phase continues with students working in pairs to retest stacks over which there was disagreement, and finally a whole-class session in which consensus on each stack is held as the model for decision-making in data-based interactions. Phase II ends with students recording the disposition of each of the tested stacks, and making a list of the stacks that were verified as possible. Again, each of the dimensions of discourse is discussed, along with patterns of status and participation in this phase.

Phase III begins with a copy of the parameters students were given before they moved into groups of four to plan and produce posters about Colored Solutions. Transcripts of groupwork then give us a sense of the kinds of interactions in which students involved themselves during this task, and provide evidence of the further emergence of specialized patterns of language and action that signal further development of the classroom discourse community. These transcripts are then followed by excerpts from the poster presentations, and finally by individual logbook entries about Patterns and Explanations in Colored Solutions. In discussing the dimensions of discourse in this phase, I note that (as in other phases) the differing social arrangements from which the data in this phase are taken help us to see and understand how ideas and language in one particular setting may appear *en toto* or as more subtle influences in subsequent interactions in other settings.

Finally, Phase IV presents data from a much longer span of time, approximately fifteen days of classroom instruction in which the teacher's goals were to extend and deepen students' understandings of the concepts of mass, volume, and density. This phase includes transcript data from a whole-class demonstration conducted by the teacher, as well as a selection of questions from the final test given on mass, volume, and density and Colored Solutions. Again, my interest in presenting discourse of different forms (spoken and written) from different social settings (and thus encompassing different purposes) lies in tracing ideas and language across these settings. In this phase, as these situations demanded more precise and definitive language and action, differential status and participation patterns that emerged as important dynamics in Phase III continue to influence what students get from classroom discourse events. As mentioned above, I then characterize the development of the discourse community by reviewing each dimension across all four phases.

I turn now to Phase 1, at the beginning of the instructional sequence.

Phase I: Getting and Recording Data in Colored Solutions

The Colored Solutions instructional sequence began approximately one week after Mr. V and students had first met. In that week, he had introduced the use of the logbook and talked about the kinds of writing and groupwork that would be expected. The class also worked together on the Two Flasks problem, (see Appendix A) and on properties of substances. On this particular day, Mr. V began by introducing the TOPE instructional scheme (see Figure 3). This set of four activities were characterized as typical of scientists seeking to build new knowledge about substances.

This scheme (the product of several years' attempts to engage students in the activities of scientific working groups, and the felt need for a relatively simple and easily remembered characterization of these activities) was presented as an organizing framework so that students would have some idea of the kinds of activities in which they would be involved during the unit; Mr. V asked them to copy the four entries in the "Activity" column into their logbooks. He intended to come back to this table often and to reference future classroom activity to it.

Once the students had been exposed to these activities of scientists, Mr. V asked them to set up a clean page in their logbooks in the following way, to get ready for the next part of the lesson. As he did this, he noted that the table was structured to enable record keeping for two of the activities just discussed, developing Techniques, and making Observations.

<u>Colored Solutions</u>
1/19/93

Techniques (What I did)	Observations (Things I saw)
1)	1)
2)	2)

Setting the table up before the activity began had the effect of creating an organizing framework for the work that would ensue. Mr. V valued a systematic approach to laboratory activity, including assiduous recording of the activity as it progressed. This is a value shared in the scientific community, in which one must be able to accurately describe (and often reconstruct) the trials one has run in order to verify claims derived from the data one collects. The two-column format was intended to scaffold students into a record-as-you-go routine that would avoid a result that he had seen many times before in his own classroom, that of students "doing the activity", and yet making no records in doing so. In the scientific community, having no record of the parameters of a trial greatly reduces the value of the data, and also reduces the likelihood that the scientist will be able to establish a progression of trials that lead to data that will have some significance in relation to the question being asked. Thus, the two-column logbook page was a direct attempt to value in the classroom the same kind of careful record keeping that is valued in scientific working groups. One further benefit of this format; its inherent structure that assumes that the activity will consist of a series of like trials, each one resulting in some kind of a written observation. This structure, coupled with the expectation that students would record carefully, had the effect of focusing and constraining what the students did with the liquids (for instance, we observed much less unstructured "play" this year than in preceding years in which the two-column format was not used).

Once the logbook page was set up, Mr. V took some of the Clear solution in a vial, and used an eyedropper to layer some Red solution on top of the clear. This event was intended to pique the curiosity and interest of the students; their vocalizations ("cool!" and "neato!") at this point showed that it had achieved the desired effect for many. The students were then asked what they might write in the Techniques column, and a volunteer suggested "Put a dropperful of red into the clear". Mr. V recorded this statement on the overhead projector, modeling what he expected each of the students to do. A second volunteer was solicited to provide a statement for the Observations column, giving the response "Red liquid didn't mix with clear liquid".

These two responses were accepted by Mr. V without qualification or correction, and were written on the projector where all could see them. In terms of the science goals of precise description, though, each of these statements leaves something to be desired. The first does not specify how much clear solution, in what kind of container, or how it should be "put". The second fails to mention the actual observation (that the red was on top and clear on the bottom), but instead tells what the viewer did not see. One might question Mr. V's acceptance of these statements as models of scientific work, especially since they lack important detail, and fall short of the kinds of recording that he encouraged for this activity. The rationale for this choice can be found in his desire to keep students interested and engaged, and his judgment that setting standards too high at this early stage would be one way to quash interest. Knowing that the students who volunteered gave reasonable responses that were within the acceptable range was all that mattered. Precision in recording would be a continuing theme in the work on this unit, a practice which, until it became habit, would require significant scaffolding and support. In hindsight, accepting these answers and asking if other students could add to each of them, or offer modifications, might have achieved the desired result of including all students and still have gotten the observations off on a more productive foot. The model presented by these two statements was less than optimum; given a better model, some students may not have spent so much time on work that was not valued in later data-gathering sessions.

Once students had seen the demonstration and the model statements, Mr. V was eager to give them the materials to run some trials themselves. After a brief reminder to exercise care in observation and recording, and a word about working in pairs, the students were provided solutions, vials, droppers, and straws to try their hands at making stacks. At this stage, most of their efforts were exploratory, and had as much to do with mastering the use of droppers, vials, and straws as trying to achieve particular outcomes.

During this first day of work with the solutions, Mr. V circulated (handing out paper towels as he went) to each of the pairs, watching what students were doing, coaching them on techniques, and reminding them to record each trial in their logbooks. As the end of the period neared, he noted that many of the students had recorded little, and that some students were still unclear about how to use the various pieces of equipment. Thus, he started the next day with a quick review and explanation of the equipment on the tray. Then he asked students to read from a handout given at the outset of their laboratory work:

Colored Solutions

Let's start by thinking about techniques. When you mix colored solutions together, you often end up with a muddy brown mixture. If you work very carefully, though, you can figure out techniques for observing what happens to the solutions *before* they mix together.

Two good ways to start studying colored solutions are ***dropping*** one solution into another, and ***making stacks*** in straws or in vials. There are lots of other techniques for studying colored solutions, too. You will probably think of some of them when you start working. You may want to jot notes in your journal about some of these techniques, so that you won't forget them before you get to try them.

Here is the special format you should use in your journal for recording techniques and observations in colored solutions:

Techniques: (What I did)	**Observations:** (Things I saw)
1.	1.
2.	2.
3.	3.

***A note about recording techniques and observations:** One way to tell whether you are recording as a scientist might is to pretend that you are writing instructions (techniques) and descriptions of what you see (observations) for a friend that is in another class. As you write, ask yourself if they would know what is going on just by reading your notes. If not, you may want to add notes to make your techniques and observations more clear and complete.*

One focus in this handout was further defining what kinds of activities might be fruitful, while leaving the door open for student ideas and innovation. From observing the students the previous day, Mr. V knew that most of the students found the work with the solutions engaging. His goals here were to reinforce some suggestions he had made the day before about working productively to learn something about the solutions. And, as the boxed paragraph at the bottom of the page indicates, he also hoped to continue to encourage accuracy and completeness in recording trials by suggesting that students evaluate their own records of each trial. This, too, is a value among working scientists, who as a matter of course often review their data, keeping a sense of the overall picture and evaluating their progress towards long- and short-term goals. There was an underlying message for students here, too; while these activities may seem simple and commonplace, if we approach them with care, pay close attention, and make records of what we do and see, we are essentially doing what scientists do. This legitimizing of student efforts as scientific may have had the effect of helping some students to feel themselves a part of a subject area that often seemed foreign to them.

Next, students went back to working in pairs, accumulating data in their logbooks as they ran trials in straws and with vials and droppers. During this time, Mr. V again moved from group to group, monitoring progress, answering questions, and coaching students to record and work together.

During this initial phase, Mr. V held goals that reflected his desire to engage students in scientific activity in ways that were meaningful to them, as well as true to his understanding of scientific values. His attention to the TOPE framework as representative of the kinds of activities in which scientists engage when they are describing substances, and his creation of a two-column recording format which would promote a sequential and ordered approach are indicators of his desire for students to make sense of the activity while they were working with the solutions. Further representation of scientists as careful workers who often share their work and results, and as people whose work is often like the work done by students in many ways, may have aided students in seeing themselves as part of a developing scientific community in the classroom. Mr. V's goal, in a larger sense, was to represent specific features of scientific activity to them in ways that would serve them well in their investigations, as well as develop specific strategies and habits of mind that are typical of a scientific world view. Given these representations, he hoped to scaffold them into just that kind of activity. We shall now see what sense students made of these representations, by looking at how they played out in pairs of students working with the solutions, and in the logbook entries that each pair generated in recording their Techniques and Observations.

Student Groupwork in Phase I:

A. Adam and Lisa

In Group 1, Adam and Lisa (a working pair) performed three tests in vials and three in straws, with one success (one trial in which the liquids clearly stacked) in a straw. Sandra and Kyle, their partners in Group 1, ran nine trials in vials and one in a straw, reporting three successes in vials.

Below, Adam and Lisa explored the solutions:

1 Lisa- The observation is that it turns olive green. (Adam passes materials to Lisa)
2 Adam- What do you want to do?
3 Lisa- Is this how you dump it?(Adam describes how to use dropper, then shows her.)
4 Lisa- One dropper of red, one white, one clear. (doesn't know how to use it. Adam shows her again. She changes her mind once she gets one dropperful of red in.) Let's take two. Now we'll take the white. (squirts it roughly in, then takes green and squirts it in.)
5 Adam- (to himself) It turned olive green. (to Lisa) Is that olive green again?
6 Lisa- It turned colors. (they both write)
7 Adam- You put red in first, right?
8 Lisa- (writes) Two eyedroppers of... red, green, white. And what happened? (pause) It kept on changing colors. Each color we put in, it turned that color.
9 Adam- Okay
10 Lisa- Now
11 Adam- Just a second, just a second. (shows her how to put something in a straw. He asks her what color should go first.) Green. Then red.

12 Lisa- What happened? What'd we do?
13 Adam- (as writes) We put green in straw, we put red in straw... it turned clear.

1. Adam's and Lisa's Goals

Lisa and Adam quickly fell into a routine that reflected shared understanding of the nature of the task, and shared responsibility for completing it. However, this shared responsibility was accomplished by turn-taking rather than by equally distributed joint responsibility for each test. Lisa's first statement above (move 1) was a restatement of an observation from the previous test that Adam had just run. She repeated this as she wrote it down, signaling the end of a trial. Adam then gave her the materials, and coached her into using the dropper (3). She invented a test in an *ad hoc* fashion, squirting the colors together (4). He then mouthed an observation statement, checking it with her before recording it (5). Clearly, this pair followed a tightly prescribed routine in which the person manipulating the liquids had control over the test to be run and the results to be reported. This was a shared version of the exploring task, in which turns alternated and Adam took responsibility for teaching Lisa basic use of the equipment so that she could fulfill her part of the task.

While completing the task, Adam and Lisa recorded the following information (copied verbatim) in their logbooks:

1-19-93

Adam

Colored Solutions

Techniques: What I Did	*Observations: Things I Saw*
1. Put clear into vial: put two eye-droppers of red into it	*1. The red liquid didn't mix with the clear liquid*
2. Put green in vial; 1 eye-dropper full of clear; 2 eye-droppers full of red	*2. They all mixed and stayed the color of green.*
3. Put 3 eye-droppers full of green in vial; 3 eye-droppers full of clear in vial' 3 eye-droppers full of red in vial.	*3. It turned an olive green color.*
4. 2 eye-droppers full red in vial; 2 eye-droppers full of clear in vial; 2 eye-droppers full of green in vial.	*4. Each time we put a color in it changed that color.*

5. Put green in straw, put red in straw and put in vial.	*5. It turned clear.*
6. Put red in straw, put clear in straw, put green in straw.	*6. The stacked and did not mix. Red on top, clear in middle, green on bottom.*
7. Same test as number 6.	*7. Same results as number 6.*

1/19/93

Lisa C.	*Color solutions*
Techniques: (What I Did)	*Observations: (Things I Saw)*
1. Put clear into vial: put two eye-droppers of red into it	*1. The red liquid didn't mix with the clear liquid*
2. Put green in vial; 1 eye-dropper full of clear; 2 eye-droppers full of red	*2. They all mixed and stayed the color of green.*
1/20/93	
3. 3 eye-droppers of green, clear, and red.	*3. It turned a olive green color.*
4. We put 2 eyedroppers of red, clear and green	*4. Each color we put in it turned that color.*
5. Put green in straw, put red in straw and put in vial.	*5. It turned clear.*
6. Red in straw, put clear in straw, put green in straw.	*6. They stacked and did not mix.*

Note: For both Adam and Lisa, trial #1 is a record of the class demonstration done by the teacher; student work begins with #2.

There is a very close correlation between the entries in the Observations columns of these two students. This correlation resulted, at least partly, from the joint view of nature and purposes of the task that these two students held, and the routine that they worked out to get it done. For them, while making a stack was clearly a bonus, carefully recorded attempts were the name of the game, and shared (but not necessarily equal) responsibility was also a basic feature of their work. Both of these students made accurate and detailed recordings in their logbooks, especially in terms of techniques. Their records differed from one another in seemingly small ways.

One entry that was different for these students was the observation that each recorded for trial #6. Adam wrote

The stacked and did not mix. Red on top, clear in middle, green on bottom.

while Lisa recorded

They stacked and did not mix.

Adam's last statement, which he composed without proposing it verbally (in an exception to their routine), reflected attention to stacking behavior, and in fact stacking order. This observation stood out among all others made in this pair of students because it moved from the general "mixed or didn't mix" formulation to one of greater specificity. The initial formulation was still there, but Adam had begun to gather data that would be meaningful in figuring out the relative density of the liquids. While there was no specialized terminology or use of language associated with this move at this point, the move appears significant in terms of the longer-range goals of the instructional unit. Having made this move put Adam in a potentially better position to focus on density as the causal feature for the stacking behavior of the solutions.

2. Other dimensions: mediational means, standards, and connections

The observations of these two students are characteristic of common approaches of many students from early in the instructional sequence, as represented by their use of vernacular language in routine ways to describe their tests and their observations ("they stacked"). Here, the first two observation statements resulted in gross estimations of color; in their third trial Lisa suggested a pattern statement, which might be interpreted as a progressive description of what they had seen. They then switched to using straws. Their first trial resulted in another gross statement of color; finally, when they got a stack, they carefully recorded the stacking order. They then repeated the test, getting the same results.

From a scientist's standpoint, paying attention to the order in which solutions were added made sense (though it may have had little to do with eventual stacking order), and paying attention to the amount of each solution added was also a reasonable move, providing the students did not understand the mechanisms at play in making stacks of liquids. Both of these moves might have represented a careful, studied approach in which these students paid attention to detail, particularly in making records of the trials. Scientists generally value being able to repeat trials based on the records they keep, and these students came close to producing such records. Adam and Lisa clearly held standards for careful recording and attention to detail in each trial. They established an evenly paced, methodical routine for conducting trials, which both of them followed. In doing this, they shared these values with Mr. V, who had encouraged care and attention in his instructions to students at the outset of the activity.

However, paying attention to order and to amount are both essentially moot points when one understands the mechanisms (and related concepts) that make the liquids stack the ways they do. Relative density makes the liquids stack in definite ways, independent of amount or the order in which they are added to a container. Thus, Adam's and Lisa's work in this first segment reflected more general understandings of the scientific endeavor, but clearly did not demonstrate command of the workings of the system, or the related concepts. In one instance, trial #3, Lisa appeared to have made a system-level generalization about each added color determining the color of the mixture. Yet, the generalization did not hold for either of the first two trials, nor the fourth. Thus, I believe that her statement represented a proposal that described the particular trial, rather than a generalized pattern.

B. Chet and Donnie

Members of group 2, Chet and Donnie set out to work with the solutions:

1 Chet: Alright, now, I'm gonna try and put white on the top of red and see what happens.
2 Emma: It doesn't do anything.
3 Chet: It doesn't?
4 Donnie: That's what I'm trying to do. It just turns it light.
5 Chet: It does?
6 Emma: Oh! So, if you put white on top of something, it mixes. (Shewrites in logbook).
7 Chet: It doesn't mix (looking at his vial).

8 Donnie: (looking at Chet's vial) See? Oh, I should have mixed red
(he has clear in the vial first)
9 Emma: yes it does.
10 Donnie: not with red!
11 Chet: (shakes head no) Look, it's all on the top (shows to Emma and
Donnie)
12 Emma: Put more white on. I can't...I really, I truly can't see.
13 Donnie: Oh, it does work with red

Moves 1 and 4 show that Chet and Donnie were working in parallel and clearly separate ways, with each student taking ownership of his work ("I'm gonna try....", and "That's what I'm trying to do."). This parallel pattern, which extended to their larger group of four, included showing results to others, and cross-talk about intentions and findings. In move 12, Emma suggested that Chet add more white (Clear) solution to make the effect more visible. Chet took this as a challenge, as illustrated below.

14 Chet: (adds more clear)
15 Emma: You need to put more in.
16 Donnie: Yo, let me borrow some red.
17 Emma: Let me see it again (Chet still adding to it).
18 Chet: (holding up vial) You see it? You see it now?
19 Emma: Mmm hmm.
20 Donnie: Here, let me borrow some red. (gets from Chet, squirts it into
clear in his vial)
21 Chet: (watching Donnie) It mixes.
22 Donnie: Ah, it mixes.
23 Chet: You squirted it too fast. Squirt it slowly. You squirted it in and it
went all the way down... yeah, it does mix.
24 Chet: Hey, what do I do when I'm done? Do I dump it into this big thing right
here? Do I dump it into this big thing?
25 Donnie: Yeah. OH, COOL! (Chet looks at Donnie's vial intently, Donnie reaches
over and gets more red) (to Chet) A bunch of bubbles come to the top.
(Squirts it into mixture) See it?

In move 15, Emma continued to push Chet to make the visual effect easier to see. Chet finally finished this in move 18, getting Emma's validation in doing so. Donnie's trial then interested Chet (move 21), who made a judgment about his technique. Finally, in move 25, Donnie bid for Chet's attention, but to show off a visual effect other than a stack.

1. Chet's and Donnie's Goals

As noted above, Chet and Donnie did not develop a jointly held routine, instead taking the task as individually exploring with a shared set of materials. This was the case for three of the four students in this group. Amy just watched as Emma and the two boys explored, choosing to join in after ten minutes or so. During this exploratory phase of activity, all of the group members were involved in running their own trials, and dropping in and out of the conversation. Most of the talk in this group was loud and demonstrative. Both Chet and Donnie explored for several minutes without recording trials in their logbooks.

In this exploration, these students appeared to have the goal of making interesting things happen with the liquids, and showing them to others in their group. There was a competitive and hurried nature to their work, which stood in stark contrast to the work of the students in Group 1. Logbook entries for Donnie and Chet are reproduced below:

1-19-93 *Colored Solutions* *Donnie*

Techniques (What did)	*Observation (Thing I saw)*
Put clear into vial; put 2 eye-droppers of red into it.	*The red didn't mix with the clear liquid.*
1-20-93	
Put the red, then he put the clear on the top	*The red didn't mix with the green.*

Colored Solutions

1-19-93 *What did Techniques*	*Things I saw Observations* *Chet R.*
1) ~~Put a dropper full of red into the clear~~	*1) The red didn't mix with the clear liquid.*
1) Put clear into vial; put 2 eye-droppers of red in it.	*2) they mixed*
1-20-93	
2) Put drops of clear into vial of red	
	**3) they mix*
**3) Put clear into straw then put red into straw*	*4) Red gathers on sides of vial*
4) Put drops of red into vial of white	

Beyond the first trial (which was a record of the demonstration done by Mr. V), the Technique and Observation statements of these students differ markedly. As mentioned above, these students worked independently, and thus did not share trials or results with each other, beyond showing interesting visual effects to one another. While making stacks was clearly a goal for these students, each brought a competitive edge to his work, appearing to try to outdo one another in visual effect. One interesting result of this approach was the attention each paid to carefully examining the results of any trial (even those conducted by other group members). During one such examination, Chet happened to look down through a vial containing Red and Clear (see trial 4). He observed that the Red solution appeared to have moved to the edges of the vial. While this observation was not supported by any reasoning or other trials, he quickly showed it to others. Upon showing it to Mr. V, Chet asked "why does it do that?". The teacher explained that the illusion was caused by the refraction of light by the sides of the vial. Chet's move to show his vial to others typified his approach to working with the solutions, as well as Donnie's.

2. Other dimensions: mediational means, standards, and connections

The range of mediational means that Chet and Donnie brought to the initial task was similar to that of their counterparts in Group 1. Vernacular language was common, as each of them invented and ran tests to try to "make a stack". However, while Adam and Lisa focused on the order in which the liquids were added as the defining feature for a trial, Chet and Donnie named the stack they were trying to make in each trial. This subtle difference is significant in the connections between this set of trials and the work that was to ensue, because Chet and Donnie might be more likely to try several *ways* to make Clear float on Red, for instance. In doing this, they ended up with an idea of whether this stack was at all possible or likely. Meanwhile, Adam's and Lisa's attempts were by design to try one *order* *of addition* per trial, paying attention also to the amount of each solution added. Other technique issues like the force with which a solution was squirted from a dropper, which easily come into play in this system, were not taken into account.

Standards also emerged in the work of Chet and Donnie for what counted as an appropriate technique. In the transcript included above that represents their work with the solutions, Chet suggested, after watching Donnie add one liquid to another, (move 23)

> Chet: You squirted it too fast. Squirt it slowly. You squirted it in and it went all the way down... yeah, it does mix.

Chet held Donnie's method responsible for the mixture that resulted, rather than attributing it to amount or order of addition. In doing so, he demonstrated his understanding that adding solutions slowly was the only way to get them to stack. His vocalization was a reflection of this technique standard for successfully stacking liquids. This standard appeared to emerge as students in this group showed results to each other, and requests were made to make the results clearer.

Dimensions of Discourse in Phase I

Although they did not recognize that they were doing so, Adam, Lisa, Chet, Donnie, and the other students were beginning to work on the upper right-hand corner of the TOPE x MVD activities (developing Techniques and making Observations for comparing Density, in Table 2 above). In testing different combinations of liquids and attempting to make stacks, they were developing and practicing techniques that would eventually allow them to compare the densities of the liquids. At the same time, they were developing and practicing language that would eventually develop into ways of communicating about their density comparisons.

Rather than functioning as a discourse community with common goals, standards, techniques, and means of communication, however, the transcripts for Phase I reveal the class to consist of multiple pairs of students who initially construct the task and their results in quite different ways. The similarities among the groups are discussed in terms of the four dimensions of discourse below.

Goals and Standards in Phase 1

One view of the different ways in which students approached the task of exploring the interactions between the liquids states that they populate the task with their own goals (Ballenger, 199X). Ballenger's idea, drawn from Bakhtin, is that when students take on a task, they make the task their own by figuring out what to do in their own ways. At the outset of the Colored Solutions activity, when the class was given the challenge to explore the solutions and see what stacks they could make, none of the class members had previously developed skills in this activity. This put all of the members in a position of deciding how to proceed. As a result, students developed a variety of approaches. In the transcripts above, Adam and Lisa might be characterized as having transformed the goal of exploring the system of solutions into producing a series of tightly constrained tests in a repetitive mode that ensured consistency between their observed results and their records. Donnie and Chet, in juxtaposition, saw the goal as making interesting things happen and showing them to each other. For them, record keeping was clearly a secondary concern, to which they attended only after significant exploration. So, even though one might construe all of these students as having tried to make stacks, we did not see any of them that had previously developed manipulative skills or routines to accomplish this goal. In fact, many may have been just trying different things to see if they could get a stack to appear.

The episodes of student work included here illustrate Bakhtin's notion of students making the process theirs by populating it with their own goals and purposes. While the explicit goals that Mr. V stated centered on attempting to see what they could learn about the liquids, and later moved to attempting to get the liquids to stack, these were not necessarily the goals that the students held in their work with the solutions. We noted that

Adam and Lisa did follow Mr. V's lead very closely, patiently squirting one liquid into another and sometimes adding a third. For them, standards indicated that whatever the result, it should be recorded. They persevered in their work until the time was up, even though they repeatedly made mixtures. In this quest, Adam developed a sense of the importance of carefully adding one solution to the next, and he taught Lisa to do this. But, no evidence is seen of Adam or Lisa having preconceived notions of what they were doing, or what the outcome of a given test might be. Instead, they methodically tried one test after another, holding the results up for observation. They saw the task as requiring agreement on what should be recorded, and as doing one test at a time, between them (even though there were adequate materials for them to work simultaneously). Their routine exhibited features that set it apart from the work of Chet and Donnie.

Chet and Donnie established a different set of understandings about the nature and purposes of their activity. Their interpretation led them to work on different tests at the same time, with each person carrying on a broken commentary to anyone who would listen. Their work appeared hurried by comparison. We saw several instances in which Donnie bid for Chet to look at his results, and like bids from Chet to Donnie. Part of their work was apparently aimed at getting the solutions to mix in interesting ways, or to make visually appealing results. Their work appeared enthusiastic and disorderly, but in fact represented a significant effort reflecting standards not seen in the other pair. Chet, it is apparent, held a standard of replicability as important; when he made an interesting stack, he set out to "do it again". Likewise, the careful observation that these students exhibited led them to notice more than just the gross features of the solutions after each trial. While they did not always come up with the accepted scientific explanation, they did take note of what they saw, and in some cases followed up with additional questions about the mechanisms involved.

The work of both of these pairs of students, different as it was in outward appearance and approach, generally encompassed the goals which the teacher had set out as important in working with the solutions. Explicitly, his goals were to engage students in the problem of figuring out what the liquids would and would not do in terms of stacking. This was translated in the classroom setting into "working with the solutions" and "observing carefully". Students seemed to take on these goals, though they used strikingly different approaches in their initial work with the solutions.

Another goal that Mr. V held for the students, careful recording, was accomplished by many of the students who actively used the two-column format for keeping track of tests run and observational data. Yet, there was variance in the degree to which this goal was accomplished in the classroom as well, and again this was related to the approach that the students took; Adam and Lisa's careful, studied approach clearly revolved around the activity of filling in each attempt and results on their data pages. Chet and Donnie, on the other hand, filled in their tables almost as an afterthought; for them, it seemed to represent an academic task rather than an integral part of the scientific process. While understandable in academic settings, this approach to the recording task risked much of what scientists strive for in gathering data, which is a high correspondence between what is observed and what is recorded. In this sense, Adam and Lisa's methodology appears to have been more likely to capture significant observations in a way that would be useful in further work, and thus came closer to reflecting standards that would be valued in scientific circles.

Mediational Means and Connections in Phase I

During this phase, students were working on using tools (like vials, droppers, and straws), techniques, and observational language (all mediational means) for comparing density. After the first day, most students worked on developing techniques for making valid density comparisons (based on stacking), as opposed to just mixing solutions. Much of this work was done tacitly, embedded in the actions of the students more than their talk or writing. Yet, we did see evidence of this work in some of the recorded logbook entries and dialogue of the working pairs.

During this exploratory part of the investigation, all four of these students were clearly invested in working with the solutions, and learning about techniques and observations (and possibly patterns as well). The tasks of observing and recording within the framework of "Techniques" and "Observations" clearly engaged all four of these students, albeit with different results. And, while they were working on this two-column format in their logbooks, I believe that they were also involved in less overt ways in figuring out what patterns might exist in the liquids. While I do not have direct evidence of this on a larger scale, some of the group members made forays into suggesting patterns during this part of the investigation. And, the ease with which most members were able to suggest patterns a day after this event led me to believe that this was a vital part of the territory in these interactions.

In terms of external appearances, the ordered and careful activities of Group 1 seemed to be more like those that scientists would employ than did those of Group 2. Observers of Group 1 could make a case for the students having understood the studied, incremental approach of scientists, and for having valued the care and assiduousness that characterizes record keeping in scientific work. I am not confident in this characterization; evidence to the contrary suggests that the students did not understand the relationship between careful addition of one liquid to another and possible stacks resulting. Adam and Lisa conducted three different trials in droppers that all failed (their first test was a record of the class demonstration). Examination of video images of these trials suggest that they squirted solutions into one another, using a technique that clearly eliminated any possibility of resulting stacks. Only when they switched to using straws, where technique is much less of an issue, did they make a stack. Instead, their actions seem to focus on a routine way of doing things that they had evolved, based largely on each of them being relatively shy. Adam started the process of investigating (somebody had to), and Lisa watched. She then checked with him to see what to write down, and this routine then continued, with roles alternating.

In terms of productivity, however, the members of Group 2 seem to have benefited more from their efforts. Even though they did not work together on a single trial as did Group 1, their quest to make the solutions do interesting things led them to attempt to make stacks. In doing this, they wrote down less, and did not check each other's logbooks or statements for consistency. Yet, their explorations included Chet making a stack with droppers and vials, and showing it to other group members. He flexibly responded to Emma's request that he add more Clear to it, to improve the visibility of the effect. At the same time, Emma suggested a pattern, "So, if you put white on top of something, it mixes." So, while this group's work appeared less orderly, and included less attention to record keeping than the work of Group 1, there was a wider range of considerations in play in the interactions between group members here, as one member constructed a stack with droppers and showed it to the others (as proof), and another member suggested a pattern for stacking behavior based on her observations of the solutions. In some sense, the lack of constraint seems to have worked in this group's favor in their quest for interesting results.

Yet, the activities in which both pairs of students were involved in this initial phase were removed from the work of scientists who seek to describe substances in a couple of significant ways. First, the mediational means in use here included some specialized techniques, and to a very limited extent, language that focused on describing substances. Scientists with a more thorough and practical understanding of the process of describing substances would be expected to bring other intellectual tools to bear on this problem, tools which our students generally had either not encountered or not mastered. This finding relates directly to the explicit and implicit goals that Mr. V held for these situations centered on engaging students in the phenomena and establishing a structure for generating information (in the form of data) about the phenomena. Both of these goals are 'givens' in scientific working groups, essential to the real work of describing substances. In many ways, Mr. V's goals, and the goals with which the students approached the task of finding out more about the solutions, set the stage for the students to move towards more fruitful investigations in ensuing days. In their initial engagement with the phenomena, some students did include language in recorded observations that included data critical to density comparisons. At the same time, other students never moved beyond language that failed to report density comparisons, but instead remained in more general formulations like, "mixed" and "didn't mix", or "works" and "doesn't work". For the most part, then, students' efforts were directed towards figuring out what the liquids would do and not do, and they did so in their own, common language.

The second way that these activities differed from those of scientists was in terms of the standards for language use and technique that were in play during their investigations, as discourse emerged around the solutions. While scientists value denotative precision in description, in general the descriptive discourse of students is much less precise. In these initial forays into working with the solutions, students were asked to describe what they saw in their own terms. Few restrictions were placed on them at the outset, and in a similar way, most claims about observations were initially accepted. At some point, certain kinds were privileged over other kinds, and this did reflect standards for acceptability. But, in choosing to validate most approaches and responses, Mr. V managed to support the budding engagement of many students. When standards were applied, the problem was recast to include as many students as possible; at this point, new investigations were proposed in which all could participate.

Status and Participation in Phase I

The students' work during Phase I was notable for the general absence of differences in status, participation, and engagement among the students. This was probably due partly to the absence of stated standards that would have privileged some approaches to experimenting with the solutions. Other work in the larger project of which this study is a part has revealed that this relative absence of status differences and high levels of engagement are common when students are working in pairs (see Kurth, Anderson, & Palincsar, 1995).

It is notable, however, that at this point some students were spontaneously acting in ways that would later be privileged, while others were not. Adam, for example, noted which color was on top when recording a successful stack, while Lisa did not. Similarly, Chet sought to replicate his most interesting results and coached the more impulsive Donnie to slow down and use more careful technique.

As Day 2 of these investigations ended, students cleaned up their materials, and Mr. V encouraged them to begin looking back over their logbooks, making sure that their records reflected the work they had done with the solutions. They were encouraged to discuss and compare records with their partners, and to add to them as necessary. Class ended with some students still engaged in this activity.

Phase II: Getting Good Data in Colored Solutions

At the beginning of the third day, Mr. V conducted a quick review of each of the TOPE activities in a question-and-answer format, and then asked the students to set up two tables (following) on a page in their logbooks to record group and class data.

STACKING WITH STRAWS

STACKS WE MADE	STACKS WE COULDN'T MAKE

STACKING WITH DROPPERS*

STACKS WE MADE	STACKS WE COULDN'T MAKE

*droppers and vials were used together, so these are stacks made with droppers in vials.

Mr. V wanted to collect data from each of the working groups of four in an organized way, and to bring that data into the public arena of the class. Doing so would mirror similar events in scientific working groups, where often a data set would be examined collectively by members working on the same or related projects. This process has been characterized as one of separating the real data, the stuff that has value, from the "noise", the stuff that has no value in relation to the investigation (see Vellom et al, 1993).

The students then worked in groups of four to compile their data, with most groups appearing to take this task as simply an additive process in which all claims made by anyone within the group were to be recorded. Students then moved their desks back into rows for the whole-class data gathering session.

Significant Features of the Class Data Set

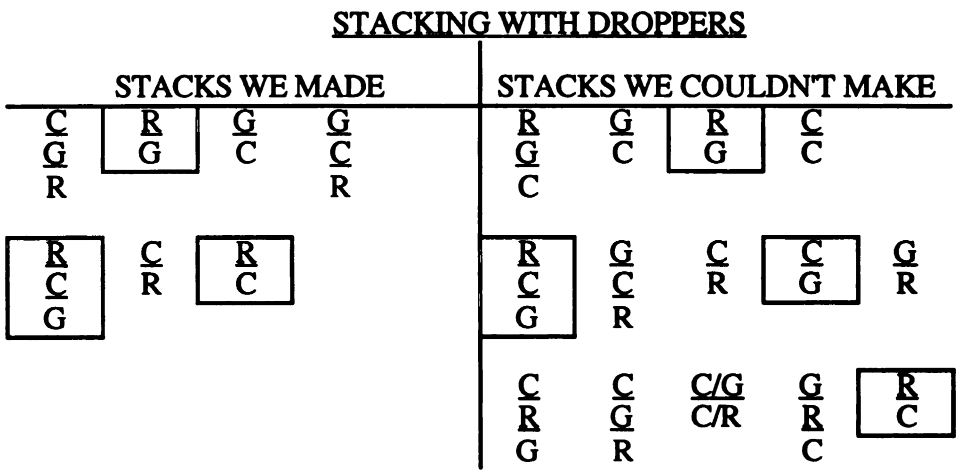
To initiate the reporting process, Mr. V began with the first column of the first chart (Stacks in straws that students had made), and asked students to nominate stacks from their data. He recorded all verbally made claims on an overhead transparency. Students were instructed to record all claims in their logbooks. Mr. V then moved in succession to each of the other columns. The result was two tables with claims about stacks on them (shown below).

STACKING WITH STRAWS

STACKS WE MADE				STACKS WE COULDN'T MAKE			
C G	G/C R	R G	G R	C R	G C	R G C	G R
R C	C/R G	R C G	C R G	G C R			
G C R							

In straws, the class "Stacks we made" included all four of the possible stacking orders (indicated by boxes on the chart); only two stacks appeared on both sides of this chart (G/R and G/C/R). Discounting the stacks that students had made that included mixtures, there were only two inaccurate claims of stacks having been made in straws that are not actually possible (again, G/R and G/C/R). However, the patterns in these may have represented inversions of possible stacks. Students did have to add substances to straws from the top of these stacks down in order to ensure that no mixing would occur. This was the reverse order from that which many students used in adding solutions to vials. Thus, while it is impossible to know whether this occurred, there remains a distinct possibility that these claims represented actual stacks made, reported in inverse order.

In this first chart, all of the stacks that students claimed they couldn't make were indeed impossible stacks. So, while there were some conflicting claims about what stacks were made, the students' failed attempts to make particular stacks led them to definitive statements. On the one hand, interpreting what one is seeing may be more difficult because of possible ambiguities or fine distinctions that must be made in order to get an accurate rendering; on the other, looking to see whether an observed result matches an expected one can be much easier and done with more surety. So, in retrospect, this side of the "Stacking with Straws" table had much to offer students in terms of determining the patterns in colored solutions, an activity which at this point had not become an explicit part of the activity of the class.



The next table, "Stacking with Droppers", gave a much more muddled picture of what stacks were possible and which were not. Among the four possibilities for actual stacks (R/C, C/G, R/G, and R/C/G), three were claimed as having been made (indicated in boxes on the chart), while all four also appeared on the list of stacks that students couldn't make. Students also reported making four stacks that are not possible. All four of these also appeared as stacks that some students couldn't make. While I noted a possibility that some students inverted the order of stacks in reporting stacks in straws, by all appearances much more is at play in the data reported for droppers and vials. An essential piece here is the range of possible approaches to introducing one liquid into another with a dropper. Salient variables include the force with which the liquid in the dropper is introduced (the range runs from slow dropping to vigorous squirting) and the position of the dropper in relation to the vial and solution(s) already in it (one could drop from above the liquid, or introduce the new solution at any vertical position within the column of liquid already there).

The students also perceived other variables to be salient, including the relative amounts of the solutions, and the order in which they were added to the vial. With all or some of these variables (salient and inconsequential) in play in the minds of the investigators, the range of observations (claims) recorded for droppers and vials was much wider than for straws. A significant percentage of all trials using droppers resulted in mixtures, but unfortunately these were not always homogeneous enough that some variation in color could not be detected. Thus, in my estimation, much of what the students reported about droppers was suspect. Some kind of validation process was needed.

Once the data had been recorded in tabular form, Mr. V turned their attention to the quality of the data that they had recorded. In the interchange below, the students' responses tell us much about what they regarded as salient to the behavior of the solutions at this point.

1 Mr. V: There's a lot of combinations up here. Would you look at that data. Any comments?

2 Jeannie: Some people made stacks that other people couldn't make. Like, someone made red over green. And then someone else couldn't make it.

3 Mr. V: How about that. Anybody else?

4 Shane: I don't think we should have clear over clear, 'cause how could you tell?

5 Mr. V: That's interesting. Here's a question, if you have two different clear solutions, how could you tell if the things stacked or not?

Beginning with the data, Jeannie and Shane pointed out discrepancies that they saw. Mr. V scaffolded the discussion that ensued by reflecting their ideas back in the form of questions and statements. For example, Shane began with an opinion (move #4) in which he suggested a standard. Mr. V's response was to formulate a question (move 5), to which Jeannie responded,

6 Jeannie: Well, if you had clear over clear you couldn't really tell because one is clear and the other one is clear and they both come from the same place...
7 Mr. V: I agree. It's generally not productive to talk about red over red, green over green, etc. What about this problem of some people claiming that they made stacks and other people not getting it to work. How do you think that happened, or what do you have to say about that?

Mr. V accepted Jeannie's reasoning, carrying it further by making a general statement in which he privileged claims of stacks of different solutions over those which claimed to have a stack of two samples of the same liquid (7). Then he went back to Jeannie's earlier observation, formulating a question from it. Other students suggested ideas:

8 Sherrie: They may have used different amounts.
9 Mick: They may have put them in in different orders.
10 Rex: They coulda had it previously mixed.
11 Jeannie: Like Sherrie said, a big amount of clear and a little bit of red, or a little bit of clear and a big amount of red....
12 Mr. V: Are there other things that you can think of that might cause people to get...besides the order they put 'em in and the amount, are there other things that you can think of that might cause people to get different stacks, that other people might not be able to get?
13 Jeannie: How long you waited. Sometimes it will settle and it won't be stacked any more.

These issues were right on target in terms of the focus on developing techniques and language for observation up to this point. Each of these students suggests aspects of technique that could result in errors or in anomalous data. Sherrie's suggestion (8) indicated, as did Mick's (9), that these students were not fully aware of the pattern that ultimately they would discover. So, essentially they were focusing on what they knew about, issues of technique that would turn out, in the end, not to be important. Jeannie's final statement (move 13) finally focused on the solutions themselves, as well as observational technique. Mr. V then refocused attention on the appearance of the whole data set.

14 Mr. V: So, there are a lot of possibilities here. What do we as a group do now? We gathered data. What does the data look like to you?
15 Mick: Jumbled
16 Mr. V: Jumbled? What do we do? I mean, put yourself in this situation. We're a group of scientists that's been hired to figure out these solutions for somebody. They're gonna pay us when we give them good data. What do we do?
17 Shane: Run the tests again...
18 Mr. V: Run the tests again and come up with....?
19 Sherrie: Well, um, we could take the ones that are on both sides and run those tests again.
20 Mr. V: The ones that some people could and some people couldn't, run those again.

Mr. V's final response solidified and privileged Sherrie's suggestion, confirming for students what an appropriate course of action would be. Since time was short, he then told students that the next day they would use Sherrie's suggestion to retest those over which there was disagreement, and class ended.

The next day, he started by drawing students' attention to those stacks that were listed as possible and impossible to make. There were nine of these, which he suggested they retest. He directed students to set up a clean logbook page in two-column format as before, and to write Technique statements for each of the tests they were to perform. At the same time, Mr. V recorded these on the overhead. Students were encouraged to check their versions of each of the tests for accuracy against those recorded on the projector, and then with their partners. Then the teacher spent a couple of minutes reminding students that for scientists, proof of data is necessary. He explained that one must be able to show the records made as the investigation proceeded, or be able to take someone into the lab and perform the investigation again so that they can see it. In either case, having good records of the investigation and data is the accepted way to prove something to your colleagues in the scientific community.

Once pairs of students had recorded the tests they were going to run, they were encouraged to get a tray of materials and begin the retesting process. They were also encouraged to work closely in pairs, to show each other results, and to decide what to write down together, before recording it.

Student Groupwork in Phase II

Once all of the tests were recorded in their logbooks, each pair of students began the retesting procedure, using the common list of nine tests which included two in straws and seven in vials.

A. Adam and Lisa

1 Lisa: I'll go first.
2 Adam: I'll go first.
3 Lisa: Okay, let's take turns. (*Adam opens jars. Tries green in straw first, then red. Dumps.*)
4 Adam: Yep they mix. Don't you think so?
5 Lisa: The observation is they mix?
6 Adam: Um, hm. (*They write. Adam uses towel to wipe up small spill, smiles.*) Okay, what's next. Is it a straw one? Yep. (*He hands her the straw*).
7 Lisa: C'n I have the tray? (*Adam puts solutions in the middle of the table. She gets dump cup.*) How does this thing [*straw*] work? (*He coaches her.*) Green, clear and then red.
8 Adam: It mixed didn't it?
9 Lisa: The green and red kind of mixed
10 Adam: Okay, mixed. Would you say mixed? Yeah, they're pretty much mixed. (*They write.*)
11 Lisa: (*Aloud*) They pretty much...
12 Adam: (*starting his next test*) Red in vial (*reads from logbook as he goes along*)

This work session reflected similarities to Adam and Lisa's first two days of investigation, reported in Phase I. Here again, they ran one test at a time, and this time were explicit about how they would do this (see move 3). They shared both responsibility for each of these tests, and results from them; as they moved carefully forward, they watched each other work and verified observations and wording with each other as they proceeded. In moves 6 and 7, where work with the straw was required (which Lisa did not do during the earlier investigations), Adam taught her how to hold the straw and how to pick up liquids in it.

Adam and Lisa report their results in similar terms to those they used in the first phase, e.g. "mixed". However, they clearly took the earlier standard of careful recording of observations to heart, and continued to work in accordance with it here.

B. Chet and Donnie

The transcript below is taken from the outset of groupwork for Chet and Donnie and the other members of Group 2 (since they worked side-by-side but independently, I have chosen to use a 2-column display format. Speakers other than Chet and Donnie cross both columns):

1 Chet: Alright, now, here we go. I'm gonna try clear, red, green (*picks up straw*)

2 Donnie: 'Kay, I'm gonna tryyyy...

3 Chet: Come out of there (*taps straw on edge of waste cup, trying to get liquid out of it*)

4 Donnie: ...red and green (*Donnie plays like he's sucking stuff out of the waste cup with his straw, Chet laughs*) Get it out.

5 Chet: There (*Chet blows through straw*)

6 Donnie: Don't put your mouth on it (*Chet continues to blow*)

7 Chet: I didn't. A little bit of white, let it drip (*picks up clear in straw*) (*Donnie watches*) (*Chet adds red by immersing straw in red vial*)

8 Donnie: It mixed. (*Chet dumps straw, blows it out*) I need that red. (*Chet hands it over*) (*Donnie has green in his straw, immerses in red, Chet watches.*)

9 Chet: Mixed. (*Donnie dumps his, Chet gets some red in his straw, but as he raises it, the red drips out into vial*) I didn't let my finger off! (*he blows straw out into waste cup*)

This episode shows a continuation of the kinds of work practices that Chet and Donnie had established in their earlier work with the solutions. Their first two statements (moves 1 and 2) clearly separated their efforts as independent. While they did "help" each other out with suggestions, opinions, and ideas, they operated independently from each other, running tests side by side. Evidence (moves 6 and 8, for example) suggests that each paid attention to their own work as well as the work of their partners and the rest of the group. It is apparent from their talk-aloud behavior as they worked that both Chet and Donnie still held goals of making interesting things happen that each could show to his peers in the group.

They were, however, working from the discrete list of nine tests, and this prompted Chet to try to make a stack using a straw:

23 Chet: Ah, dude! (*Holds straw up for Donnie to see, has a stack of red over clear*)

24 Donnie: Ah, it mixed! (*to girls*) Hey, look at that.

25 Emma: You got red over white.

26 Chet: Red over clear. That's a good one. (*Looking at Overhead*) Did anybody say red over clear in a straw didn't work?

27 Donnie: Uh huh! [*Yes*]

28 Chet: They said clear over red didn't work. (*looking at straw*) That's pretty good! I'm gonna try and take some more red! Ha, ha, ha. (*immerses straw in red vial*)

29 Donnie: No-o-o... Yo, there's green at the bottom of that vial. (*Picks it up to look closely*)

30 Chet: Look what happened. (*Donnie doesn't look*)

31 Donnie: Yo, there's green at the bottom of this vial. (*Chet dumps his straw, blows it out*)

32 Chet: I'm gonna try that again. That was sweet.

Donnie and Chet combined their own desire to make neat things happen and show them off with the over-arching goal of running a discrete list of tests. In move 23, Chet had made a stack, and immediately bid for Donnie's attention. In move 24, Donnie's first utterance was an exclamation about the test he had been running. His second was a bid for Emma and Amy to look at Chet's stack. Chet then moved to establish whether the stack he'd made was claimed or not (move 26), referring back to the list of tests to be run that remained on the projector during this activity. He then decided to add more Red to the stack. Meanwhile Donnie (move 29) noticed that the supply of Red was contaminated, and Chet indicated his desire to make the effect again.

In the ensuing moments, there was significant discussion about what stacks each of these two had "gotten to work"; this discussion involved other group members, claims, and counterclaims.

34 Chet: OK (*tries again. Donnie is writing in logbook*) That's cool! Red over clear works.

35 Donnie: Yeah, and red over green works.

MR. V COMES BY TO DROP OFF PAPER TOWEL.

36 Donnie: (*to Mr. V*) Red over green works. I got it to work.

37 Mr. V: No! (*mock amazement*)

38 Chet: (*exaggerating*) Red over clear works, too!

39 Donnie and Chet: COOL!

40 Emma: Red over clear. (*to Chet*) You just got red over clear!

41 Chet: Yeah! (*Emma begins to write in logbook*)

A bit later, Emma challenged Donnie's work. Donnie made a claim, which Chet decided to verify for himself. In choosing this course of action, Chet led the group into evidence-based resolution of the argument:

46 Emma: Yeah, you did it in a straw though; you're supposed to do it in a dropper.

47 Donnie: Nuh uh, nuh uh, look. The first one. I did green over red. The first one.

48 Chet: (*reading from logbook*) Get green in a straw, then get red in a straw. Does it work?

49 Donnie: What?

50 Chet: Green and red in a straw?

51 Donnie: Yeah.

52 Chet: You put green in the straw first, and then red? (*gets some green in straw, Donnie watches*) Like that much? Green and then red? (*Chet gets red*)

53 Donnie: You messed up. (*Chet looks, dumps straw*)(*Donnie gets green*)

54 Chet: You gotta get less than that (*Donnie gets red*)

55 Donnie: Dang. (*Holds it up, examines, dumps it out*) (*to Emma*) When I do it, it works. Well you guys don't be bitin' offa me.

56 Chet: It mixes. It mixes. The first one mixes.

57 Donnie: Nuh uh, I got it to work. (*Chet shakes his head*) Yes I did! (*reaches for straw*) Watch! (*gets green in straw*)

58 Chet: You're not supposed to use that much!

59 Donnie: (*picks up red, holds straw up*) It's red at the top. (*Dumps*)

60 Chet: But it says green over red!

61 Donnie: Oh.

In move 53, Donnie initiated his own trial. Chet then indicated that he needed less Green as Donnie moved on to Red. When this trial didn't result in a stack, Donnie stuck with his earlier claim, rather defensively. Meanwhile, Chet had seen both his and Donnie's attempts fail, and concluded that the stack was impossible. Donnie then made a final attempt, which resulted in Red over Green. Chet reminded him that the stack they were attempting to make was Green over Red, and Donnie then dropped his objection.

Significant in these interactions were a couple of indications that standards for what counted, and under what circumstances, were emerging as a part of what appeared to be a relatively free-wheeling and disordered group process. For Chet, "doing it again" appeared important. For all members, seeing was believing. This group's practice of showing results to other members, which I believe resulted mainly from the commonly held desire for social status in the group, served to validate results from many tests.

Even so, it is also clear that Chet was quite concerned with the relative amounts of the solutions (moves 54 and 58), a factor that was unrelated to stacking behavior. He and other students were intuitively invested in the idea that a large amount of a given solution could not stack on top of a small amount of another. This was because, in their minds, the smaller amount was lighter and should therefore float. Earlier, we saw evidence of this in Sherrie's suggestion in the whole-class session that different amounts would give different results. Here, we see further evidence that it was still in play in Chet and Donnie's work as well, in spite of the fact that no amounts were specified in any of the nine tests that students ran in the retesting portion of their work with solutions.

Whole-Class Consensus on Possible Stacks

Once retesting was completed, Mr. V initiated a whole-class session in which he encouraged students to look back over the data they had just gathered, and to look at previously gathered data, in order to decide whether each claim was defensible or not. Then, beginning with his class data chart on the overhead projector, he asked for a show-of-hands tally of results on the first stack listed. This was Green over Red in a straw.

At first, two pairs claimed to have made this stack, while ten pairs said they could not make it. Then a student asked whether this was Red over Green, or Green over Red. Mr. V clarified that this was Green on top of Red, and asked students again, by show of hands, who had been able to get Green to stack over Red in a straw. At this point no hands

	Claimed Stack	Result
1	G/R (traw)	No group claimed to have made this; eliminated.
2	G/C/R (straw)	No group claimed to have made this; eliminated.
3	G/C (vial)	18 students said no, 5 said yes. Retested by one 'yes' and one 'no'; eliminated when they could not make it.
4	R/G (vial)	All made this. Accepted as true stack.
5	R/C/G (vial)	14 students said yes, 6 said no. Issue of careful technique discussed. Accepted as true stack.
6	G/C/R (vial)	All except one said no. Eliminated after repeated retesting failed to produce it.
7	C/R (vial)	No group claimed to have made this; eliminated.
8	C/G/R (vial)	No group claimed to have made this; eliminated.
9	R/C (vial)	All made this. Accepted as true stack.

Figure 6: Claimed stacks in Colored Solutions

were raised, signaling that there were no claims for this stack. His response was to strike through the stack on the side of the chart labeled "Stacks we made", and to leave it under "Stacks we couldn't make".

Subsequent to this first tally, each of the other claims was questioned in succession, and either substantiated as a stack made by many in the class, or eliminated as a stack that could not be made (see Figure 6 summarizing disposition of stacks above).

As noted in the table above, in cases in which there was not clear consensus, pairs of students were sent to the back counter (where trays of materials were available) to test the claim again, and to show or report results to the class. For example, the stack of Green over Clear in a vial was one of the claims retested. When Mr. V tallied results from this retesting, 18 pairs reported they couldn't make it, while 5 pairs claimed to have made it. Mr. V sent one of the pairs that claimed to have made it to the back, asking them to bring the stack up to show the class when they had made it. After several tries, they came forward to report that they had not been able to make the stack. At this point, Mr. V asked if anyone objected to eliminating it as a possible stack. Hearing no objections, he did so.

Seven of the nine claims retested involved stacks that are not possible. In each of these cases, it was the absence of a particular observation (the "stack") that determined the outcome of the retesting process. This meant that, unlike the situation in which a stack was created and could be shown as proof, in these situations issues of technique were possible reasons for the negative result. In the last part of the process, Mr. V's attempts to leave claims untouched until all agreed that they were not possible fell prey to his sense of urgency in completing the task of tallying and passing judgment on each of the stacks in one class period. So, in a couple of situations in which one or two claimed to have made the stack, possible discussions of the sources of difficulties were quashed by his tight control over the routine of tallying, retesting if necessary, and passing judgment. Near the end of the tallying process, a couple of notable exceptions arose.

The pair of students who were retesting Red over Clear over Green in a vial brought the stack forward to show Mr. V, who then walked slowly up and down the aisles, showing it to the students. As he did this, he noted that this was proof that the stack could indeed be made, so they should strike this stack from the "Stacks we couldn't make" side of the chart. One student at this point said, "Sometimes it does work and sometimes it doesn't". Mr. V repeated this statement, giving credence to issues of technique in the process. Yet, in this and every other instance of eliminating a stack from this part of the chart, Mr. V created a shift in the meaning of the chart. This shift was from individual claims to group ones. Individual pairs of students had been the source of the stacks listed under this heading, so the stacks listed there were simply the ones that they could not make. Listing a stack there, however, did not necessarily constitute a claim that the stack was not possible (students might not have been able to make a particular stack because of poor technique). In the whole-class setting, however, this was the way that the heading was used. Mr. V noted that if no one in the class could make a particular stack, then for all intents and purposes they would regard that stack as not possible. While the shift appears not to have been hugely significant in terms of student engagement and understanding, the subtle shift away from claims in which individuals had a stake should not be regarded lightly. A succession of such shifts, which seem inevitable in teaching situations in which teachers and students move from personal experiences to more generalizable ones which reflect larger concepts, may have consequences for understanding and engagement in the longer run.

A second exception to the tallying routine came near the end of the process, when a student (Chelsea) brought her attempt to make the stack Green over Clear over Red forward. What she showed in the vial was Red over Clear over Green. Asked to explain what she had tried, Chelsea said

> "First I tried to put the Green and then the Clear the Red, but it didn't work, so then I just put the Clear in the vial, and I took an eyedropper and stuck it all the way down and let it out slowly, and the Green stayed at the bottom, and I put the Red on top.
> This top part of the stack, Red over Clear, is the same stack that those girls were testing and they got it to work."

Chelsea's description was important in two senses. First, it provided a description of the immediate discrepancy between the stack she was supposed to be testing, and the result (which was a different stack). Providing information on the process that she used showed that she had indeed been running the right test, and that her results, while they didn't show the desired stack, were consistent with results that others in the class had gotten in terms of patterns. In a second sense, Chelsea's response demonstrated the importance of technique in getting the liquids to stack or mix. Chelsea was very specific about the techniques that she used to get the stack that she got, and her moving from the failed first attempt to a second in which she modified her technique provided a good example for others in the class. Mr. V's request for explanation was a response to the first of these two senses; Chelsea's detailed description brought both of them to the center of attention. While Mr. V certainly might have noted that, in addition to these two senses, Chelsea's description moved nicely into Pattern-finding, he did not discuss this in the public arena of the classroom at this time.

Instead, with time running out for the day, Mr. V completed the process of gathering reports and making decisions on the remainder of the stacks, and then announced to the students that the next day, they would recopy the chart to eliminate all of the stricken stacks, and that they would then move into groups of four to start the process of planning posters that they would produce and present to the class. He informed them that the posters would include more than just the stacks they were able to make, but also techniques that they thought were important, and patterns that they had found in the way the liquids stacked or didn't stack. With that, the class ended.

Dimensions of Discourse in Phase II

During Phase II the class continued to work on the upper right-hand corner of the TOPE x MVD activities (Table 1). That is, they continued to work on developing effective techniques and recording observations for comparisons of density. However, we saw a shift from the "private" discourse of the students working in pairs to the '"public" arena of whole-class discussion guided by the teacher. During this discussion, Mr. V and the students made several moves that began to constitute the class as a discourse community. Starting with the diversity of goals, standards, and mediational means apparent in the pairs work, they privileged some at the expense of others. This process is discussed in light of each of the dimensions of discourse below.

Goals and Standards in Phase II

Mr. V's request for data about which stacks were possible and which were impossible was compatible with some of the goals that the students brought to their initial work in pairs. For example, making stacks was one of the "interesting things" that Chet and Donnie sought to do with their solutions. Mr. V's request for recorded data was also consistent with Adam and Lisa's care in writing down their techniques and observations.

However, Mr. V's request for observations about stacks recognized only one of the many possibilities inherent in the student's initial work with the solutions. The students' initial explorations could equally well have led in a variety of other directions. For example, they might have moved into investigations of the scientific concepts of convection, diffusion, or miscibility. Or they could have led into less overtly scientific activities, such as voting about who did the most interesting thing with their colored solutions, or having a contest to see who could fill up a vial fastest using an eyedropper. Thus Mr. V was using his authority to *privilege* some of the students' goals at the expense

As a part of the move to privilege stacking data, Mr. V introduced a standardized form for reporting stacks (with stacked letters as illustrated above). In other respects, though, Mr. V depended on the students to suggest problems with the data and develop standards. Jeannie had previously pointed out the inconsistencies in the class data set. Another student (Sherrie in line 19) suggested a standard scientific procedure--replication--as a means for resolving those inconsistencies. (In an earlier paper, Vellom, Anderson, & Palincsar, 1993, we traced the emergence of replicability as a standard in another class under similar circumstances.)

Mr. V also held standards for acceptable data; these standards, rather than being imposed as a threshold from some outside source, were essentially that all within the class must agree on the veracity of any given piece of data. In essence, he set a social standard (consensus) within which the community of learners validated its own data. He assisted this validation by brokering suggestions from the students about how it should proceed, and then overseeing the process itself. In doing so, he instructed the students about the connection between the work they were doing and the work that scientists might do in similar situations. He was thus able to raise awareness of the connected nature of their actions, and to model aspects of the scientific endeavor to them.

The students, for their part, continued to populate classroom tasks with their own purposes and intentions, but these were now influenced by the active privileging of data that denoted stacking behavior. Even so, Adam and Lisa, as well as Donnie and Chet, continued to interact according to patterns that they had established the first times they worked together with the solutions. Each working pair established their own set of standards for scientific work in the classroom, and each also had its own set of rules for determining who did what, and when.

Yet, even in privileging data about stacks, Mr. V set no other threshold for what constituted good data. If a student made a claim, whether or not there had been a validation process in pairs and groups, and regardless of origin, the claim could be accepted as valid

Yet, even in privileging data about stacks, Mr. V set no other threshold for what constituted good data. If a student made a claim, whether or not there had been a validation process in pairs and groups, and regardless of origin, the claim could be accepted as valid in this whole-class session. This strategy was rooted in a common practice of scientists who are gathering data. Essentially, when one sets out to collect data, one collects all of the data that one sets out to collect, without making judgments or interpretations before the data is recorded. This kind of arrangement ensures that the data reflect the range of possibilities in natural systems. Narrowing the data set and working out interpretations are activities in which scientists engage after the data is in. Quite often, if large amounts of anomalous or discrepant data are gathered, an investigator will modify the parameters of the investigation or data collection, and then run a new set of trials and gather new data. This is all a part of trying to make sense of what is happening in the natural world.

So, Mr. V accepted all of the claims as valid, just as a researcher might take each of them as a data point. His acceptance of each claim also fulfilled a school-based goal; it assured the greatest possible access to this activity. Essentially, any student who wished to make a verbal claim in the format of 'color A over color B' could participate. Later interactions indicated that many students who nominated stacks followed their progress closely during the validation process. Thus, it was significant that each claim was given the status of an observation at this point, carrying equal weight among others (though more students may have supported one than another, for instance, Mr. V did not make this distinction). In accepting all claims, Mr. V chose not to focus on possible inadequacies of technique, errors in recording, and data that might not have fit the stack/no stack requirement.

Once the data had been recorded on the class data tables, a discussion ensued in which a subtle shift in public goals occurred. The discussion began with students reporting their personal observations: "Stacks we made" and "Stacks we couldn't make." As the discussion proceeded, however, the understood purpose shifted to that of developing a common public data set that was validated by replication and consensus: "Stacks that can be made with proper technique" and "Stacks that cannot be made regardless of technique." In guiding the students through these shifts in goals and standards, Mr. V was trying to strike a delicate balance. Without common public goals and standards, the class would continue to function as a collection of individuals rather than as a real discourse community. On the other hand, if the teacher merely imposed his own goals and standards on the public discourse, the students would probably respond with what Edwards and Mercer (1987) describe as ritualized compliance, rather than with personal ownership and engagement. In that case, too, the goal of constituting a discourse community in the classroom would not be realized.

At this point in the unit the evidence indicates that Mr. V was striking this balance successfully. The students accepted the new goals and standards as their own and worked on them with enthusiasm. While there was little attention to underlying concepts like mass, volume, and density, the focus of this episode was on the relationship between what the students claimed to have done (Techniques) and what they claimed to have seen as a result of their attempts (Observations). In light of this focus on the T-O phases of the T-O-P-E process, the lack of attention to the concepts themselves is not surprising. Instead, the activities and talk in this episode provided strong, inclusive scaffolding aimed at helping all of the students appropriate some basic understandings and capabilities in working on a problem scientifically. They made sense of the activities and talk in a variety of ways, some of which appear, in hindsight, more ordered or scientific than others. Their overt and observable behaviors show us that most students were successful and fully involved in working with the liquids and making claims up to this point.

While Chet and Donnie's work appeared much less orderly and careful than that of Adam and Lisa, in some ways it represented a significantly richer set of interactions than that of their counterparts. In choosing to work in parallel, Chet and Donnie took on a feature of discourse that is central to the scientific enterprise, that of a healthy tension between what is claimed and what is ultimately believed by those to whom the claim is made. In essence, Chet and Donnie became two individual investigators; in the chatter between them, each drew the other into a jointly held understanding of what they were doing. But, since every move and nuance was not a subject of mutual attention, in fact they ended up having to "prove" to each other the claims they made. They most often did this by showing a stack or other result; this was "seeing is believing", a basic standard in scientific work. Where, in working groups of scientists, seeing can be accomplished via recorded data, Chet and Donnie operated in a way that took advantage of the work in progress. This approach, while apparently not a matter of conscious choice, supported their preferences for working with the liquids rather than spending their time writing things down.

Eventually, Chet and Donnie each recorded some information from memory, but the primary focus of the work did not include generation of written text. Interestingly, while these two students operated according to standards of evidence while working with the solutions (as noted above), they had not come to value the careful recording that Mr. V had set as a class standard much earlier. So, while their actual work with the solutions bore much more promise than that of some other students, the correspondence between what Chet and Donnie recorded and the actual observations they made was suspect. In effect, relying on memory to produce these records undermined the direct link between observations and recording. In scientific circles, practices such as these would render the data suspect, since memory can be influenced by events that occur in the interim.

Another standard, that of replicability, emerged in the work of these two students, and was primarily reflected by Chet when he said

> Chet: I'm gonna try that again. That was sweet.
> Donnie: I'm using your pencil, OK?
> Chet: OK (tries again. Donnie is writing in logbook) That's cool! Red over clear works.

Chet had repeated some of his trials during his earlier work with solutions, and while it is not possible to be sure for the reasons for this, two come to mind. First, given the sense that Chet made of the purpose of the activity, he essentially just wanted to "replay" the effect in the group (or individually) because it looked neat and might get him additional air time with his peers. He did announce his intentions to "do it again" on several occasions, and an observer is led to wonder whether he believed that his audience (other group members) followed these escapades. A second reason, however, is that at some level, Chet understood a distinction between one-time "fluke" happenings, and those happenings that were constant because of properties of the system. In essence, if this latter was the case, his reruns may have been primary verification (or, said another way, testing) of this distinction. Examination of other evidence (Chet's logbook, and his interactions in other group activities) did not lead me to a firm determination of which of these might be the case. Yet, again, I believe it is worth noting that for Chet, when something neat happened, he generally wanted to repeat his trial to see if he could make it happen again. While Chet's reasoning is unclear, his desire to repeat notable occurrences in effect served as an operating standard. Not being able to get the same result on these repeated tests led to further trials on more than one occasion, until he saw the same result or made a decision to move on.

Mediational Means and Connections in Phase II

During Phase II the students developed both experimental techniques and ways of communicating about their observations that were better suited to the ultimate purpose of comparing densities of substances and communicating about those comparisons. There were many points (not quoted above) in which public and private discussions turned to issues of proper technique. Chet's advice to Donnie in Phase I is one example. There were many similar examples of discussions for making stacks in straws. (For example: "You have to make sure that you put the straw deeper into the second solution than into the first." "Don't take your finger off the straw too soon. The solution will all run out.") Thus the students were developing the technical skills--the mediational means--that would allow them to compare the densities of two solutions reliably and accurately.

With the new methods for reporting on stacks, the students were also developing mediational means for reporting their observations that communicated density comparisons far more efficiently, while ignoring many details to which they had previously paid attention. (Compare the chart of stacks that could and could not be made in Phase II with Adam's and Lisa's journal entries in Phase I, for example.)

During Phase II, a majority of the students were still unaware of the conceptual connections apparent in the TOPE x MVD table (above). The connections that would become apparent through discussions of patterns and explanations were still invisible to most students, partly because the data they reported were so full of errors that the patterns were not yet clearly apparent. Thus it was necessary for them to reach consensus about reliable data before a serious discussion of patterns and explanations could take place.

In none of the work examined to this point were the terms Mass, Volume, or Density used. But, students were formulating and making use of mediational means that helped them to describe the behavior of the solutions, and some of the patterns that they were seeing. The growing awareness of patterns exhibited by some students, notably Chelsea, and their moves towards examining them, suggests that their prolonged engagement with the solutions was paying off in their understanding of the system under study.

While much of the work in this phase did not reflect widespread understanding or valuing of the kinds of standards, logic, and mediational means that scientists might use in similar situations, the forms of discourse are consistent with where these actions fall on the TOPE x MVD grid. Working to refine techniques for stacking and to validate observational data did not demand highly specialized mediational means, for instance, that would be recognized by students as perhaps more foreign or scientific than those previously used.

And, Mr. V's approach was to attempt to maximize student access to the work in progress by adding specialized intellectual tools only as they were needed.

I did find, however, significant shifts in the kinds of language that students used to describe the behavior of the liquids, and a concomitant narrowing of their focus in working with the solutions. These shifts in language and focus appear to relate directly to the privileging of stacking data over other kinds. With this privileging, standards began to emerge that affected much of the work that students did, especially in terms of techniques and the language used to report observations.

Status and Participation in Phase II

The students' work in Phase II continued to demonstrate the high levels of engagement and the lack of differences in status and participation observed in Phase I. While the work in this phase spans two whole-class sessions in which public goals emerged and were solidified, individuals and smaller groups of students were given opportunities between these two sessions to make sense of these goals in the relative safety of more private settings. When the results of small-group interactions were reported out to the whole-class, a consensus model of decision-making ensured that every student's claims were valued. Taken together, these structural features worked together to support continued deep engagement, by making these activities accessible to all students.

In the first whole-class session, Mr. V accepted all claims that fit the general descriptor of 'stacks' of colored solutions. In doing this, he chose not to focus on possible inadequacies of technique, errors in recording, and data that might not have fit the stack/no stack requirement. In essence, he privileged one kind of data, claims about which stacks were possible and which stacks were not. Other claims about mixtures, as well as other observations that students might have deemed interesting, were not valued in this setting. His acceptance of each claim assured the greatest possible access to this activity.

which a full range of explorations with the solutions was valued, to well-defined common tasks, participation was only limited by the particular patterns that pairs of students developed in working together (like the differences between the ways Adam and Lori worked in comparison to Chet and Donnie).

Other dimensions: mediational means, goals, and connections

While Chet's work with solutions (and accompanying talk) clearly indicated that some standards had come into play, it also reminds us of the situated nature of the work under examination here. His and Donnie's less careful approach to recording data are somewhat typical of the sense that some students make of school science tasks. It is relatively common that teachers find students "doing" the hands-on tasks, but neglecting the recording that is intended to go alongside. Even while this was the case, Adam's and Lisa's work appears quite different, with a strong focus on methodically doing each test and carefully recording. To them, the larger task appeared as a repetitive cycle of smaller subroutines, each to be done once and the results to be agreed upon. The standard of replication suggested in the whole-class session prior to retesting did not influence their work, as they repeated none of the nine tests. Instead, their care in doing each test seemed to be what they relied on most in getting good data.

While the concepts of Mass, Volume, and Density (and the terminology) were not a part of the discourse of the whole class or the pairs examined here, students were working to settle which issues of technique were important in making stacks. Some recognition of the care required to make stacks in vials (which occupied a lot more of the students' time in both phases than work in straws) had come out in Chet and Donnie's discussion. When this happened, a connection between T and O was established. Yet, this connection, like most of the standards noted above, occurred in the small group setting, and thus was not a part of the whole-class discourse. Thus, this connection was supported for some students, and not for others. Adam's and Lisa's retesting routine may have placed them in the latter group.

Their retesting resulted, in every case, in a mixture. Perhaps for this reason, they did not move beyond the language that they had used in phase I (in either talk or logbooks). The results of each of their tests were reported as "mixed". Likewise, Chet's and Donnie's language included specific "color over color" claims, as well as the "worked" and "mixed" terminology; both of these constructions had been evident in their work in phase I.

Phase III: Patterns and Explanations in Colored Solutions

The next day, which was the sixth day of the Colored Solutions instructional sequence, began as announced with students creating new tables in their logbooks and copying the data from the old one into it. Students were asked to check their new charts against their partner's for accuracy. Once most of the students had completed this task, Mr. V gave instructions for planning the group posters, placing a transparency with detailed information on the overhead projector as he talked (see Figure 7). He noted that each group of four would get a sheet with this information to use as a guide in planning their poster. He then talked about each of the points on the instruction sheet, giving examples.

Your Poster Should Include:

1. Both words and illustrations.
2. At least one idea (or special technique or observation) from each person in your group.
3. Something about your techniques. For example:
   - What special techniques or ways of being careful helped you to make unusual stacks or observe interesting things?
   - What are some of the special techniques that you tried that didn't work?
4. Something about your observations. For example:
   - What stacks of two or three solutions did the members of your group make?
   - What are some observations that the members of your group made about floating and sinking or stacks that you are sure are possible or impossible?
5. Your ideas about patterns and explanations. For example:
   - **Dropping.** Can you list all the possible combinations of dropping one color into another? Is there a pattern to which ones make layers and which ones just mix?
   - **Stacks in straws.** Can you list all the possible stacks of two colors? Can you make any stacks with three colors? Is there a pattern?
   - **Connections.** Are there any connections between the patterns for the dropping experiments and the patterns for the stacking experiments?
   - **Explanations.** What makes each of the different liquids act the way it does?

Figure 7: Guidelines for poster planning and production

Mr. V suggested that each group might start out hearing what stacks each member was able to make, and go from there. As Mr. V talked about Techniques, he referred to Chelsea's careful, ordered way of putting the solutions together the day before, noting that this was a technique that her group might decide to include on their poster. The groups were instructed to brainstorm first, and then to make a pencil sketch of their poster that included all of the information, and to bring this to him for approval. With this, the students moved their desks into groups of four and began the work of planning the posters.

Groups worked for the remainder of the period on poster plans, with no groups having submitted a plan for approval by the end of the hour. At the beginning of the next day, Mr. V briefly reminded students that their posters were to communicate the information that they thought was important to an audience. He encouraged them to try to make them interesting as well as informative, with writing and pictures big enough to be seen from across the room. Then, students moved back into groups of four to complete poster planning, under a ten-minute deadline given by Mr. V.

Groupwork in Phase III: Poster Planning and production

In the process of creating a poster, Mr. V intended to give each group occasion to participate in two kinds of concept-based processes that mirrored the earlier small-group and whole-class work with the solutions and data. One of these was essentially an *additive* one in which all of the accumulated information from each of the pairs (and thus their individual members) was brought together, and the potential for enriching and widening each member's views of the investigative process and products was a primary focus. The second was a *critical* one, in which all of the accumulated data, and ideas about it, were examined together in a process that focused on developing logical connections, and negotiating the importance and disposition of data that didn't support these connections. A third process, which occurred alongside these two, was the actual production of the poster itself. This process overlapped each of the other two in significant ways, as the students were driven by the need to put information and ideas on the poster in ways that would communicate their understandings to others. Far from being evenly paced and balanced, each of these processes moved forward as needs in the group drove it; at times, one or another process dominated, while often two or more could be seen operating at the same time. All of these processes were interwoven in the socially constituted interactions that occurred within the groups of four as they worked on their posters.

Vibrant examples of these interactions can be seen in an examination of one of these groups. This transcript is pretty long, but represents the richness of this group's verbal interactions well. It is included so that the reader will be able to examine evidence for claims about contexts and larger trends.). Adam, Lisa and Sandra were members of Group 1, along with Kyle, who happened to be absent this day only. Nick was a transplant into this group, since the other members of his group were absent. In the following excerpt, these four students were making initial suggestions about what should appear on their poster.

1 Adam: What are we supposed to do?
2 Nick: Man, I noticed one thing. Red's is never at the bottom.
3 Adam: [taps on mike to test it] What?
4 Nick: Red's never on the bottom. I think it's more buoyant than anything.
5 Lisa: That's what we're supposed to write down. [Adam points something out in Nick's logbook.]
6 Nick: That's on stacks we couldn't make!
7 Adam: I knew that. I knew that. [Sandra laughs.]
8 Lisa: Nick, she wants to see you. [Adam comments on how Nick is not supposed to be here.]
9 Nick: I'm the censored person who's not supposed to be here.
10 Sandra: Alright.
11 Nick: Alright. I say Red is a more buoyant liquid than anything.

This group session began with Nick suggesting a pattern (move #2). Up to this point, none of the activities of the class had focused on patterns, and Mr. V had only once given an example of a pattern statement. However, finding and reporting patterns was one of the explicit goals named in the poster guidelines (see page 133, "Your Poster Should

Include", item #5). To the extent that Nick perceived the group's task as delimited by the guidelines, his statement was not surprising. In the context of previous interactions, however, it represented a departure.

Adam then asked Nick to repeat his statement, and Nick did so in move #4, adding an explanatory mechanism (buoyancy) to the proposed pattern. Lisa encouraged that it be recorded (move 5), which I take to mean that she recognized what Nick said as fulfilling one of the guidelines. Meanwhile, Nick and Adam examined Nick's logbook together, ostensibly so that Adam could verify the pattern proposed by Nick. The result, Adam's discovery that Nick was using a list of stacks that they hadn't been able to make as backing for his claim, brought a quick disclaimer from Nick and laughter from Sandra. Lisa, meanwhile, brought up a social agenda to Nick, and Adam commented on Nick's being in this group in the first place. Nick responded by labeling himself "censored", and Sandra redirected the conversation by indicating that she was ready to write patterns and explanations (move #10). Nick then transformed his earlier pattern statement "Red's never at the bottom." into a statement of comparison based on a property of the solutions.

12 Adam: More buoyant? Let me turn back. [flips back in his logbook][both boys looking at "Whole Class Data" in logbooks]
13 Nick: It has less buoyance. 'Cause look at the overall thing..
14 Adam: There's stacks we made with droppers, Red's always on top.
15 Nick: Yep.
16 Adam: And...
17 Nick: Nuh, ugh. There's one we made with... Clear... and Red. But, we didn't use Red. So you're right. All the one's we used with Red...that we used. [he shows his logbook to Adam]
18 Adam: Yeah. Not over here in straws. We made one with Red in the middle.
19 Sandra: Green is mostly always at the bottom. [not heard]
20 Nick: Yeah, so it's mostly on top.
21 Adam: Red's almost always on top. (to Sandra) Write it down.
22 Nick: And G's almost always... G's always at the bottom.

Adam questioned Nick's global statement about Red, looking back in his logbook to see if the data he had recorded supported the assertion. Nick looked at his own data, then misspoke (in move 13) in trying to convince Adam by having him look at the overall pattern (recall that Nick and Adam had done this work in separate groups, but that both had been present for the class consensus on stacks).

Adam looked at his data for stacks in droppers, where he verified that the pattern held; then Nick jumped in (move #17) to interpret his data, which seemed to agree. Adam then noted an exception to the rule in move #18. Sandra, meanwhile, suggested another pattern, but her groupmates offer no sign of having heard her. However, Nick suggested a statement that closely mimicked the form of hers in the next move. Adam formalized the statement by repeating it, and asking Sandra to record it on the planning sheet. This statement was then recorded, and the group moved on to consider other patterns, which included "Green's always on the bottom", and "Clear and Red are usually in the middle or the top".

In this negotiation, the students moved from a focus solely on Techniques and Observations, down the grid to begin seeking Patterns and developing Explanations. While the poster guidelines did state that groups would have to do some work in this area, Mr. V had not focused on either of these activities in the whole-class setting. In this series of interactions, each student in the group had his or her logbook open to pairs or class data, and group members were tossing suggestions out for consideration by their peers. The activity included suggesting patterns and verifying suggested patterns using recorded data.

In the group examined above, Patterns formed the nexus of their conversations, and their own standards for data-based claims led them to use their logbook pages to try to settle differences and establish the veracity of each claim. These standards for what counted as evidence, as well as developing precision in language, were the primary mechanisms driving these students as they began to exhibit highly connected thought and action (in comparison, for instance, to the less tightly proscribed way that each pair worked with the solutions, even in the retesting phase) that would be more typical of a group of scientists working on a problem together. As a part of the ensuing discussion of other patterns and examination of recorded data, the pattern already recorded for Red was questioned again several times.

Later in the same poster planning session, the following interaction about patterns unfolded as Lisa was recording information and Sandra was examining her logbook:

55 Adam: Let's put it this way... Red..
56 Sandra: Five out of seven times Green is at the bottom.
57 Adam: Okay. (to Nick) Five out of seven times Green is at the bottom?
58 Sandra: If you're counting the stacks you made.
59 Adam: Okay.
60 Nick: Five out of seven times...
61 Adam: Green's at the bottom.
62 Sandra: And Red's at the top.
63 Lisa: (to Nick) Let me write.
64 Sandra: (to Lisa) Okay, 5 out of 7 times Green is at the bottom

Notable here was Sandra's move to quantify, which is one way that accumulated data may be reported. She proposed "Five out of seven times Green is at the bottom." This statement was then subject to validation, in which Sandra noted her data source. At the same time, she connected the position of Green (at the bottom) in the pattern to the position of Red in the same pattern, with no objections from her peers. Finally, she made a statement that was recorded as a pattern for this group. This statement numerically denoted the group's negotiated resolution on the position of the Green solution, which also was a statement of comparison of Density. It was clearly a data-based declaration, as well.

A few minutes later, Nick suggested that the group include some Techniques and Observations on their poster, as indicated in the guidelines. Lisa held the group accountable for what she viewed as an incomplete set of Pattern statements, and in the process suggested a Pattern for Clear, which Nick attempted to verify:

92 Lisa: Wait, we haven't wrote Clear yet. It's always in the middle.
93 Nick: Clear. Well, let's look here.[looks in logbook] Clear usually it mixes.
94 Sandra: (to Lisa) Clear usually mixes. (to group) Right?[looks in logbook] Well, Clear stacks on top Green on mine.
95 Nick: Well, let's look on this. Let's look on the class data.
96 Adam: I've got Red eight times.[he's been looking at his logbook for a while].
97 Lisa: No, Clear's in the middle. I say Clear is in the middle.

98 Adam: Well, pretty much that's what it is: Red on top, Clear in the middle, and Green on the bottom.
99 Nick: [looking at logbook from 1-26] Nine different tests. Nine different tests, and out of those... one, two, three, four...[Sandra is looking in her logbook]
100 Lisa: (to Adam) Clear is in the middle!
101 Adam: (to Lisa) I know, that's what I said.
102 Nick: ...five, six, seven. We had nine different tests, and in seven of those tests... Clear mixed. [He's looking at his data wrong--7 times Clear was used out of 9, but one time it stacked- #8]
103 Adam: (to Sandra) Just put, just put Red is the most buoyant and Green sinks.

In move 94, Sandra sought group validation, and then examined her own logbook, where she found that Clear stacked atop Green. Nick took this challenge as necessitating more information, and referred her to the class data. Adam (move 96) then pitched in with a statement about Red, and Lisa reiterated her initial claim. Adam then agreed with her, putting her Pattern into a larger one that included all three solutions. Nick, however, (move 99) was still examining data from a previous day. At the same time, Sandra looked at her data. Lisa reemphasized her Pattern by repeating it again (move 100), and Adam again agreed.

In the meantime, Nick continued counting stacks in his logbook, and finally gave a summary statement, "We had nine different tests, and in seven of those tests... Clear mixed" (move 102). This statement was enough to cause Adam to propose an alternative to his earlier pattern statement that did not include Clear, the subject of controversy. This statement was recorded on the group poster plan.

These segments of transcript illustrate the emergence of differential status in this group, which played out in the group's acceptance or rejection of suggestions (and sometimes demands) made by members of the group. Lisa had pushed the group to include Clear in their pattern statements, a move that was complicated by the group's lack of definitive data on the stacking behavior of this solution (this turned out to be common in other groups as well). She clearly got Adam's support early on, but when Nick disagreed, Adam dropped Clear from his pattern statement altogether. Laying the logbooks side by side to solve this problem did not occur; this seems to indicate a point at which a data-based validation of any of the claims stretched beyond the operating norms of the group. A social solution, negotiated by Adam, had the effect of solving the problem by removing the point of contention. Unfortunately, it also had the effect of silencing Lisa, at whose behest the discussion had begun.

The transcript also indicates that these students were still deeply engaged in pattern-finding, and had developed a strong set of standards for validating claims using recorded data. While this process in some ways resembled the interactions in working groups of scientists, consensus was clearly not the decision-making model here. Instead, 'agreement among key players' seemed to operate as the mechanism by which claims were validated. Recorded data was used and valued in this process, but when it failed, social processes took over.

Poster production

As Mr. V approved each group's plan, they retrieved materials (posterboard, markers, rulers) from the counter at the back of the room and then moved on to the task of actually producing their poster. Approved plans most often did not include the exact wording of each part of the poster. Instead, they included sketches of the different elements in a proposed layout, with some key statements written on them. So, the task of producing the poster included negotiating which ideas and information should be included. In the course of earlier negotiations, some of the groups had worked out the exact wording for the Patterns that they would include. However, their Explanations tended to be less well elaborated or had not been included at this stage, and these became a topic of much discussion and negotiation during the actual production of the posters.

Poster production was supposed to occur in one day, but every group was challenged by these time constraints. Mr. V allotted fifteen minutes the next day, as posters were to be presented during this class period as well. This time pressure appeared to work well, since much was accomplished during this short period in most of the groups. As each group finished its poster and returned materials, Mr. V encouraged practice for the presentation, which was to be done by two members of each group.

Finally, all the posters were complete. Mr. V directed that remaining materials be returned, and that desks be moved back into rows. He placed a template for a logbook page onto the projector, and asked students to set up their logbooks to record information from the posters. The template simply provided a place for each student to record the Patterns and Explanations reported on each group's poster (see Figure 8).

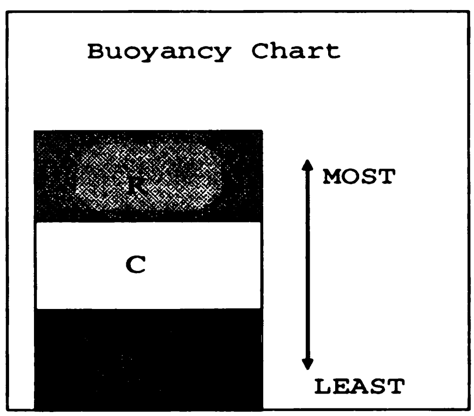
Mr. V then described the routine for poster presentation, including roles of the presenters. He encouraged members of the audience (the rest of the class) to ask questions at the end of each presentation. He noted that questions could be requests for a repeat of information, or for clarification of something that was not understood, especially Patterns and Explanations. With that, he asked the first group to begin. The written portion of each of the target groups' posters is recorded in Figure 8, below:

Features of the posters

In the course of the six poster presentations, each group was able to suggest at least one pattern that they had detected in their examination of the data, and in their own work with the solutions. These patterns included "Red is almost always at the top", "Same observations for straws + droppers", "Green is never over clear", and "Clear in middle or mixed". Three of the groups suggested mechanisms for the behavior of the liquids. These included, "Because of the weight of the liquids", "Amount of liquid makes a difference", and "Red is least dense, at top. Clear is second dense, middle. Green is most dense, bottom."

The patterns that were suggested were overwhelmingly correct. Interesting variations included the statements from Group 1, based on numerical counting of data to report discrepancies, and Group 2's patterns statements, which employed an "always/never" formulation. The statements from Group 2 would generally be regarded as more absolute pattern statements, while the numerical and "almost" formulations from Group 1 were more like the kinds of precursors to pattern statements that one would expect from novices. While an initial impression derived from the statements themselves might lead one to believe that Group 2's statements were much more a consensus-like product (and thus that the less deterministic statements from Group 1 indicated an incomplete process of consensus-forming), this is not true to the dynamics I observed in these groups. Instead, the developing standards in each group, often determined by one or two influential members, had the most to do with the final form of these statements.

<u>Group 1:</u>
(Adam, Kyle, Lisa, Nick, Sandra)



Techniques: (shown in a test tube, atop RCG) Let the top liquid slide down the side of a vile with an eyedropper. Drop droppers slowly on the side.

Patterns: (Shown in a beaker) 1) Red is almost always at the top 2) Almost five out of seven times green is at the bottom.

Important Stacks:
straws - c/g r/c/g
droppers c/g r/c/g

Group 2:
(Amy, Chet, Donnie, Emma)

Green On The Top Never Works
Red On The Bottom Never Works
Green On The Bottom Always Works

If you put green close to the bottom and squirt slowly the green will stay on the bottom

Figure 8: Excerpts of posters Groups 1 and 2

Class validation

Once all of the posters had been presented, Mr. V projected his copy of all of the Patterns and Explanations, and asked the students to check what they had written against his copy to ensure a complete record. He invited students who had written Patterns or Explanations that did not appear on his sheet to tell him so. After a few minutes with no suggestions, he read aloud the two patterns he had listed for Group 1, "Red almost always at the top", and "5 out of 7 times green at the bottom". A student named Steve took this opportunity to ask a question:

1 Steve: I have a question for group one. Most of the groups said that Green is usually on the bottom. You put five out of s--...is always on the bottom, most groups said. You put 5 out of 7 times. When did it d--.when didn't it end up on the bottom?

2 Mr. V: Let me ask a question here. Group 1, can you answer the question without looking back at your data?

3 Adam: (softly) I think that was a misprint.

4 Mr. V: You think it was a misprint?

5 Adam: Yes. Cause I looked back through there, and every time it was on the bottom.

6 Mr. V: OK, Adam, you're gonna have to speak up.

7 Adam: (louder) I think whoever wrote that messed up or something, because when I looked back at the data we had, it said that Green was always on the bottom. All seven times it was on the bottom.

8 Mr. V: Now you had another partner pair, plus Nate. So I'd say that, really, to double check, that they should double check, too. Is that right? (Adam nods yes). I think that's a worthwhile question, Steve, so let's let them check that for a few minutes, and then we'll talk to them again. Tina?

9 Tina: I know what they did, maybe, they were looking at all of the stacks maybe, even the ones where they didn't use green. And maybe there

were like two where they didn't use green, and maybe those were the two that, where green wasn't on the bottom...

10 Mr. V: OK, that's a good possibility. Let's let them check their data see what they have.

In asking the initial question, Steve changed the activity from a simple recitation to a critical examination of the patterns that had been claimed. Adam's response was to discount the entire claim as a mistake, even though he had been a key player in negotiating the wording for this claim. He laid blame on an unnamed someone who "messed up", declaring that his own analysis of the data did not support the claim as written. Mr. V, in the interest of fairness to other group members and in keeping with the developing standards for what counted in disagreements, noted that the claim was made by all group members (since it appeared on the poster), and that any challenges or changes to it had to be agreed upon by the membership. He sent them back to their data to resolve the challenge, and the members of this group spent the next eight minutes looking at logbooks individually and together, and talking about where the claim originated and whether it was an accurate reflection of their data.

Giving the group an opportunity to reexamine their data maintained the standards for reporting and accuracy that had been developing in the public discourse of the classroom over the earlier days of the instructional sequence. The recorded data, held by the group that generated it, was regarded in this interchange as the ultimate authority in resolving the question, in contrast to many classroom interactions in which students regard the teacher as the ultimate authority for knowledge, or in which one student's challenge to another is resolved on the basis of popularity or social acumen.

Once Mr. V had given this group the power to resolve the question, he moved on to consider the Patterns and Explanations that had been posed by other groups. There were several clarifying questions that ensued, but no other student-initiated critical challenges of the type that Steve made. When the class finished the process of reviewing all of the reported Patterns and Explanations, Mr. V checked back with Adam, who reported that the group did indeed want to change its claim to read, "Green is always on the bottom". This occurred at the very end of the class period, and Mr. V repeated Adam's report and dismissed the class.

Logbook Entries for Colored Solutions

The next day, students were asked to complete a written evaluation of how well the members in their group had worked together, what kind of grade they thought each member of the group deserved, and why. Mr. V then initiated a discussion of the role of evidence in resolving arguments and disputes in scientific circles. He used examples from the Colored Solutions presentations and discussion the previous day.

Next, he asked students to turn in their logbooks to the page of Patterns and Explanations they had recorded from the poster presentations, informing them that they were going to write about their own understandings of Colored Solutions. The class was prompted (by a series of questions) to first discuss (in pairs) and then write a logbook entries which included the Patterns that they had recorded (from the poster presentations), and their Explanations for why the liquids behaved as they did. The challenge to write about why the solutions acted the way they did was intended to draw students into consideration of causes for the observed phenomena, and away from the earlier focus on defining the phenomena themselves.

The mediational means central to this activity, the ideas of heaviness and density, are concepts that help scientists (and others familiar with their ways of acting, thinking, and communicating) to describe and explain the behavior of phenomena like the Colored Solutions. The realm of cause (the "why" to the "what" that the students had worked out) is where these mediational means, including understandings of the precise ways that scientists use them, are most powerful and useful.

Mr. V instructed students to use the provided questions as guides, and to structure their answers into a paragraph or two in which they described what they had learned about

Colored Solutions, and in which they recorded questions they still had. The guiding questions were:

1. What Patterns did you find in the ways that the liquids acted? What Explanations can you give for them acting the way they did?

   (Now look back at <u>your</u> data from when you and your partner made stacks in vials and straws.)
2. Does all of your data match the Pattern you wrote about above? Does all of it have to match? What Pattern made sense to you?
3. Do you have any questions about the colored solutions that you are wondering about?

Students worked on this writing for the remainder of the class, which was about fifteen minutes, with only a few students finishing in that time. Mr. V announced that those who had not finished could continue the next day, and the class ended. All students had finished this writing by fifteen minutes into the next day's class.

The four logbook entries from Group 1 are reproduced below verbatim (recall that Adam & Lisa were a working pair, and Sandra & Kyle were another). Each of the students discussed Patterns first, then proposed an Explanation, as requested by the teacher.

Adam: The only patterns that made any sense to me at all were the patterns that had red over clear over green or any two of those in that order. I think the reason for them being in this order is their weight. Red being lightes, green being the heaviest, clear being in between.

Lisa: Red is always at the top and clear is almost always in the middle. Clear probaly dozen't have as much chemicals in it as red. But where does green stand. Green dozen't really have a place it's just kind of hanging.

Sandra: Red always goes to the top because red is less dence; Clear is almost always in the middle because it is second/middle dence and Green always goes to the bottom because green is most dence.

Kyle: Red is always at the top and clear is always in the middle. But green is alway at the bottom. To make the pattern how you want to. You have to put the colors in the order you want them in and droop the color down the side.

*<u>Note</u>: I have included only the paragraphs that students produced in their logbooks. These are verbatim. Notes and answers to individual questions were common precursors to these paragraphs.

All four of the students offered Patterns that they had found in the data. Though they offered them in different ways, and to different degrees of completeness, all of the Patterns were essentially accurate, and reflective of the data under examination. So, to look over the data and to see what happened to each colored solution, to look for repetition in combinations of solutions--these things were within the academic and intellectual capabilities and the social and cultural identities of each of these students.

The students in Group 2 wrote the following, also arranged by working pairs:

> ***Amy:*** The patternces that I found were red over clear, Red over green, and clear over green mixes. It happense this way because green is the heavyest so it's always at the bottom clear is meadiom lightest, so it always is in the middle and red is litest so it's always at the top. All my data does not match and I don't think it adsalutly has to. I wandor what is in or what the colored salutions are made out of. All the paterns made sense to me.
>
> ***Emma:*** Some of the patterns that I found are: Green is usually at the bottom, Red is susually at the top and clear is usually in the middle. All the patterns that I wrote above are in my data. I don't think that all my data has to match. Patterns that make sense to me are the ones I wrote about in the 1st sentance and that clear makes a color lighter.
>
> ***Donnie:*** Some of my partten work, some of them don't. Red stay on the to, clean stay in the middle. Green stay at the bottom.
>
> ***Chet:*** (no logbook entry).

Of the students in this group who wrote entries, all offered patterns that were accurate, based on their recorded data. The one statement that reflects an inaccuracy is Amy's, "clear over green mixes." This statement reflected an observation that Amy had made, but one that lacked the focus on stacks evident in the other statements. Amy's inclusion of this pattern might indicate that she had not caught on to the privilege accorded stacking data, and the resulting lack of acceptance of data that included mixtures. This distinction, which she apparently did not understand or value, was an important standard for data that had been established earlier in negotiations about the meaning of data, for which she had been absent. In this case, I was unable to determine what role her absence played in her clinging to outdated norms in reporting observational data, but the situation did cause me to wonder about this relationship, especially since Amy was the only student in these two target groups that was absent for more than one day during the Colored Solutions unit.

Concluding the Colored Solutions Unit

The next day, Mr. V talked to the class about how scientists use writing to communicate important ideas, and how important the process of writing can be in helping scientists who are doing research to figure out what they have learned and what they still don't know, and thus could research further. He provided a stack of scientific journal articles (actually edited research summaries from a science weekly magazine) to give the students an idea of how scientists communicate about what they learn in their research. These were passed around in the class, with students looking at them over the remainder of the class period (while other activities went on). Meanwhile, Mr. V asked students to notice how similar the writing they had done was to the articles he provided. He wanted them to get a chance to see how others in the class had written about what they had learned, so he asked them to swap logbooks with their partners, to read and to notice what their partners had chosen to include, and perhaps what they had left out. He offered the opportunity for students to nominate their partner's paragraphs to be read aloud, with no names attached unless the partner gave the OK.

The students swapped logbooks and read, and several nominated paragraphs which Mr. V read aloud, commenting on positive aspects of each. Then Mr. V asked students to read questions that they or their partners still had about Colored Solutions. Several questions were read, including,

> Can Clear really be on the top?
> Is Clear over Red over Green a stack?

These questions remained unanswered, as Mr. V indicated that for each of the individuals who posed them, these questions represented good places for further research in order to improve their understanding of Colored Solutions. With this, he handed out a packet titled "Learning Like a Scientist in Colored Solutions" (see Appendix A). This was read aloud by a succession of students, with periodic interludes in which Mr. V emphasized the importance of using data as evidence in trying to convince other people about your ideas. He invited those who were interested to consider writing more in their logbooks about some of the ideas and questions they had that could help them to learn more about the Colored Solutions.

Dimensions of Discourse in Phase III

The transcripts in this phase illustrate the development of the classroom discourse community by providing rich examples of discourse and action in small-group settings, where the teacher had no direct influence. They show that the students had, to a substantial degree, appropriated the goals, standards, and mediational means that were privileged in the public domain. In other words, they show that the classroom discourse community was beginning to function!

For instance, as the students in Group 1 (the only group examined closely in this particular phase) planned and produced their poster, they moved from the work on Techniques and Observations that had been their focus, to the new tasks of considering Patterns and developing Explanations. As they began developing Explanations, the rest of the TOPE x MVD grid became important, since they began to focus on the properties of the solutions in question as the salient factors in their stacking behavior. During this activity, Adam, Lisa, Sandra, and Nick considered density-related patterns and explanations at the same time as they discussed how to report their techniques and observations.

The poster presentations and the questions that followed provided direct evidence of the kinds of standards, mediational means, and connections that were in play in each group's work. Each poster was evaluated by peers in the discourse community in light of the operating standards for the community as a whole.

The dimensions of discourse for this phase are discussed below.

Goals and Standards in Phase III

The students' appropriation of describing and explaining the stacking behavior of the solutions as the "central goal" of the unit is evident in the transcripts included in this phase. The students focused exclusively on the stacking data, as many of them worked back and forth between the poster and their recorded data to verify claims made within the group. During the process of creating the poster, students took various roles related to the group processes of validation and production of the poster itself. Their varying roles, often shaped by the kinds of tasks each chose to do, essentially meant that each student was involved in a unique combination of experiences in this phase of group work. These differing experiences in turn reflected differential involvement in the cognitive work of the group. In several cases, students' roles seemed to be determined by their groupmates in overt ways, but as often students were relegated to a particular role or task by the actions of their peers (for instance, in valuing or ignoring claims that were made by a particular student).

Early in this phase, the standard that claims had to be based on recorded data emerged. This standard was apparently universally accepted across the different arrangements of students, although work in pairs still illustrated that some students generated their written data in ways that relied heavily on memory and consent rather than agreement about verifiable observations. In a similar way, social factors such as the desire to avoid conflict seem to have played a significant role in determining what a group decided to include on their poster. Adam clearly demonstrated this set of priorities as he sought to work out a resolution to the disagreement about the status of the Clear solution in his group (move 103, p. 40). Although an observer might have suggested laying the logbooks of the group members side by side to resolve the conflict, this would have meant that one or more students was proven wrong in the process. Instead, Adam sought to resolve the conflict by omitting the Clear solution from their pattern statements altogether, and this is what the group did.

In most cases in this group, the basis for a decision seemed to rest on a kind of informal agreement, rather than a true consensus process which would have valued every member's input equally. In this process, Nick, Adam, and Sandra appeared to hold determining votes. Lisa was able to bring attention to her concerns in instances in which she recruited one of this core group. Unlike the others, Lisa did not use data recorded in her logbook to convince others of the veracity of a claim; she instead recruited someone to carry the claim for her, and as such she was relatively less involved in the actual reasoning and negotiation of the validation process than these other three students.

The standard of replicability as necessary for separating good data from "noise," however, seemed to be less thoroughly understood and accepted by the students as they worked in groups. This was evident in the discussion that took place after they had retested the nine stacks that were reported as both possible and impossible. During this discussion, they were often distracted or confused by their tendency to refer to multiple data sources of various reliability--their original observations, the original class data reported in Phase II, and the results of their replication tests. Although this confusion did not prevent them from seeing the basic pattern--Green on the bottom, Clear in the middle, and Red on top--it did make deciding what data to report and how to word their claims about patterns much more difficult.

In presenting the posters, each group again made public claims about which stacks were possible, and about how the solutions behaved (in their Patterns and Explanations). By this time, most groups' validation processes had worked to reduce the number of false claims. However, the differences in the two groups' posters presented here (see page 43) illustrates that some groups' products reflected a more complete and absolute set of Patterns than others'. Standards for what counted as a Pattern had been determined within groups, and the presentation afforded groups the opportunity to question the standards of their peer groups (as illustrated by the interchange initiated by Steve's question about "5 out of 7 times..." on page 44). Reflections of individuals' standards in the logbook entries of these students showed a range of approaches and differing levels of sophistication in describing Patterns, as well as in proposing Explanations. Where individual students fell in these ranges was related to the kinds of activities in which they participated within the group, and the relation of these activities to cognitive work on the poster.

Mediational Means and Connections in Phase III

In this phase students continued to negotiate language and verify recorded data as they worked together to develop pattern statements and explanations. The group transcripts included in this phase show how important the wording of particular statements and claims was in the poster-creation process. In this relatively small public setting, students repeatedly proposed and revised statements to accurately reflect the understandings of the group's members, which was often indexed against the recorded data. Sometimes they tried to use an absolute language in which a single exception would invalidate the pattern ("Red is never on the bottom.") When they could not reach consensus on patterns of this type, they settled for a more statistical language ("Five out of seven times green is at the bottom.") which seemed more socially acceptable.

As the group moved from working on techniques and observations to a discussion of patterns and explanations, they began to consider more connections among their experiences as well. Even so, the group most often used the mediational means for communicating about techniques and observations that had been developed in earlier class discussions. Although the terminology used did not include 'density' specifically, it was apparent that their search for Patterns focused on comparisons of density between the solutions. The group did come to agreement about the most important pattern, and Nick suggested an explanation. His explanation, which anticipated the next part of the unit, suggested that the observed pattern was caused by a property of the solutions (buoyancy).

It is apparent that some students in this group better understood the connections between their actions than did others. Nick and Adam clearly understood that Patterns come from Observations and depend upon Techniques. They examined batches of data in order to detect and verify Patterns, and then looked across their many trials to verify their hunches. In this process, Nick appeared to have some difficulty because he repeatedly consulted the list of stacks that couldn't be made, a list of "non-data".

Even so, the students who were most involved in suggesting and validating pattern statements appear to have developed the most complete and precise understandings of the patterns and possible mechanisms for them. The journal entries of these students illustrate this point in several ways, one of which is the inclusiveness of the patterns recorded by each student. Six students (including Kyle, Sandra, and Adam in group 1 and Amy, Emma, and Donnie in group 2) wrote pattern statements that included all three solutions, and designated the order in which they would stack. These students, I believe, reflected an understanding of the “rules” for stacking behavior. That is, given the chance, I would have expected that each of these students could have correctly predicted the stacking order of any two- or three-solution combination at this point.

Of the other two students, Chet did not write a journal entry due to an absence, and Lisa's pattern reflected a less clear picture of her understanding. While it was apparent that she had worked out a pretty consistent picture of what the Red solution would do, she was less sure of the behavior of Clear, and wrote a question about Green. She was thus unwilling or unable to predict how these two solutions would behave, and did not have the clear mental picture of how the system worked that would have enabled her to move towards an explanatory mechanism.

While no claims are made here about the representative nature of Lisa's position with regard to other marginalized students, she does stand as an example of how a student might "fall out" of the significant cognitive work of a group, and as a result might not develop the solid conceptual grasp that some other members may hold. In Lisa's case, this position had direct ramifications for her difficulty in entering into subsequent portions of the instructional sequence in which this conceptual grasp was assumed to be common among students. Clearly, Lisa was at a disadvantage in ensuing interactions having to do with the mechanism at play in this system, including direct instruction in mass, volume, and density. Her sensitivity to this position may have further encumbered her as she attempted to make sense of the instruction and participate in group and whole-class activities.

Status and Participation in Phase III

In contrast with the work in pairs during Phases I and II, clear status hierarchies quickly emerged in this phase when students worked in groups of four on posters. The development of a status hierarchy in the group highlighted in this phase was examined in detail in Kollar, Anderson, & Palincsar (1994). One result of this hierarchy was that Lisa, the least academically successful of the students in this group, was often ignored when she made substantive suggestions and was often excluded from the consensus-building process. This exclusion matches a pattern that we have seen in several other case studies describing work in group settings (e.g., Holland, Anderson, & Palincsar, 1994; Kurth, Anderson, & Palincsar, 1994, 1995; Striley & Richmond, 1993). It seemed to be especially salient here when the students were working in groups of four.

The emergence of status hierarchies was clearly related to the kinds of work in which individual students were engaged (this relationship went both ways), although initial impressions belied this connection (and the existence of the hierarchies themselves). The usual practice, that each group figured out just whom would do what in their own ways, led this observer to judge the work of the groups as fairly distributed among members. Even those members who were least involved in negotiating wording and verifying patterns often appeared busily occupied and happy about the work they were doing on the poster. At least in terms of activity, they were most often accepted as full participants in the work of the group; differential participation thus had most to do with the *kinds* of tasks, rather than the access to tasks in more general terms.

During the poster presentations, all students were engaged as participants and observers. Many students asked presenters for clarifications, and presenters were obliged to respond to the satisfaction of each questioner. However, no claims about Patterns or Explanations were challenged during these presentations. The sole challenge, initiated by Steve, came later as Mr. V directed students to review the Pattern statements made by each group. In this instance, the group was asked to confer and respond to the challenge, and their continued engagement was supported.

The final activity for this phase, writing about Patterns and Explanations in Colored Solutions, was scaffolded by each students' own record of the Pattern and Explanation statements from the posters the previous day. While every student in attendance did manage to write about these topics, the students' logbook entries give evidence of the differential involvement of these students in the work of the group.

Phase IV: Developing the Concepts of Mass, Volume, and Density:

At this point, the concepts of Mass, Volume, and Density had not been formally introduced. In fact, although equivalent concepts had been used in Colored Solutions (stated in vernacular terms), these scientific terms had not entered into the discourse of the teacher in whole-class settings. Some groups had been exposed to these terms by some of their members, but their uses were limited by a lack of common grasp of these terms and their place in discourse (as shown by a lack of uptake when these terms were used by a group member). In the public and group settings, few instances in which these terms were necessary (by virtue of the imprecise nature of the vernacular terms that were being used, for instance) were evident. In short, the class and the teacher used the vernacular constructions that came naturally, because they worked.

At the end of the Colored Solutions unit, it was also true that many students had proposed explanatory mechanisms for stacking behavior (there were three mechanisms that had been a part of the whole-class discourse up to this point, and a few others), but that no further testing had been done to determine which of these mechanisms held promise for explaining the stacking behavior of the solutions. Nor had Mr. V focused on a mechanism or explained why one or another did or did not work or make sense. So, in essence, the students had come to a point of making conjectures, but no proof had been offered. In the lessons ahead, these conjectures would become a central point of further study.

Over the next ten class days, Mr. V initiated a series of activities designed to help promote these two foci. Some of the activities that furthered these goals were:

- A whole-class diffusion demonstration consisting of 5 liquids (corn syrup; the Green, Clear, and Red colored solutions; and vegetable oil) layered in a large graduated cylinder was conducted. On the first day, students drew the column of liquids as it appeared (the liquids stack from bottom to top in the order given above), and then drew a second graduate in which they drew the liquids as they predicted they would appear in a month. Students also wrote descriptions of what they saw and predicted next to these drawings. While the part of this demonstration having to do with diffusion was not a part of the immediate teaching plan (and was a later subject of study), the stacking order of the liquids used in the demonstration was an issue that paralleled and extended the students' questions about the mechanism that determined the stacking order of the Colored Solutions.

- Mr. V initiated a discussion in which he encouraged students to further define some of the terms that they had used to describe properties of the Colored Solutions (in the course of writing explanations for stacking patterns). Eventually, this discussion led to consideration of tests that could be run to determine which of the terms was most appropriate to use to describe the stacking behavior of the liquids. The terms on the initial list were:

  - heavier
  - thicker
  - dense
  - less buoyant

  So, for example, Mr. V led a discussion about the terms 'heavy' and 'thick', in which he and students worked on making distinctions between these terms. In this case, suggesting other terms was a part of the activity, and using multiple representations to "talk through" the meanings that students who used the terms intended, as well as other meanings that might be inferred by those who read their writing. Having worked out these distinctions, the class set about designing tests to determine whether “heaviness” or “thickness” was the salient property that determined stacking behavior. Necessarily, these activities were characterized by interspersed periods in which language and action was modeled and constrained by Mr. V, and other periods in which students were more free to work out their own understandings and actions.

- Tests that were aimed at making the distinctions between these terms clear, and at clarifying which of them had to do with the stacking behavior of the liquids, were run. Some of the tests were run by the students in pairs, and some were run by Mr. V as demonstrations. Discussions of the results of these tests, and what they meant in terms of the students' understandings about the terms and their uses, were a vital part of these activities. Over the course of the ten days, these tests followed a continuum from those that mainly focused on clarifying which properties had to do with the behavior of the liquids, to those which functioned mainly to make distinctions between Mass, Volume, and Density more clear.

- Reading and writing about terms that scientists use to describe liquids, including viscosity, volume, mass or weight (these terms were used synonymously in this unit), and density (see Appendix A, "Describing Properties of Liquids") was an important part of the instructional sequence. Formal instruction in these terms was tied to the four vernacular terms for which the students had been developing and running tests.
- Students worked together over a period of two days, first in pairs and then in groups of four, to sort terms used to describe substances into respective columns for Mass, Volume, and Density (see Appendix A, "Sorting Terms for Mass, Volume, and Density") and then presented their group's results to the class using an overhead transparency they had made. During this activity, previously mentioned norms for collaboration and for giving reasons to settle disputes were emphasized. Many of the terms given the students to sort were most likely to be encountered in home or school settings, like 'teaspoon' or ‘floating and sinking’. Some, however, were more specifically tied to school science, like 'scale or balance’ and 'milliliters’. So, the challenge for the students was to try to think flexibly about the relationships and the meanings and limitations of each of the terms, which included imagining contexts for use.

Student Groupwork: Sorting Terms for MVD

The Sorting Terms activity began with students arranged in pairs, sorting terms individually first and then discussing and making changes when they disagreed. The student handout, showing the terms and the instructions given, is shown below:

Sorting Terms Related to
Mass, Volume, and Density

1. Make a page in your journal with three columns headed, Mass, Volume, and Density. (Both journals.)
2. Work with your partner to put each of the following terms in one of the three columns. Check them off as you go:

DEFINITIONS: ☐ weight ☐ weight for the same amount
☐ size ☐ amount of space

MEASUREMENT TECHNIQUES: ☐ balance or scale ☐ measuring cup
☐ graduated cylinder ☐ floating and sinking
☐ stacks of liquids

ADJECTIVES: ☐ heavy ☐ light
☐ dense ☐ less dense
☐ larger ☐ smaller
☐ more ☐ less

UNITS OF MEASURE: ☐ grams ☐ kilograms
☐ pounds ☐ g/ml
☐ liters ☐ milliliters
☐ teaspoons ☐ cups
☐ quarts

Try to understand how your partner thinks about any terms that you don't agree on. Put a question mark beside any terms that you still don't agree on after you have explained your thinking to each other.

3. Work with your group to fill out their terms on an overhead transparency. Make sure that everyone in the group can explain your reasons forputting the terms where you did. Again, put a question mark beside the terms that you can't agree about.

The excerpts below were taken from interactions in which the two pairs that made up each group came together with their results to try to negotiate a group position on each of the terms. The terms were to be written on a transparency sheet by each group, to be presented to the class later. While there was much agreement in each of the groups, and many terms were simply listed on the group transparency on this basis, disagreements about the placement of some terms caused individuals to seek evidence or marshal support amongst peers. These points of negotiation reflected much of what these students understood about these concepts, and what kinds of standards and mediational means they were using in their attempts to persuade each other of the veracity of their claims.

Unlike earlier situations in which data was the deciding reference point for establishing claims, here the success of a claim rested on the claimant marshalling support from peers and giving reasons that held sway over those given by others. In some cases, a reading packet on mass, volume, and density (see Appendix A) became a reference text, providing definitions from which claims were justified.

In the Group 1 transcript below, Sandra & Kyle (a working pair) and Lisa & Adam (another pair) had just finished negotiating the terms for mass, and moved on to those listed for volume. The term "size" came up as one with a question mark beside it.

(Sandra has transparency and marker.)
4 Kyle: What about size?
5 Sandra: Oh, yeah, we have size.
6 Adam: Size? In mass?
7 Kyle: Yeah
8 Adam: (to Kyle) Don't you have that in volume?
9 Sandra: Or is that in volume? (Kyle and Sandra examine their lists)
10 Kyle: I mean in volume.
11 Sandra: In volume.
12 Kyle: You guys have it in mass?
13 Adam: Uh, yeah.
14 Lisa: We have mass.

In this initial interchange, all four students participated. There were two main kinds of activities going on: first, the students located each term, and second, they reported the column in which it was recorded. All four students were involved in both aspects of this activity, in which 'size' was reported in two different columns. Adam then began talking through the problem:

15 Adam: I don't know about that one. It seems it could go in either one of 'em.
16 Lisa: What (could go in either one)?
17 Sandra: Yeah, doesn't it? Kind of...
18 Lisa: What?
19 (Adam reads the packet to himself)
20 Lisa: What are you guys talking about?
21 Sandra: We're talking about, um,
22 Kyle: (looking through packet) The size.
23 Sandra: The size. You guys put it in mass...and we put it in volume. So we have to see what we can do... (looks through her packet)

In move 16, Lisa indicated that she did not understand that 'size' was the subject of the conversation. Meanwhile, while she requested more information (moves 16, 18, and 20), each of the other members of the group sought definitive information in the packet that had been handed out earlier. In moves 22 and 23, Kyle and Sandra helped Lisa to understand what the discussion was about. She then returned to examination of her own list, as the rest of the group continued to look for information in the packet.

24 Kyle: What is it, size?
25 Sandra: Yep.
26 Kyle: I think we're right because it says this [somewhat garbled](reading aloud from the packet, about amounts of liquids)
27 Lisa: (to Adam) Do you have a question mark?
28 Adam: Yep. (still reading packet)
29 Lisa: Do you have a question mark near anything? (Adam ignores her) (Kyle is still reading aloud)
30 Kyle: Volume means almost size.
31 Adam: Huh?

Lisa failed to find the term 'size' on her initial list, and set about recording it after checking with Adam to determine the correct placement. She then asked her partner about whether the term should have a question mark next to it. When she did not get a response, she reframed the question to include all terms, and asked it again. Meanwhile, Kyle found and read a statement in the packet that had to do with volume (the column in which he and Sandra had placed the term 'size') being a measure of the amount of a liquid. While this did not explicitly include the word 'size', his claim in move 30 indicated that he understood a connection between volume and size. Adam's query in move 31 provided the opportunity for Kyle to explain:

32 Kyle: Volume means almost the same thing as size. Because it says you use volume when you're thinking about taking up the amount of liquids.

33 Adam: Yeah, but mass is ... just a different kind of thing.

34 Lisa: Oh, gosh..

35 Adam: They're both talking about the same, see, a total weight, that means talking about the size of it.

36 Sandra: So it can go in..

37 Adam: No, wait a minute, I guess it is under volume, it says it right here. (points to packet)

38 Sandra: Size IS under volume

39 Adam: I guess we'll change it (erases)

Kyle's explanation began with a formulation that roughly equated volume and size. Yet, in his reasoning, his attempt to build the link between these two terms still left the connection unclear to Adam, who responded (move 33) with a statement about mass that was similarly vague. It appeared that both of these students understood connections, one between mass and size and the other between volume and size, that they could not verbalize. Meanwhile, Lisa had finished recording 'size' and a question mark in the 'mass' column, only to realize that she might have to change it (move 34). Adam, meanwhile, continued to try to formulate the connection as he looked through his packet.

For Adam at this point, the term "size" reflected its vernacular or common dimensions. Though it is commonly used in the vernacular to refer to outside dimensions, things that are heavier are often also bigger. So, for Adam, deciding that "size" was either a Mass term or a Volume term created a problem. His statement this time equated size and 'total weight', a phrase used in the section of the packet having to do with mass. Sandra then called for a decision (move 36), while Adam finally found a direct reference in the packet and pointed it out to her and Kyle. Sandra triumphantly announced the correct placement, and Adam moved to change it on his paper. Sandra, having the term already in the right place, noted that Lisa was confused and directed her to make the same change:

40 Sandra: (to Lisa) Wait. You have size over there? Put it over here now.
41 Lisa: I know.
42 Sandra: Alright.
43 Lisa: Now what do we do with the blank space?
44 Sandra: Nothing. Just leave it there.

In this final pair of moves, Lisa was most concerned about the mechanics of recording the term in the right column and making it look right. She had not entered into the negotiations about placement in any substantial way, and relied heavily on her peers to maintain minimum levels of participation in the task.

The group continued the task to completion with much the same kinds of interactions characterized here. Sandra maintained control of the marker and transparency, and continued to call for decisions as time grew short. In each case, she understood that assent of the other members was a necessary precursor to recording a term. Thus, this group operated on a rough consensus model for decision making.

Sandra and Adam clearly carried the weight of decisions in this group, and it was their insistence on including Kyle and Lisa that scaffolded these students along. Kyle was invited to participate in reasoning and searching for proof, but his suggestions and claims were never taken as final without further verification from Adam or Sandra. Lisa did not bid to participate in discussions, limiting her claims to reporting what was on her list. She took a sideline role as each term was placed, and then focused intensely on recording terms and making necessary changes on her paper.

More Groupwork on Sorting Terms for MVD

When Group 2 met to try to settle on an arrangement for the terms, Emma began with the transparency, marker, and her data (her partner Amy was absent), and Chet & Donnie (a working pair) went about checking their data against hers.

1 Chet: OK, wait (to Emma, who writes on the transparency), what're you putting now, floating and sinking?

2 Donnie: Yup

3 Chet: OK, 'cuz, ah, floating and sinking...

4 Donnie: We got large.

5 Chet: No..

6 Emma: Now we have pounds

7 Chet: Large goes under

8 Donnie: Ah, we got pounds, we got larger under mass, and kilo grams under mass

9 Chet: Slow down, Donnie, slow down

10 Emma: We have kilograms

11 Chet: Hunh? After pounds, kilograms

12 Donnie: But we got large in here

13 Chet: Isn't larger s'posed to be under density?

14 Donnie: Nuh, uh.

15 Emma: No, it's volume. Volume is um, volume is how much of something, it's how much space it takes up, I think (looks back a page in logbook, reads) Volume, the word that scientists use for how much space something takes up.

16 Chet: OK

17 Emma: So it's s'posed to be under volume

18 Chet: OK, (to Emma) can I write the, can I write the next column?

19 Donnie: I want to write density

20 Chet: I want to write the next column

21 Donnie: I get to write density

22 Chet: It's fair.

23 Emma: (gives transparency to Chet) Don't mess up.

This group's negotiation differed from that of Group 1 in significant ways. First, Group 1 clearly established a pattern of interaction based on negotiating two sets of data. As a result, their decisions were the product of comparisons of the two pairs' placements of each of the terms. Their interactions reflected a routine in which one pair proposed a placement, and the other either agreed or disagreed. Agreement signaled consensus, and the term was recorded on the group transparency; disagreement resulted in further discussion and marshalling of evidence, most often from the reading packet.

In Group 2, however, we did not see this kind of routine. Instead, these interactions appeared a lot more like the previous pairs interactions with the solutions; each individual made claims from his or her logbook. The claims were recognized as pairs' claims, as indicated by the forms, "We got..." and "We have..." that recurred in moves 4, 6, 8, 10, and 12. However, they were nominated in a competitive fashion, as Chet and Donnie bid to get their claims included next. As a result, the interchange appeared jumbled, with multiple and overlapping claims made as the members vied for acceptance of their claims.

Also notable in this group was the relative paucity of textual references. Emma was the only member of this group that referred to an outside source to resolve a dispute (see move 15). She used her logbook, reading the definition of 'volume' to settle a dispute about the term 'larger'. She won this dispute based on the textual reference; one might guess that this kind of evidence reflected a standard that was unevenly understood by members of this group. Essentially, the standard was that disputes could be settled by argument or discussion resulting in assent (which all seemed to understand), or by bringing in evidence (which Emma did). Textual evidence generally prevailed over personal position in this process; I did not see instances in which textual evidence was challenged.

Consensus was much more loosely defined in this group. In fact, evidence suggests that the person doing the recording had veto power over the placement of specific terms, and that the way this group made this 'fair' was to have each member take the role of recorder for one of the columns (moves 18-23). Apparently, this was both 'fair' in terms of who got veto power, as well as 'fair' in terms of who got to (or had to) do the recording task.

Just who controlled the mediational means in this task was more difficult to determine. In the excerpt above, Emma was the only person who gave reasons for her position, and these were supplemented by evidence from her logbook. Chet and Donnie focused on bidding, competing for Emma's attention. Finally, they bid for turns as recorder, competing again. Their focus did not include giving reasons or evidence at this point, as demonstrated in an interchange that occurred a few seconds later when Chet had taken the role of recorder:

30 Emma: I have amount of space
31 Donnie: We got size
32 Chet: OK, amount of space
33 Donnie: Size first.
34 Emma: No, amount of space
35 Donnie: Size!
36 Emma: What - do you have amount of space down there?
37 Donnie: Yup.
38 Emma: So, we can write it.
39 Donnie: Do you have space on - size on yours?
40 Emma: Yeah
41 Donnie: So, we put it on. Size.
42 Emma: It's amount of space
43 Donnie: Size. Just put size down.
44 Chet: Size?
45 Donnie: Yes.
46 Emma: Whatever.
47 Chet: (funny voice) Let's see if I can do it.
48 Donnie: Amount of space is next.

49 Chet: Amount of space is next? (he writes) I-yi-yi! (Emma gets up and moves Amy's desk back into row)

Emma and Donnie first voiced competing claims, and Chet accepted Emma's, which had been said first. Donnie then bid for his term to be accepted first, and the interchange continued without attention to the question of agreement over the placement of these terms until Emma checked this in move 36. Her justification led Donnie to check the placement of the term he was suggesting, and once each found that there was no disagreement about placement, the bidding to be first (far from a critical issue in terms of the group's results) continued. Finally, Chet accepted Donnie's bid over Emma's (move 44). This caused Emma to distance herself from the decision (move 46), and eventually to physically involve herself in another activity while Donnie and Chet finished the recording of these claims. I saw this competitive approach, pursued mainly by Donnie and to a lesser degree by Chet and Emma, as a factor that reduced the possibilities of negotiations about meaning in placing each of the terms. I saw this as especially true in situations where Emma was automatically at a disadvantage because the arguments centered on personal influence and power (Chet and Donnie ganged up on her). In these situations, Emma tended to remove herself from the interchange once it was apparent that she would not prevail. In instances where evidence was brought to bear, however, she seemed to fare much better, and the distancing did not occur.

Later interactions, near the end of Chet's term as the recorder, demonstrated this point well:

124 Emma: Yeah. OK, now to density. Now Donnie has to write.

125 Chet: Measuring cup...stacks of liquids.

126 Emma: I have that under density.

127 Donnie: We've got that under volume.

128 Emma: Because density is how closely packed the mass of a substance is.

129 Chet: Volume, volume, volume

130 Emma: Volume is how much s..

131 Chet: Volume

132 Emma: Volume is how much space it takes up.

133 Donnie: Nnn nnn nnn nnn. Nope, volume. Put a question mark by it, then.

134 Chet: OK, which column do you want to put it in?

135 Donnie: No, volume, put it under both.

136 Chet: OK. What are we talkin' about here?

137 Emma: Um...

138 Donnie: Stacks of liquids.

139 Emma: Stacks of liquids. (Chet writes) (Emma gets up to go get a kleenex).

140 Chet: OK, and....is that it?

141 Donnie: Yup. Yes!

In move 125, Chet was completing the task of copying terms from his logbook onto the transparency for the Volume column. As he did this, he repeated each term aloud; Emma objected to his placing 'stacks of liquids' in the 'Volume' column in move 126. Donnie added his voice to the interchange, reiterating the position that Chet had voiced earlier. Emma then gave a reason for her placement, which consisted of a definition of density (from memory). Chet's response, rather than resorting to his logbook, the packet, or what he remembered, was to filibuster. Emma continued to try to make the distinction complete, beginning on the definition for volume. Chet continued the lobbying effort in move 131, and Emma finally got the definition out in the next move. Donnie rejected her attempt, but without stating a reason or giving evidence, and instead suggested a question mark. Again, Chet accepted this suggestion, and also accepted Donnie's somewhat conciliatory suggestion to write it in both columns. Emma, without further argument or comment, accepted this turn of events and physically removed herself again. This left Donnie and Chet to finalize the column. This group completed the activity in much the same ways that these excerpts portray their interactions; there were no further instances in which evidence was brought to bear on disagreements over placement of terms. Donnie started to record the Density column, and then gave the transparency to Emma to finish after he made an error.

Once each of the groups of four had negotiated placements for each of the terms, these were reported out to the whole class. This began a lively discussion session in which whole-class consensus was the goal, and in which students were encouraged to share their reasoning for placement of each term upon which there was disagreement. As consensus was reached on each of the terms, students were encouraged to make appropriate adjustments in their logbooks so that they would have the completed table for reference in future activities.

Dimensions of Discourse in Sorting MVD Terms

One important feature of the term-sorting task can be seen by examining the domain which it represented on the TOPE x MVD grid. Essentially, this task involved students in work with a particular set of the mediational means that had become a part of the formal (instructional) and informal (conversational) discourse of the classroom, as well as some extensions to common vernacular situations. Each of the terms represented some approach to either Mass, Volume, or Density. The range of terms included those that would be important to people working on Techniques and Observations in these areas (like 'measuring cup' and 'grams'), as well as those attempting to describe Patterns and develop Explanations ('larger' and 'less dense'). Thus, the students were working across all of the cells in the grid. The focus on properties in this work had the effect of privileging this kind of information and concepts over other kinds. So, the students spent significant class time and effort working out distinctions and relationships between terms in this arena. In essence, their work was on connections between the cells; they worked to define the area of each cell by thinking and talking about the placement of these terms.

In the interactions examined here, substantial differences emerged between the ways that Group 1 negotiated placement of terms and the work of Group 2 on the same task. While Group 1 appeared to operate according to standards of evidence like those in place in previous whole-class interactions (3 of the 4 members used textual reference to resolve disputes), Group 2 appeared to operate on standards of personal influence and authority in settling disputes. One member of Group 2 did, on 2 occasions, give reasons for her position. In one of these cases, the presence of a textual reference appears to have decided the question. In the other, her explanation, which was based on definitions given in class, was rejected by the other members of her group, with no cause given. In instances like this when a group member lost an argument, often that member distanced him/herself from the result. This appeared to be a face-saving measure. On two occasions in which Emma lost arguments in this way, she physically removed herself from the group for a short period of time.

While Group 1 did hold standards for evidence, these standards did not always guarantee equal voice in disagreements, or consensus as the basis for decisions. Clearly, Sandra and Adam controlled the discourse in this group, and it was their implicit or explicit approval that determined the value of ideas and strategies in the overall work of the group. Neither Kyle nor Lisa proposed ideas in their own words, instead mimicking the words of others or the written text. Kyle was relatively adept at acquiring and using key phrases and terms, but we did not see him mount a convincing argument in which he convinced others of his position, though he tried. In the sorting terms task, he told why he thought 'size' should be under 'volume', but did not refute its placement under 'mass', and his peers remained skeptical. Of all of the group members, Adam showed the greatest facility in making connections in reasoning. He was able to convince others as he synthesized his own understandings of the meanings of the terms, and the distinctions between them.

Whole-class work on Mass, Volume, and Density

Over the next several days, Mr. V continued to refer to the TOPE activity framework in classroom discourse events, reinforcing the cyclical nature of scientists' work, and the consistency that scientists seek in developing techniques, making and recording observations, finding patterns, and developing explanations. In particular, he focused on finding patterns and proposing explanations as fruitful ways to make sense of the data that members of the class had gathered in several activities and demonstrations. In doing so, he sought to clarify and magnify the distinctions between the concepts of Mass, Volume, and Density.

Inherent in this instruction was a focus on properties of substances; as noted above, significant time and energy was devoted to study of the original list of terms, which included 'heavier', 'thicker', 'dense', and 'less buoyant'. The challenge for the students was to figure out which of these properties of solutions was responsible for stacking behavior; in time, this goal was widened to include making important distinctions between properties in order to make decisions about which might have a bearing on stacking. Over the course of this instruction, 'thicker' and 'less buoyant' got pushed aside, the first by virtue of its being equated with the term 'viscosity' (tests were run to determine whether viscosity was a determiner of stacking behavior), and the second by virtue of it being equated with 'more dense'. 'Heavier' was matched to 'weight', which was found not to be a determining factor. At the same time, Mr. V privileged Mass, Volume, and Density as important scientific properties (by conducting demonstrations that focused on these) and direct instruction in these terms. Eventually 'dense' in the original construction (converted to 'Density' as the name of a property) was found to be the determining factor for stacking behavior. An example of the activities that represented significant privileging of these terms is included below.

Making Distinctions: The Brass Weight and the Film Can

This teacher-led demonstration had most to do with the distinction between Mass and Volume. During the following interchange, Mrs. P, the cooperating teacher (who was in the classroom most of the time), joined in encouraging students to think about these distinctions, based on the definitions previously given.

1 Mr. V: I have two objects in my hands here. This one is a little brass weight that goes to the balance, and this one's a film can that you get film in when you go to the store, and it has stuff in it, not film.

2 Donnie: What kind of stuff?

3 Mr. V: What I would like for you to do first, I would like you to write a statement comparing the volume of these two objects. (Repeats) (Hand goes up) Just try this. I'm gonna help you out in a few minutes. Write a statement comparing the volume, the amount of space they take up.

4 Mrs. P: Do they take up the same amount of space? Don't they? What's the comparison? Write a statement. Look at 'em. It's a visual thing.

5 Mr. V: Write a statement. I'm walkin' around so you can give 'em the evil eye, if you want to. Write a statement. We're gonna call this one the brass weight; we're gonna call this one the film can. Write a statement that compares the volume of these two objects. Remember volume is the amount of space they take up.

Students were already expected to know what 'volume' meant, and in this excerpt were encouraged by both teachers to write a statement that focused on this particular property of the two objects. When a student sought to ask a question in move 3, Mr. V encouraged the first try at composing a statement before he answered questions. Mrs. P contributed other scaffolds to the exercise, helping students to think about the relationship between appearance and the property of volume. Finally in move 5, Mr. V repeated the class definition of volume to assist students who might have been having some difficulty remembering this.

6 Mr. V: All right, I would like to hear a couple of those statements, or at least one. Let's see. Keith, what did you write?

7 Keith: The film can has a bigger volume than the brass weight. (Mr. V writes this on OH, says it as he writes.)

8 Mr. V: OK there's one statement, and I underlined the word volume, and I'd like you to do that, so that you can just glance at that and your eye will catch that word volume. What's another statement that you could have written. Adam?

9 Adam: The volume of the film can is about twice as much as the volume of the brass weight.

10 Mr. V: OK. He said...(repeats Adam's statement). Nice job, Adam. Michelle?

11 Michelle: the brass weight has a smaller volume than the film can.

12 Mr. V: Good. You can approach it from a different angle and say the brass weight has a smaller volume, or a smaller amount of volume, than the film can.

13 Emma: The film can takes up more space

14 Mr. V: I would follow that with the word volume, so that the word volume appears.

In these interchanges, Mr. V tightly controlled both the interactions and their content, as he expressed approval for each of the first three students' comparative statements (moves 8, 10, 12). In Emma's case, he modified her statement to include the word 'volume', keeping the overt focus on naming that property. In a similar fashion, he kept tight control over the ensuing interactions about mass:

16 Mr. V: OK. Now we would like to do another kind of comparison, that of mass or weight. No, wait! Heh, heh. So, let's put 'em on the balance, and ah, there's a little deal here that stops the balance from swinging. (Many Ss lean forward, peering at balance). And that's about as close to dead on as you get. So, would you write a statement about mass, please. Include the word mass.(waits and watches students write).. oh, that's balanced, folks; it's right on. Include the word mass or weight in the statement. So you're writing a statement about mass now. Alright, let's hear a couple of those statements, please. Mort, what do you got for a statement about mass?

17 Mort: the brass weight has a little bit lighter mass than the weight of the film can.

18 Mr. V: 'Scuse me?

19 (Mort repeats.)

20 Mr. V: I said they were equal. See the balance....so, they're equal. Alright? You wanta change that statement? Amy, what did you write?

21 Amy: The mass is the same for both the brass weight and the film can. (Mr. V writes this on OH)

22 Mr. V: OK, there's one statement. What's another statement, Tess?

23 Tess: The mass of the film can is equal to the mass of the brass weight, even though the film can has a much larger volume.

24 Mr. V: OK. Good statement. What do you got, Chelsea?

25 Chelsea: The film can and the brass weight weigh the same, therefore they have the same mass.

26 Mr. V: OK, they weigh the same, therefore they have the same mass. That's great. Sandra, what'd you write?

27 Sandra: The brass weight and the film can have the same mass.

In move 20 Mr. V corrected Mort, asking him to change his statement to reflect equal mass on the balance. He then recorded correct statements from Amy, Tess, Chelsea, and Sandra. Each got his approval. In each case, the students proposed statements that they had written which reflected their understanding of the property in comparing the two objects. While these statements represented a range of approaches to comparing the objects, each had to meet Mr. V's standards for a good statement, which were the operating standards in the class at this time. Those statements that did not meet his standards were either rejected or corrected on the spot. This kind of active filtering of responses represented a dramatic departure from earlier whole-class sessions in which multiple options and ideas were encouraged. At this point, Mr. V wanted most to represent accurately the more scientifically accepted versions of these concepts and their application. In doing so, he hoped that the variety of formulations within these constraints would help scaffold some students into ways of talking and writing about these properties that were close to those that they would encounter in textbooks, on tests, and in future science classes.

Finally, with time running out on the instructional period, Mr. V issued the following challenge:

28 Mr. V: OK, good. Alright, now, here's a challenge, and I'm just gonna say this once and I'm gonna leave you with it, and if you want to try it, you can. See if you can write a statement about density. (Bell rings). Maybe we should try that tomorrow.

Over the next couple of days, Mr. V ran several other demonstrations, ending the set with a rapid-fire sequence of comparisons in which students were asked to voice comparison statements for each of Mass, Volume, and Density. While many students participated well in this final activity, as judged by the ease with which these statements were generated in the whole-class session, questions remain about the effectiveness of this tactic for understanding. It is clear that this kind of activity privileged (and encouraged) a formulaic approach to making comparison statements of the type the students made above, which are also the kinds of statements that might be useful on a test. Yet, it is unclear whether these statements helped students who had not made important conceptual distinctions to understand the concepts any better.

MVD Test: Privileged Forms

The test on Mass, Volume, and Density included questions having to do with the Colored Solutions. It was administered at the end of approximately seven weeks of instruction. In keeping with consistent practices of valuing student logbooks as tools for learning, students were encouraged to use their logbooks as reference material while taking the MVD test. Mr. V believed that this would give the students the benefit of their own thoughts and writing in creating responses to the test questions.

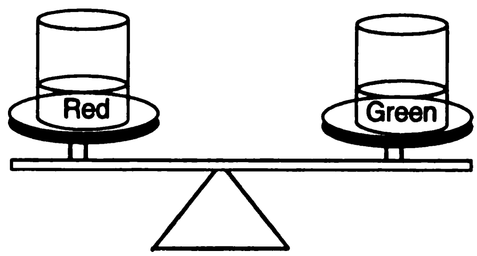
Several days before the test was given, students were coached on ways they might use their logbooks during the test, and encouraged to study by reviewing what they had done and learned so far. Two days before the test, they began working on a worksheet (by choice either individually or with a partner) that would help to prepare them for the test. This worksheet was then corrected during a whole-class session in which answers were shared and discussed, and students were encouraged to record helpful information in one place in their logbooks.

The test questions related to Colored Solutions included:

2. Predict whether each of the stacks below is possible or impossible. Write "yes" if the stack is possible and "no" if it is impossible.

			R	R	G
G	R	G	G	C	C
G	G	R	C	G	R
_____	_____	_____	_____	_____	_____

3. Predict which side will be heavier for each of the balances below and explain your answer.

100ml  100ml

Which side will be heavier? ___________ Why?____________________

____

On question 2 (above), all of the target students identified those stacks that were possible correctly, and similarly identified those that were not possible. And, all of them answered that the green side would be heavier on problem 3 (this is the correct response). The first of these questions could have been answered correctly from the students' notebooks, or their recollections of their experiences with Colored Solutions. Thus, it is difficult to determine whether individual responses to question 2 alone reflected understanding of the underlying mechanism (density), or whether some or all of these students answered on the basis of recorded information in their logbooks.

Question 3, however, was an extension of the Colored Solutions problem, one that the students had encountered in class a couple of days after they wrote about Patterns and Explanations in Colored Solutions in their logbooks. Many of the students had records of this particular activity, and should have been able to describe the behavior of the solutions on the balance. Explaining why this happened, however, was intended to be a test of their understanding of the relationships between Mass, Volume, and Density. In order to effectively tell why, students would have had to focus on the salient features of the system that determined why the Green side would be heavier. In this instance, then, they had to notice equal volumes of Red and Green, and from past experience (perhaps recorded in their logbooks) recall that Green had the greatest weight-per-amount (Density). This line of reasoning would lead one to conclude that the Green was heavier because it was more dense.

Student responses to this problem varied. All of the students except Lisa selected the green side to be heavier, a correct response. (Lisa picked red, and said there was a little bit more of it, even though the diagram labeled each side at 100ml). Most of the remaining target students, including Adam, Sandra, Anna, Emma, and Donnie indicated attention to the salient property of Density. However, some of these responses reflected understandings that were less complete or focused than others, perhaps indicating a ritualized use (cf, Edwards & Mercer 1988) of the term. For instance, Donnie gave the following reason,

> because green is the must dence out of the color solutions

while Chet wrote that the green would be heavier because it has a greater mass. Kyle wrote a response similar to Chets', indicating mass as the reason. It was impossible to determine from these response in isolation whether Chet and Kyle did or did not have a good concept of density as the mechanism at work in stacking. One reason for this difficulty lay the design of the test problem. Donnie's response, for instance, indicated reasoning focusing on why a given amount of one solution would have been heavier than the same amount of another. Chet's and Kyle's responses, on the other hand, may have represented transformations of the problem from "which side will be heavier?" to "which side of the balance will go down?". These are incomplete transformations that focused on visual effect rather than working through that step to causation. As written, the problem should have pushed students to causation, but a misreading, a hurried approach, or an incomplete understanding on Chet's (and Kyle's) part might have led to a different response.

Adam's response was

Green is a lot denser than the red so it will be heavier.

Adam, like Donnie, indicated that he had attended to the important features of the system in determining his answer, and that he understood the connections between Mass, Volume, and Density. His statement rested on the assumption that Volume was kept constant across both containers of liquid. That being the case, he simply reflected his understanding of the relationship between heaviness, size and the linguistic construction-- that things that are heavier for the same volume are said to be more dense.

This response demonstrated the increased importance of connectedness as a dimension of discourse over time in this science learning community. Adam connected three important concepts, all related, and all mediational means that had been in play in the discourse system of the class for some time. Developing these connections and verbalizing them showed that, for Adam, the instruction over the last ten days had been appropriate and was working. Adam's facility with these concepts and terms was evident on individual tasks as well as in his relative control over group interactions.

Given the limited views of student understanding that this test afforded, I examined post-instructional interviews that had been conducted several weeks after the test, help to elucidate the kinds of understandings with which these students came away from instruction. One task asked each student to compare two cubes of equal outside dimensions, one made of clear lucite and the other of aluminum. Transcripts of these interviews reveal that Adam did, indeed, understand these relationships (see transcripts in Appendix B). When prompted, he first equated the volume of the two cubes, then noted that one was heavier, and then said that the heavier one "would be more dense".

Donnie, who had produced a good reasoning statement on the test, was only able to make the comparison on the basis of mass correctly. He said that the volumes of the cubes were the same, based on them both being the same shape. Then, when asked about density, he said that the lucite cube had more density, because the aluminum one "weighs more". When this statement was repeated back to Donnie for verification, he indicated that it was correct. Objects that weigh less have more density. This contradicts Donnie's response on the test, indicating that at best he had a muddled or vacillating view of the relationships between these properties.

Chet's response on the test had been difficult to interpret, but definitely less complete than Adam's. Yet his response to the comparing cubes task showed that he did, indeed, understand the relationships between these properties. Like Adam, he readily compared mass and volume, and then used these comparisons to judge comparative density. Even though his involvement in the verbal interactions of the term-sorting activity did not reflect deep negotiation with other students over concepts, it is clear that some of the activities in which Chet engaged did assist him in making the necessary distinctions and focusing on the important properties.

Dimensions of Discourse in Phase IV

Phase IV includes a long teaching sequence in which the class moved from a focus on a single system (Colored Solutions) to the use of mass, volume, and density as mediational means for describing a wide variety of objects and substances. By the time the 'Brass Weight and Film Can' demonstration (exerpted above) occurred, the public discourse of the classroom had come to include the entire TOPE x MVD table. As the transcript indicates, some students, at least, had become successful participants in a discussion that reflected many of the goals, standards, and mediational means that scientists use for describing substances. Each of the dimensions of discourse is discussed in more detail below.

Goals and Standards in Phase IV

This phase demonstrated the completion of a shift in public goals. Earlier, the initial goal of experimenting with Colored Solutions gave way to a goal of finding and understanding patterns in Colored Solutions. This goal then changed as students attempted to explain these patterns in terms of a property of the solutions (density). Finally, students were challenged to describe and compare other substances in terms of properties such as mass, volume, and density.

Alongside this shift in public goals, public standards also shifted to include the explicit expectation that students would use scientific terms in a manner acceptable to scientists. This expectation, coupled with the shift in public goals noted above, highlighted the critical and uncharted nature of the "balancing act" that the teacher performed in attempting to constitute a discourse community around the description of substances.

Seeing (and hearing) students use scientific-sounding terms and formulations, and observing their attempts to generalize their understandings to other settings brought out underlying questions about the effectiveness of this kind of instruction. Had the class successfully constituted a discourse community around this kind of discourse, or were students instead just producing appropriate words on demand in public settings while their private discourse retained many non-scientific elements?

In this study, the answer to this question appeared to vary with individual students. Some, like Adam and Tess, were successful at using mass, volume, and density in both public and private settings, while others' statements and actions were less convincing. Donnie's use of the term closely followed a formulation used in class, one which sometimes fit the activities well, and at other times seemed to fit less well. Students like Kyle and Chet, however, used the term in ritualized ways that did not include a good sense of how to use it appropriately for different contexts. Their approach clearly indicated school goals for these terms (getting the right answer by memorizing key phrases) rather than scientific ones (describing substances using the term appropriately, and understanding the ideas that the term represented).

Mediational Means and Connections in Phase IV

In this part of the instructional sequence, the range of situations in which students were required to work with mass, volume, and density broadened markedly. Far from the relatively singular track of Colored Solutions, the range herein expanded to include several kinds of work on terms themselves, eventually leading to endeavors which assumed an underlying conceptual grasp. Thus, successful participation in the activities of small groups and the whole class demanded that students come to understand the full range of mediational means and connections between them that appear in the TOPE x MVD table.

As the transcripts above indicate, at least some of the students (Sandra and Adam, for instance) were close to mastering the concepts and related activities across the full range of the table during this phase. Others who had less command of the concepts and terminology still worked across a considerable portion of the table. For these students, including Donnie, Chet, and Kyle, only close analysis of language and action revealed limitations in their understanding of the mediational means around which this instruction revolved. Their participation in discourse indicated appropriation of the 'school' aspects of tasks, for which they may have resorted to memorizing a term embedded in a linguistic formulation, and applying this formulation whenever their understanding indicated a need for the term or idea.

Lisa stood out as the one student in the target group for whom key mediational means remained an elusive target. Bound by her own confusion and by her exclusion from the cognitive work of the group, she never brought most of these mediational means into her repertoire. Her actions remained connected mainly to immediate concerns, and she was creative about establishing roles for herself that kept her at least marginally involved, but did not lead others to depend on her for answers.

Status and Participation in Phase IV

In this final phase, Lisa, Donnie, and other low-status students were largely silent in whole-class discussions and activities which required public nomination. This lack of participation, notable in contrast to their involvement and engagement in earlier phases, may serve as evidence of their limited understandings of the mediational means that had become privileged forms.

When students worked in pairs during this phase, all of the target students participated fully on most occasions, regardless of academic and social status. In these settings, Donnie and Lisa were active participants in the tasks, as evidenced by their willingness to nominate terms and give answers during the 'Sorting Terms for Mass, Volume, and Density' activity. It was clear, however, that the more academically successful students were more adept at incorporating scientific uses of mass, volume, and density into their conversations in varied ways. This differential participation was sometimes barely discernible in pairs work and became more obvious in larger group settings (groups of 4 and whole-class), a finding that is further explored in a study of levels of engagement in pair and groups-of-4 tasks in this and another classroom by Kurth *et al* (1995).

Kurth found that when students worked in pairs, central engagement was essentially equal for both high-status and low-status students (well over 95% of the time both students were centrally engaged), but when these same pairs combined into groups of 4, all students experienced less central engagement (62-85% of the time). Among the students studied, the lower-status were centrally engaged markedly less than their higher-status counterparts. Kurth's findings mirror and expand the differential participation encountered in this study, which emerged most dramatically as contexts for instruction changed and students were asked to flexibly apply their understandings to new situations.

Mr. V's choice to move to a teacher-centered model of instruction had much to do with the emergent differential in participation. For students who had made the initial connections between the stacking behavior of liquids and the salient property, like Adam and Sandra, this was a logical move. Teacher-directed instruction ensured that their understandings of this property (and the others under study) would be further developed and refined; they had webs of understanding that related their work in Colored Solutions (and Sorting Terms for Mass, Volume, and Density) to the situations they were encountering here.

For students who had not made the connection between their experiences with Colored Solutions and the ensuing instruction (like Lisa and Donnie), this instructional mode was less likely to be fruitful. Having not understood *properties* as the causal factor in the observed phenomena, these students were less likely to gain further understandings of these concepts during the series of events over the ten days following Colored Solutions. They were not ready to propose statements of comparison, since they had not been able to make clear distinctions between these properties earlier. And, their work in Sorting Terms for Mass, Volume, and Density had been peripheral to the activity of reasoning out the placement of terms that went on in groups of four. This may have also been the case in the pairs work on these terms. Students who emerged from this setting with strong understandings would be well prepared for participation in such activities in the larger group.

CHAPTER 5

This study focused on the analysis of classroom discourse across the multiple social arrangements in a sixth grade science classroom. A primary goal was to attempt to characterize some of the interplay between the development of individual understanding and the development of collective knowledge as the class worked together on problems related to mass, volume, and density.

A major commitment underlying this study was that conceptual knowledge is developed hand-in-hand with social and linguistic knowledge. Thus, meaningful learning in each of these domains requires, and is supported by, learning in the other. Given this commitment, the analysis of classroom discourse was seen as the most appropriate way to investigate the development of language-in-action and conceptual understanding of these three concepts.

Four major *dimensions* of discourse were examined. These dimensions crossed traditional boundaries of analysis in order to trace the thought, action, and word that are all essential to the scientific endeavor. The dimensions studied were:

- <u>Goals</u> - the nature and purposes of the activity
- <u>Mediational means</u> - the physical, intellectual, and social tools used in the activity
- <u>Connections</u> - between each action and other actions in describing substances
- <u>Standards</u> - minimum thresholds for acceptable language and action in describing substances in a given situation.

For example, videotapes of students working with Colored Solutions for the first time were examined and transcribed in order to describe the different ways that students *populated the task with their own goals*, (cf. Ballenger, 1994) or made sense of the activity (across all four dimensions). At the same time, the students' logbook entries were examined, and the kinds of data they recorded were noted in detail. These initial characterizations formed the backdrop for examination of the first whole-class data gathering session, and for understanding the roles various students took in it. The teacher actively *privileged* (Wertsch 1991) stacking data over other kinds during this session by recognizing and requesting data in this form, and by discounting data of other kinds. This process of teacher privileging was noted as a principle mechanism by which the teacher influenced the nature and purpose of the students' work during the entire instructional sequence.

As discourse and mediated action were studied, the analysis presented here portrayed some of the essence of scientific endeavor, as seen through the students' eyes, over the course of the instructional sequence. During this sequence, the students worked to understand mass, volume, and density in four major kinds of activity:

- Acceptable <u>techniques</u> for comparing or measuring mass, volume, and density of substances
- Acceptable ways of reporting <u>observations</u>, such as comparisons or measurements of mass, volume, and density
- <u>Patterns</u> that are consistent for observations of mass, volume, and density for many different substances in different circumstances
- <u>Explanations</u> of why these patterns hold, and what underlying mechanisms are at work.

The students' involvement in each of these four kinds of activity was traced in terms of each of the concepts of mass, volume, and density. A grid representing the kinds of scientific activity that would be typical for each concept was created. At each phase of data analysis, the domain of student activity on this grid was noted. As the instructional sequence unfolded, students worked across larger and larger areas of the grid (in general terms, most students began working on techniques and observations having to do with density, and then broadened their study down and across the grid). In many cases, earlier work formed a foundation for current efforts, so that as students worked down and across the grid, we observed their work in ever larger domains.

	MASS	VOLUME	DENSITY
T	• Weighing substances using a balance. • Comparisons of mass can be made using a double pan balance.	• Measuring liquid volume using volumetric containers. • Measuring volume by linear or displacement means. • Comparisons of volume can be made by height of liquids in identical containers.	• Comparing density of substances by floating and sinking • Calculating density from measures of mass and volume
O	• Measured in units, gram is standard unit • We say that objects with more mass are heavier, while objects with less mass are lighter.	• Measured in units, liter is standard unit • Comparing volume of liquids leads us to say we have more or less of one. • Comparing volume of solids leads us to say one is bigger or smaller than another.	• Relative density determined by introducing one substance into another to see which floats and which sinks. • Calculated and referenced to standard (water = 1g/ml) • Comparisons can result in stacking, floating and sinking, or lead us to say one is more dense or less dense than another.
P	• Mass is dependent on sample size. • Mass is independent of gravity	• Volume is dependent on sample size for solids and liquids.	• More dense liquids sink, less dense liquids float • Floating and sinking is independent of sample size • Floating and sinking is independent of shape or size of container • Floating and sinking is independent of order of introduction into container
E	• Mass is a measure of how much matter is in a sample	• Volume is a measure of how much space a sample takes up	• Density is a measure of how closely packed matter is. • Measures of density assume samples are uniform

Table 2: The TOPE x MVD grid

Analysis of segments of mediated action revealed much about the students and their understandings of science concepts, as well as their approaches to scientific activity. As instruction proceeded, the roles that individual students took in each setting and activity were seen as important indicators of success in the long run. Evidence of full engagement in language-based activities became the principal indicator of the status that individuals held in group and whole-class interactions. Using the four dimensions of discourse as an organizing framework for each research question, significant findings are summarized below.

Summary of findings:

Question 1

- How did the construction of the concepts of Mass, Volume, and Density proceed in the discourse system of the classroom community as a whole over the seven week instructional period? In what ways did teacher and student privileging of mediated action influence the development of these concepts?

The four dimensions of discourse examined in this study formed a framework for charting the development of the concepts of mass, volume, and density in the discourse system of the class. While the data were presented in discrete chunks defined by each of the four phases, the definitions of the phases themselves had much to do with the students' emergent understandings and the concomitant teaching strategies aimed at furthering them. Said another way, as students first engaged in vernacular terms and then began to move towards more scientific ones, the tasks in which they were engaged also changed in order to challenge and scaffold them along this continuum. Each phase was defined in terms of the activities in which the students were involved; thus, when the entire sequence was examined, a picture emerged of the entwined and interdependent nature of their language, thought, and action as represented by the four dimensions of discourse.

This study traced the development and use of *mediational means* (or cultural tools, (Wertsch, 1993)) in the collective setting of the classroom community. These tools included all kinds of language-in-use as well as physical and mental tools (specialized terms, ways of using them, factual information, concepts, strategies, approaches, models, dispositions, habits of mind, et cetera). During the instructional sequence studied here, the class worked in four distinct social configurations: as individuals, in pairs, in groups of four, and as a whole class. Each of these configurations framed particular kinds of activity. Generally, the sequence unfolded in these ways:

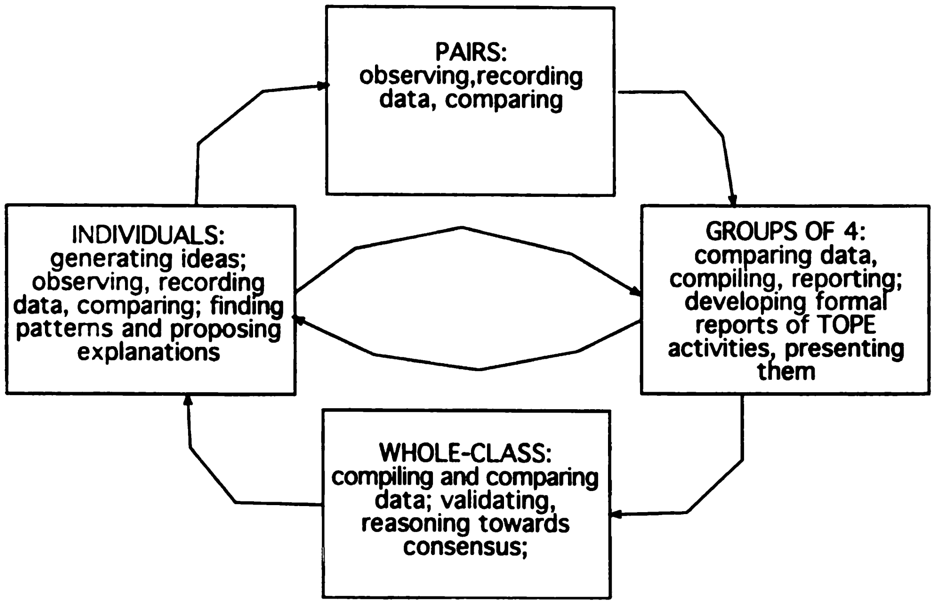


Figure 9: Activities related to describing substances in each of four social configurations in the classroom

This diagram shows that students often worked in pairs and groups of four on particular ways of describing substances, and that they then moved from these settings to a whole-class setting in which data was compiled and verified for the entire class. One important feature of these class data-verification sessions was reasoning towards consensus, first in terms of what counted as data, then in terms of what counted as good data, and finally about what the good data meant. Ultimately, these whole-class sessions were a filter for what went on individually, in pairs, and in groups of four. Opportunities to question and probe were common in these whole-class sessions, which were almost always teacher-directed. This flow from relatively less-structured interactions in pairs and small groups towards more tightly constrained whole-class sessions influenced the development of the discourse community as goals, standards, mediational means, and interconnectedness developed across these settings. Most noticeable in this process was the generative nature of group interactions, and the privileging that shaped the whole-class sessions.

The development of the classroom discourse community is discussed below in light of each of the four dimensions of discourse. For the purposes of this discussion, the four goals have been linked as two pairs, based on affinities that emerged during this study. Goals and standards, both having to do with the nature and quality of students' endeavors in the classroom, are discussed first. Next, mediational means and connections are explored in elaboration of linguistic and conceptual knowledge in the multiple contexts of school, classroom, and groups as well as contexts of task and role.

Goals and Standards

At the outset, the class did not function as a discourse community with common goals, standards, techniques, and means of communication. Instead, the class functioned as individuals and pairs of students who constructed the tasks and their results in a range of quite different ways. The students figured out individually or in pairs what the task meant and required, and then proceeded to fulfill those meanings and requirements in their work.

Each of the two groups studied here developed it's own ways of operating, which included assumptions about productive ways to investigate the Colored Solutions. The pairs that constituted one of the groups adopted relatively orderly, sequenced interactions that constituted routines. These routines provided for a systematic approach to work with the solutions. The pairs that constituted the other group, however, worked in dramatically less ordered and constrained ways. Their approach of working as individuals, and competing to make interesting visual effects, led them to an *engineering approach* (cf. Schauble et al 1991) to the Colored Solutions problem, one that involved considerable attention to matters of technique. While they did not keep records of each trial as assiduously as their counterparts, they were able to make some stacks, and to discover some patterns in the way the solutions stacked. Thus, the careful and ordered approach that one might first identify as the more 'scientific' of the two actually represented a narrower range of inquiry, which in these circumstances paid off less in terms of the group members' findings during this exploratory phase.

The results of these initial investigations, the students' recorded information (and perhaps some that was not recorded), then became the focus of further study by the whole class. Interactions in the whole-class session supported the development of the classroom discourse community by establishing common goals (reporting stacks of liquids that could and could not be made) and by engaging each pair of students in the interaction around the data. During this initial whole-class session, standards for accurate and meaningful reporting of data emerged, as the class settled on how to say and write stacks, and how to verify that the recorded information was correct. A key factor in the development of these standards was the teacher's privileging of stacking data over other kinds. This process effectively eliminated a range of observational endeavors that had little to do with the stacking behavior of the liquids, and served to focus the students' attention on the particular aspects of the system that had to do with floating and sinking, and eventually on issues of validity and reliability of the data they had gathered.

As the verification process proceeded, a subtle but important shift in the public goals of the class occurred, in which the students moved from reporting "Stacks we made" and "Stacks we couldn't make" to that of developing a common public data set that was validated by replication and consensus: "Stacks that can be made with proper technique" and "Stacks that cannot be made regardless of technique." In guiding the students through these shifts in goals and standards, the teacher was trying to strike a delicate balance. Without common public goals and standards, the class would continue to function as a collection of individuals rather than as a real discourse community. On the other hand, if the teacher merely imposed his own goals and standards on the public discourse, the students would probably respond with what Edwards and Mercer (1987) describe as ritualized compliance, rather than with personal ownership and engagement. In that case, too, the goal of constituting a discourse community in the classroom would not be realized. As the students accepted the new goals and standards as their own, they moved further towards constituting their own discourse community.

As the possible stacks were finally verified in the whole class session and students moved on to consider patterns in their data, the new common goal of describing the stacking behavior of the solutions became more evident in the language and action of the membership of the class. Students were able to point out inconsistencies in the data, and held each other to the established standards for reporting and verifying data. In small-group interactions during this time period, the standards and language evident in the whole-class sessions were applied relatively evenly. This was firm evidence of the emergence of the discourse community, as common thresholds of understanding and practice were applied in more private settings.

Finally, students were challenged to explain the patterns they had found in terms of a property of the solutions (density), and to describe other substances in terms of properties such as mass, volume, and density. Alongside this shift in public goals, public standards also shifted to include the explicit expectation that students would use scientific terms in a manner more like that of scientists. This expectation, coupled with the shift in public goals noted above, highlighted the critical and uncharted nature of the "balancing act" that the teacher had to perform in attempting to constitute a discourse community around the description of substances.

Mediational Means and Connections

Initially, students were working on comparing density using tools (like vials, droppers, and straws), techniques, and language related to observation (all mediational means). After the first day, most students focused on developing techniques for making valid density comparisons (based on stacking), as opposed to just mixing solutions. Much of this work was embedded in the actions of the students more than their talk or writing. Yet, we did see evidence of this work in some of the recorded logbook entries and dialogue of the working pairs.

The tasks of observing and recording within the framework of "Techniques" and "Observations" clearly engaged all students, albeit with different results. While they were working on this two-column format in their logbooks, they appeared to be involved in less overt ways in figuring out what patterns might exist in the liquids. Some of the group members made forays into suggesting patterns during this part of the investigation. The ease with which most members were able to suggest patterns a day after this event indicated that this was a vital part of the territory in these interactions.

During Phase II the students developed both experimental techniques and ways of communicating about their observations that were better suited to the ultimate purpose of comparing densities of substances and communicating about those comparisons. At many points, both public and private discussions turned to issues of proper technique. Chet's advice to Donnie in Phase I ("You squirted it too fast. Squirt it *slowly*") is one example. There were many similar examples of discussions for making stacks in straws. (For example: "You have to make sure that you put the straw deeper into the second solution than into the first." "Don't take your finger off the straw too soon. The solution will all run out.") Thus the students were developing the technical skills--the mediational means--that would allow them to compare the densities of two solutions reliably and accurately.

With the new methods for reporting on stacks, the students also developed mediational means for reporting their observations that communicated density comparisons far more efficiently while ignoring many details to which they had previously paid attention. (Compare the chart of stacks that could and could not be made in Phase II with Adam's and Lisa's journal entries in Phase I, for example.) However, during Phase II the students were still unaware of the conceptual connections apparent in the TOPE x MVD table. The connections that would become apparent through discussions of patterns and explanations were still invisible to most students, partly because the data they reported were so full of errors that the patterns were not yet clearly apparent. Thus it became necessary for them to reach consensus about reliable data before any serious discussion of patterns and explanations could take place.

As the students worked to verify their data, they sometimes tried to use absolute language in which a single exception would invalidate the pattern ("Red is never on the bottom.") When they could not reach consensus on patterns of this type, they settled for a more statistical language ("Five out of seven times green is at the bottom."). Later, as the groups moved to consider patterns in their data and explanations for them, the groups began to consider more connections among their experiences. Although they negotiated considerably (and in very different ways) over language to express them, both groups studied here were able to report patterns on their posters, and one group suggested that the patterns were caused by a property of the solutions: buoyancy.

In the final part of the instructional sequence, the range of situations in which students were required to work with mass, volume, and density broadened markedly. Far from the relatively singular track of Colored Solutions, the range here expanded to include work on terms that the students had suggested as mechanisms for the stacking behavior of the solutions. Much of this work assumed an underlying conceptual grasp. Thus, successful participation in the activities of small groups and the whole class demanded that students understand the full range of mediational means and connections between them that appear in the TOPE x MVD table.

As the transcripts from late in the instructional sequence indicate, at least some of the students were close to mastering the concepts and related activities across the full range of the table. Others who had less of a command of the concepts and terminology still worked across a considerable portion of the table. For these students, only close analysis of language and action revealed limitations in their understanding of the mediational means around which this instruction revolved.

Question 2

- In what ways did eight individual students in this class take on the "identity kit" of science, as demonstrated by participation in classroom and collaborative group discourse and investigations about mass, volume, and density? How was the emerging discourse system of the classroom community and collaborative groups facilitative (or not facilitative) of their participation in the activity of describing substances, and especially their understanding of Mass, Volume and Density?

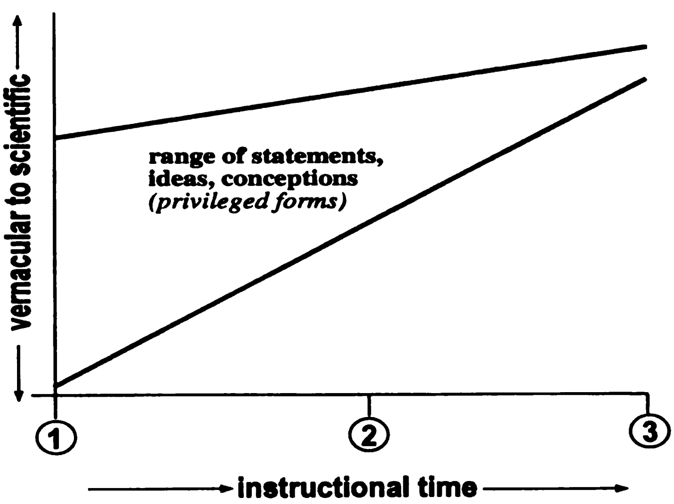


Figure 1: One representation of the goals of discourse-based science instruction

The four dimensions of discourse I used as analytical frames (goals, standards, mediational means, and connectedness) were useful for looking at the relative positions of each of these students at the end of the instructional sequence. Also useful was the graphic that I proposed in Chapter 1. This graphic represents a range of statements, ideas, and conceptions that students and teacher might exhibit over the course of instruction. As instruction proceeded, the range was expected to narrow as certain forms were privileged over others, and as standards for accepted speech and action came into play. In the following section, important findings about how individuals made sense of the actiivities, and the standards that they established, are examined.

Goals and Standards

The students' work during the initial investigations with Colored Solutions, in which they were exploring and recording observational data, was notable for the general absence of differences in status, participation, and engagement among the students. This was probably due partly to the absence of stated **standards** that would have privileged some approaches to experimenting with the solutions. The high levels of engagement and relative absence of status differences are general features that were apparent in this classroom whenever students were working in pairs (see Kurth et al, 1995).

Very early in the sequence, we observed some students had spontaneously established **goals** (in making their own sense of the activities) that would later be privileged, while others had not. Adam, for example, noted which color was on top when recording a successful stack, while Lisa did not. Similarly, Chet sought to replicate his most interesting results while he coached the more impulsive Donnie to slow down and use more careful technique.

In the whole-class session, participation was maintained by the teacher's acceptance of all claims as valid, as long as they represented the privileged form (in effect, a standard by which claims were judged relevant or not), stacks of one liquid over another. Thus, any student who wished to make a verbal claim in the format of 'color A over color B' could participate. Later interactions indicated that many students who nominated stacks followed their progress closely during the validation process. Significant in maintaining engagement, however, was that each claim carried equal weight among others (though more students may have supported one than another, for instance).

When the groups began working on posters, a clear status hierarchy was evident in one of the groups (and casual observation suggests, most of the other groups as well). For this particular group, the development of this status hierarchy and its effects is examined in detail in Kollar, Anderson, & Palincsar (1994). Lisa, the least academically successful of the students in the group, was often ignored when she made substantive suggestions and was often excluded from the consensus-building process. This exclusion may be largely due to the limited range of mediational means with which she had been involved up to this point. Apparently, other members of her group saw her as not meeting minimum standards for the cognitive work they were doing, as evidenced by their lack of uptake when she made suggestions, even good ones (ones that were scientifically correct and would have added to what the group had already proposed on the poster. This is a pattern that we have seen in many other case studies of group work (e. g., Holland et al 1994, Kurth et al 1994, 1995, Striley & Richmond, 1993). It seemed to be especially salient when the students were working in groups of four.

In the other group, the text and drawings that ended up on the poster seemed to be determined by social default, rather than any subgroup determining standards for what should be included. The dynamics of this group were characterized by conflict between Emma and the two boys, Chet and Donnie. For their part, these boys seemed to be most interested in making things hard for Emma, and in the processes of doing activities rather than the quality of the products. Thus, their poster work was characterized by repetitive arguments about who would do what, and under what circumstances. Emma ended up making the poster almost single-handedly, and in so doing applied her own standards for what counted. She did this with assent from Chet and Donnie, who watched and commented on her work.

During the final phases of instruction, Lisa, Donnie, and other low-status students were largely silent in whole-class discussions and activities which required public nomination. Taking evidence from their work on the posters and later endeavors, their participation patterns seemed to be closely related to their limited understanding and use of many of the mediational means that had become privileged forms.

Similar mixed results appeared in more private conversations involving these students. All of our students participated fully on some occasions, but the more academically successful students were clearly more successful in incorporating scientific uses of mass, volume, and density into their conversations. This differential participation emerged most dramatically as contexts for instruction changed, and students were asked to flexibly apply their understandings to new situations.

When I made the choice to move to a teacher-centered model of instruction (during Phase IV, as students worked to refine their understandings of mass, volume, and density), students who had made the initial connections between the stacking behavior of liquids and the salient property, like Adam and Sandra, were ready. Their understandings of this property (and the others under study) would now be further developed and refined; they had webs of understanding that related their work in Colored Solutions (and Sorting Terms for Mass, Volume, and Density) to the situations they were encountering here.

For students who had not made this connection, however, like Lisa and Donnie, this instructional mode was less likely to be fruitful. Having not made important links to properties as the causal factor in the observed phenomena, these students were less likely to gain further understandings of these concepts during the series of events over the ten days following Colored Solutions. They were not ready to propose statements of comparison, since they had not been able to make clear distinctions between these properties earlier. And, their work in Sorting Terms for Mass, Volume, and Density had been peripheral to the activity of reasoning out the placement of terms that went on in groups of four. This peripheral work may also have been the case as the pairs worked on these terms, since coming from this setting with strong understandings would have supported full participation in such activities in the larger group. While this is not a certainty, I did not see evidence in examining the pairs interactions of substantial negotiation beyond the role each person took in the groups of four.

Mediational Means and Connections

The most successful students, Sandra and Adam, were able to stay within the range, and to capitalize on instructional events to make sense of the concepts of mass, volume, and density as these became the privileged forms. Both of these students began the unit with a pretty typical set of vernacular constructions, and both gave indications early on that they had not yet made important distinctions between some of these properties. As instruction progressed, these students were consistently most involved in the conceptual work of the activities, often taking responsibility (or setting minimum standards) for acceptable work in the groups and pairs. In these roles, they pioneered the use of some of the **mediational means** (like terminology and routines) that helped them to benefit from the instructional sequence. They were most able to pick up on contextual clues about what was important at each stage, developing senses of the importance of connectedness in the ways that they understood the concepts. At several points, Adam and Sandra seemed to push the top of the range (on the graphic) by leading their peers in using privileged forms.

Other moderately successful students, like Chet, Emma, and Amy, at times appeared to have good command of privileged forms. Depending on the task and their roles, they were sometimes moderately successful and at other times not so. Their understandings seemed to be characterized by less consistent use of the mediational means that their more successful peers fully incorporated. For them, **connections** were sometimes obscured by difficulties in understanding what was to be connected, or why. These students seemed to be able to set standards for their own work and the work of others, but sometimes these seemed to be inappropriate for those who fully understood the task and concepts. As a result, their standards were often compromised by personal agendas in the face of their lack of deeper conceptual understanding. Yet, as a testament to the resilience of these students, they often succeeded at tasks by attention to the structural or "school" features, which for them were the bottom line.

By the end of the instructional sequence, a third group of students (which included Lisa and Donnie) had effectively fallen out of the range of accepted actions on the graphic. For them, at some critical junctures, links and connections were not made. For Lisa, I suspect that this trend began with her limited involvement in the conceptual work of figuring out the Colored Solutions and the limited range of mediational means with which she initially chose to work. Her confusion continued into subsequent instruction; without a solid idea of what the solutions did, she was unable to construct networks that fit her experience and the concepts taught in class. As a result, she withdrew from attempting the conceptual work, and instead took on supporting roles that would scaffold her into positions to do passable work on school tasks. But, even this was difficult for her.

Donnie, on the other hand, eventually understood the stacking order patterns, but did not focus on the properties of the solutions as the salient cause. Instead, he believed that techniques like the order in which the liquids were added made a difference. This was a persistent belief with him, and when he was asked to develop an explanation, he did not understand why his ideas were anything but correct. This put him in a compromising position in developing links beyond Colored Solutions. He was not ready for the subsequent direct instruction and focus on terms; to him, these were not a logical next step. As a result, he participated marginally in the conceptual work during this phase, preferring instead to exert social influence in being a full and vocal member of his group. As a result, few fruitful negotiations of meaning took place in his presence, and he too, fell out of the range of privileged forms.

Implications for teaching practice

In the instructional sequence reported here, I (the teacher) was committed to establishing a discourse community in the classroom. In doing so, I wanted students to make their own sense of the tasks by populating them with their own goals, and in so doing to begin with the mediational means with which they were most familiar. As they worked on describing substances, I expected that they would establish standards for what counted as good work, and that they would begin to understand connections among and between their activities and with the activities of scientists. This kind of instruction is quite different from what happens in many science classrooms, in which a transmission mode is predominant or in which students work within tightly prescribed sequences of hands-on activities. To me, the sensemaking and thinking about the full range of structural, practical, and conceptual considerations was more in keeping with my goal of scaffolding both linguistic and conceptual development, together with the full range of mediational means for describing substances in our classroom (and thus the development of a discourse community).

Swales' six criteria for a discourse community, elaborated in Chapter 2, resonate well with what I attempted to promote in teaching students about mass, volume, and density. Again, briefly, these six criteria are:

- a broadly agreed set of *common public goals*.
- *mechanisms of intercommunication* among its members.

- participatory mechanisms are used primarily to provide *information* and *feedback.*
- use and possession of one or more *genres* in the communicative furtherance of its aims.
- some specific *lexis.*
- a threshold level of members with a suitable degree *of relevant content and discoursal expertise.*

When we compare the kinds and nature of interaction that are assumed in a discourse community with the range and nature of interactions in a traditional classroom, we see some marked differences. These differences are most marked in terms of the presence or absence of common public goals, the range of intercommunicative mechanisms, the uses for participatory mechanisms, and the recognition of members with significant expertise in content and discourse. While more traditional classrooms usually involve the use and possession of particular genres to further their aims, and command a specific lexis, it is worth noting here that the range of genres may be more limited, and the lexis may be less a product of discoursal interactions within the classroom, and more closely reflect what is found in textbooks. The overall picture that emerges here is that teaching to support the establishment of a discourse community entails a set of interactions that are vastly richer than those in a traditional classroom.

Establishing a working discourse community that helped students to learn about describing substances involved the teacher in two ongoing processes. The first process, creating and maintaining the discourse community, included establishing reasonable baselines for each of the six criteria listed above. That is to say, the teacher laid out a variety of endeavors for students, and then assisted them as they worked on the tasks, allowing them to apply what they knew from other settings, vernacular language, and familiar genres to their learning. As they worked together and individually, the teacher established participatory mechanisms that supported student ideas and inquiry, rather than the more common and artificial school authority hierarchies. The teacher was also willing to flexibly tailor tasks and teaching avenues to the perceived interests and questions of the students, while keeping overarching goals for conceptual learning in mind. In all of these different activities, the teacher was consciously seeking active engagement by all, primarily by structuring interactions so that each individual could fully engage based on the knowledge and experiences that they initially brought to the setting, and on the accumulated common experiences that they encountered together with their classmates in the instructional tasks.

In addition to working on the functioning of the classroom as a discourse community, the teacher incorporated the second process, that of constructing new mediational means and privileging more scientific forms over others. It was this process of constructing and privileging that ensured conceptual coherence and growth along the continuum towards the scientific canon. Considerable care was taken in this process to ensure that realistic standards were established by students and the teacher, since it was this process of privileging that most often caused some students to disengage from the activities, based on their lack of understanding of the privileged forms. Balancing participation against privileging became the teacher's constant focus as the instruction unfolded.

Privileging in this classroom was an ongoing process that involved the actions of the teacher and the students. It occurred in three major forms, which included *explicit teaching*, *coaching* as a peer, and *crafting rules for activity* to ensure a particular approach or product. In the first, the teacher overtly privileged one form of language, goal, or action over another, and explained why he did so. For instance, in Colored Solutions work, I privileged certain kinds of data (in the form of 'liquid A over liquid B') in the whole-class setting, as students nominated interesting phenomena that they had observed. This had the effect of limiting the kind of data that students could nominate. The danger in this kind of privileging lay in considering how many students might be excluded by this kind of restriction on claims. I was fairly confident, after having watched many of the students work with the solutions, that few would be excluded at this point. In accepting claims, I affirmed each claimant's work. This affirmation worked to keep them engaged, and willing to continue to work on the problem. At key points, privileging also helped students to be ready for direct instruction in the scientific canon, in this case mass, volume, and density. Instances of students privileging some forms of language or action over others can be seen in their poster presentations, and in discussions between group members when they disagreed about how to proceed.

Coaching as a peer occurred mainly between students, but sometimes involved the teacher as well. Quite often, this kind of privileging began with students' questions about how to resolve particular conflicts or disagreements, and other students' suggestions often provided the impetus for settling on a preferred or more efficient way of doing the task. This kind of privileging was observed frequently as students helped each other figure out how to make the liquids stack, or as they asked the teacher for help in doing so. In the learning community environment, the teacher tried to give feedback rather than answers, and was seen more as a valued community member rather than an external authority. His coaching and the coaching from other students often took the form of laying out options for discussion, or questioning what the students' motives were for doing particular things. Once the issues were raised, ensuing discussion often led to selection or design of a preferred way of accomplishing the task.

Crafting the rules for activity to ensure a particular approach was almost entirely the teacher's domain, and was one of the principal considerations in the ongoing modification of instruction on the basis of students' work. This is kind of like teaching a bunch of kids the rules for basketball and sending them out to play. Their play highlights their weaknesses and strengths, and as the teacher or other students coach and referee, the individuals and teams adjust and eventually play better ball. For instance, when the students reported their initial stacks of Colored Solutions, many conflicting claims were made about which stacks were possible and which were not. Instead of deciding which of these were correct and telling the students these answers, my (teacher's) choice was to engage students in the kind of validation process common among scientists who get conflicting data, i.e. to retest each set of conflicting claims. In this way, students' efforts were focused on what I regarded as productive investigations into the behavior of the solutions, and they were encouraged and enabled to participate fully. While the teacher's word still had a lot to do with what happened, he more commonly set the ground rules and then stepped back to see what happened.

One feature of this kind of privileging is the relative lack of direct involvement of the teacher in the actual investigation or activity. Crafting the rules in this way always involves a certain amount of guesswork amidst all of the well-laid plans, and intimate involvement with the students' activities along the way is essential to acheive satisfactory gains. Still, sharing explicitly the features of the task, including limitations, is important in developing ownership of the task among students. Said another way, the students must be able to see the activity as a part of the broadly shared set of public goals in order to own and make sense of it.

These three forms of privileging lay out some of the ways that teachers who are committed to discourse-based instruction can scaffold students into more scientific understandings. They involve a range of roles for the teacher, some of which are atypical in more traditional classrooms. Essentially, when a teacher commits to establishing a discourse community, he or she must be willing to step from the center of attention and authority, and let the students and their ideas take the spotlight. Once this is done initially, the process of careful monitoring begins as the teacher works to balance the two processes elaborated above.

This view of teaching essentially recasts what many teachers regard as their biggest challenges: teaching content and motivating students to learn. This study suggests that reformulating these two issues as a single challenge, that of constituting a classroom discourse community around content-based studies, may open up a number of avenues for thinking about how to meet these challenges. When motivation is considered the problem, extrinsic solutions are suggested, but it is intrinsic changes we seek. In accepting the discourse-based formulation, teachers encourage students to bring their own approaches to bear on a problem as they are engaged deeply in it, and then scaffolded as they attempt to reason through the problem using new tools and ideas. This formulation validates students' intrinsic values, and works with them to effect change in understanding of the content. It demands much of teachers and students, but holds considerable promise, as well.

Research-related connections and issues:

This study builds on our understanding of middle school science instruction by providing glimpses of the mediated actions of students and teacher that fit together into a more coherent picture of the whole sequence. A classroom can be seen as a collection of individuals that sometimes act as a whole, or it may be viewed as a collective within which individuals act. These two points of view, represented here by the stories of individuals and the story of the collective, directly shaped the decision to look across settings within the classroom in order to characterize understanding and related action for individuals, while tracing the development of collective understandings.

The essential characteristic of this analysis is a belief that neither the individual stories nor the collective one should be told out of the context of the other. When these stories are told together, the result is a much richer representation of the complex interactional system of the classroom. Yet, the story told here is far from complete. Interactions in the classroom, like many other human endeavors, are often rapid-fire, emotionally laden, and themselves represent "first drafts" of formative thought. By nature of our role as observers, much of our "take" on these interactions are from appearances.

We cannot know what goes on in the minds of our students, and whether we have taken what they intended. All we can do to ensure some validity is to push for certainty in checking a variety of data sources, rechecking with other researchers, and looking for the "ring of truth" in our analyses.

The story that is reported here is excerpted from a much larger one that is complex in nature. Selecting excerpts is, at one level, making choices about what to show and what to omit. While much time and energy was devoted to the selection of excerpts, the researcher acknowledges that the selected excerpts may not represent the larger story accurately or completely. My hope is that the representation is close enough to give the reader confidence in my "take" on the events recorded here. In all instances, my own best sense of what was a true representation guided these decisions.

The findings of this study extend beyond those which are reported above, to include some important considerations related to the design and conduct of the study itself. In effect, this study was all about developing mediational means for the activities of analyzing and improving science teaching. As such, this study attempted to create a synthesis of key ideas from the conceptual change and sociolinguistic research traditions. Each of these traditions includes some powerful mediational means for analyzing classroom learning and teaching, but each also lacks some tools that are necessary in understanding what goes on in the rich and fast-paced interactions of a classroom. The conceptual change approach captures quite well the content-related issues of what students learn, but lacks sufficient attention to the contexts of learning which can often determine just what is learned and how. The sociolinguistic approach, on the other hand, characterizes the contexts of learning well in focusing on the social aspects of teaching and learning. What it lacks, though, is a set of tools for the detailed analysis of the science part of the language and activities of the classroom. In building on these two traditions, this study was unique in creating tools that draw on both traditions and create a more powerful synthesis.

In Chapters 1 and 3, I propose some of the tools that helped me to examine this classroom with both traditions in mind. Key among these tools is Figure 1, which illustrates how I have thought about discourse-based instruction that builds scientific understanding. Keeping track of the range of accepted or privileged forms, and where students position themselves by the roles they take in classroom interactions can tell us much about what is being learned and by whom. This graphic gives a simple, overarching framework for instruction that can assist teachers in selecting and designing activities that build understanding on conceptual and linguistic grounds. It illustrates how the process of privileging by teachers and students can affect individual student outcomes, as well as the emergence of new and more powerful mediational means in the classroom community. It can also be useful to researchers examining teaching and learning, as a heuristic for thinking about the relative goals and positions of students in instructional settings.

A second tool, the TOPE framework (of techniques, observations, patterns, and explanations), lays out in simple terms an alternative to the "scientific method" that is common in American classrooms. These four activities of scientists essentially direct students' attention to some of the different aspects of scientific work. In doing so, it also suggests language that is likely to engage students in authentic work that includes their own ideas. The students in this study naturally understood that techniques, in order to be most valuable, had to result in recordable observations, for instance. If they didn't, they were noted as the negative case (what not to do), and not repeated. Observations were only valued when they were recorded, and students quickly learned that the more precise and detailed observations gave them more ammunition when disagreements arose. These examples illuminate some of the value of this framework in discourse-based instruction. And, they further suggest that carefully crafted, simple linguistic touchstones like these can give students the overarching organizational pictures they need to be able to build webs of understanding of the scientific enterprise.

The third key tool that emerged from this study was the four dimensions of discourse used to examine the interactions in this classroom. These dimensions were selected on the basis of their individual foci, as well as on the unified whole that they make when taken together. Building on Wertsch's idea of mediated action, these dimensions allow examination of the sense that students make of tasks and activities in school science, the intellectual and physical tools they bring to bear on these activities, the standards that they establish and modify that affect their claims and results, and the connectedness of their actions. Comparison of these dimensions with Swales' criteria for discourse communities showed that these dimensions reduce some of the detail in language use that were Swales' focus, but give a broader picture of the scientific nature of the students' work. These dimensions provide a rich set of approaches to the problem of characterizing mediated action in the classroom.

With the development of these tools, I have laid the groundwork for further study that builds on the synthesis of the conceptual change and sociolinguistic research traditions. This study, for instance, foregrounded the sociolinguistic approach, which meshed well with the commitments of the teacher. I wonder about crafting other approaches that foreground the conceptual change aspects, and that might give more vibrant pictures of other kinds of classrooms, particularly those in which higher cognitive demands are the rule. In each case, I believe that the approach must involve a re-synthesis of these two approaches to arrive at a powerful and appropriate set of analytical tools. This means that developing new tools, or mediational means, will help us to learn more about teaching and learning situations.

This investigation also raises further questions about teaching and learning about mass, volume, and density. As mentioned previously, these concepts seem dry and uninteresting to many students, and the instructional sequence examined here gave some clues about why this is so. Where these students are at a given time in terms of the range of privileged ideas, concepts, and language has a lot to do with how ready are for this kind of instruction. When they are ready, the instruction makes sense as a logical extension of the privileged forms that is within grasp. When they are not ready, it may bewilder or confuse students who have not developed the supporting mediational means to understand it. Given this dynamic, and the continuing problems that students like Lisa, Kyle, and Donnie face, further explorations of systematic scaffolding along the instructional sequence seem warranted. Are there ways that we can better support students who come to the instructional setting with reduced language or mathematics skills, low self-esteem, or a fear of science? In our observations, we noted specific points at which some students were excluded by their group, or removed themselves from the most fruitful interactions in an effort to save face. We also noticed that some students have difficulty maintaining interest in work that is hard and requires thought, largely because of the available alternative, which is purely social interaction with classmates. Questions about how best to scaffold these students along the learning continuum seem to have much to do with establishing a positive working culture in which these students are full members. At present, we haven't fully understood the problems these students face. While this work adds some to our understanding, a wide range of research efforts is needed to more effectively characterize the challenges, and suggest possible solutions.

Another field of questioning has most to do with the nature of the concepts under consideration here. For instance, what are some the best combinations of representations of these concepts that work to help students develop rich understandings of them? In this study, we worked primarily with density comparisons by floating and sinking first, and then broadened our study to other areas. Are there more fruitful ways to approach these concepts? How can we ensure deep engagement by all students in concepts that seem to be so far removed from their daily lives?

In the final analysis, it is the traditionally marginalized students by which we should judge the success or failure of any curricular program or teaching approach. If we can find ways to richly involve these students and move them towards the accepted canonical understandings within the heterogeneous classroom, then we can call our efforts a success. Today, opinions vary on how well we are doing at teaching science. All agree, however, that we do not serve a significant number of students well. It was questions about these poorly served students that drove this study. We have learned something about them here, and something about us as well. Yet, we have much to learn as we continue to face the challenge of 'science for all'.

APPENDIX A

INSTRUCTIONAL MATERIALS

Journal Writing: Patterns and Explanations in Colored Solutions

1. What patterns did you find in the ways that the liquids acted? What explanations can you give for them acting the way they did?

(Now look back at your data from when you and your partner made stacks in vials and straws.)

2. Does all of your data match the pattern you wrote about above? Does all of it have to match? What pattern made sense to you?

3. Do you have any questions about the colored solutions that you are wondering about?

LEARNING LIKE A SCIENTIST ABOUT COLORED SOLUTIONS

By now, you probably know quite a bit about colored solutions and how they act in different situations. Can you predict what will happen if you drop one colored solution into another? Can you predict which stacks are possible to make and which are impossible? Can you explain some techniques for making good stacks?

You learned about colored solutions in the way that scientists learn when they are doing research: You developed *techniques* for studying how colored solutions mix and stack; you did experiments and made *observations;* you found *patterns* in your observations; and you tried to figure out *explanations* for the patterns that you found. By comparing results, testing, checking, and doing experiments over, you were able to get results that *everyone could agree* about.

If you think about how you studied colored solutions and learned about them, you may realize that there are some important differences between the way that you learned about colored solutions and the way that you usually learn in school. For example, you learned without anyone telling you the answers, you learned by sometimes being wrong, you learned from arguments, and you didn't really finish learning. Let's talk about these special ways of learning from research.

Learning without telling. In school you normally learn by reading about new ideas or by your teacher explaining them to you. Scientists who are doing research can't learn that way, though. If no one knows about something, then there is no one to tell you! So when they have to, scientists learn instead by doing research: by developing techniques, making observations, looking for patterns, and developing observations. Doing research is a lot of work, but it is the only way to learn when there is no one to tell you the answers.

Think about what you have learned about colored solutions. There was nothing to read about them, so you didn't learn about them that way. Can you think of anything that you learned because your teacher told you? What did you learn from your own experiments? What did you learn from experiments done by other members of your class?

Learning by being wrong. When you are learning in school, you normally try to avoid being wrong. You try not to make mistakes in your work because you don't want a bad grade. If you give a wrong answer in class and the teacher corrects you, you may feel embarrassed.

Scientists like to be right, too, but they know that when they are working on a difficult problem, they can only find good answers by trying out dozens of ideas that don't work. When they are doing research, even the best scientists are wrong more often than they are right! Scientists often have to try a lot of different techniques that don't work before they find one that does. They often find that their observations or data are not as good as they had hoped. Scientists keep searching for new techniques and observations, though, because they know that they need to try a lot of different techniques before they can be sure of their results.

Scientists even have a special name (hypotheses) for ideas about patterns and explanations that might be right, but that they aren't sure about. Scientists have learned that even incorrect hypotheses are often valuable because they lead to new observations and better ideas. Scientists who are good at coming up with interesting hypotheses and ways to test them are important valuable members of the scientific community whether their hypotheses turn out to be correct or not!

Think about your learning about colored solutions. Can you think of a time that you tried a technique that didn't work? What about a time that you thought you saw something but later changed your mind? Do you think that there was anyone in the class who was never wrong? Can you think of a time that an incorrect idea led to a discussion or some experiments that helped you learn more about the colored solutions? When you are trying to learn about something by doing research, ideas that you later change are not something to feel bad about. Those "incorrect" ideas are an important and valuable part of learning.

Learning from arguments. Normally you try to avoid arguments in school. If you get in an argument and get angry, you will probably feel bad, and you are likely to get in trouble. Scientists don't like arguments that leave people upset and angry, either. They think of those as "bad" arguments.

On the other hand, scientists know that *good* arguments are an important part of learning by doing research. In order to find patterns and explanations that they can all agree about, they know that they will have to consider many different ideas in order to find some that work. Scientists say that they have had a *good* discussion or a *good* argument when it helps them to learn and improve their ideas. For the scientists, learning is as important as winning or losing.

Can you think of a time that the class had a good discussion or argument about colored solutions? How did it help you or other members of the class learn?

Learning without finishing. Often in school when you finish a chapter or a section of a book it is done. You don't have any more questions, you stop thinking about it, and you go on to the next chapter. Scientists doing research, though, hardly ever finish learning. Even when a project ends, they almost always have ideas that they still aren't sure about or questions that they would still like to answer. Scientists know that good questions (like good hypotheses) are important and valuable.

How about you? Can you think of any new experiments that you would like to try with colored solutions? How about explanations; can you explain why the solutions act the way they do or how they were made? What questions would you like to answer? Maybe some of those questions can help the class to learn more about colored solutions or other substances.

HOW DO SCIENTISTS BUILD NEW KNOWLEDGE ABOUT SUBSTANCES?

Developing and learning <u>techniques</u>

- trying to figure out how to make interesting things happen with substances, like stacking different liquids or dissolving something fast or slowly.

<u>Observing</u> carefully and recording what they see

- using one's senses (and instruments) to notice details as well as the obvious things when you compare substances and changes in them. Making careful notes and drawings so that you can tell or show others what you observe.

Finding <u>patterns</u>

- looking for patterns in the data from your observations. Sometimes, testing your ideas about patterns to see if they <u>always</u> work is important.

Developing <u>explanations</u> about substances

- explaining the patterns you found, and matching patterns with reasons why they happen. Often, scientists develop ideas to explain something, and then later change their explanations when they see new patterns. So, your ideas can change, and you can write new explanations to replace old ones.

COLORED SOLUTIONS

Colored solutions are substances (actually mixtures of substances) that are very interesting if you observe them carefully and watch what happens as you mix them. Your will have a chance to study these solutions like scientists investigating new and unknown substances. You will have to develop **techniques** for doing experiments with the solutions, make and record **observations** from your experiments, look for **patterns** in your observations, and try to **explain** why they act as they do.

Later, you will discuss what you have learned, first with your group, then with the whole class. Our goal is to find some observations, patterns, and explanations that everyone (or almost everyone) in the class can agree about. You will have to figure these out for yourselves, though. No one is going to tell you the answers!

Let's start by talking about techniques. When you mix colored solutions together, you often end up with a muddy brown mixture. If you work very carefully, though, you can figure out techniques for observing what happens to the solutions *before* they mix together. Two good ways to start studying colored solutions are *dropping* one solution into another, and *making stacks* in straws or in vials. There are lots of other techniques for studying colored solutions, too. Maybe you can think of some of them when you start working. So now it's time to start studying colored solutions. Here are some suggestions to get you started:

ideas about what to do:

•With a straw:

-First, figure out how to make a liquid stay in the straw using your finger over the end. Then try to stack two colors in the straw. Show your partner what happens. If they mix, try reversing the order of the same two colors. Remember to write down (in your journal) what you try, and what happens as you go.

•With a dropper:

-Pour some of one solution into a vial. Now, try to carefully observe what happens when you drop another colored solution into it. Show your partner. Try this again with the same solution in the vial, and the third color in the dropper. Write down what you try and what happens in your journal.

<u>A note about recording techniques and observations:</u> One way to tell whether you are recording as a scientist might is to pretend that you are writing instructions (techniques) and descriptions of what you see (observations) for a friend that is in another class. As you write, ask yourself if they would know what is going on just by reading your notes. If not, you may want to add notes to make your techniques and observations more clear and complete.

Colored solutions experiments and journal

1. Start by having two members of your group studying the colored solutions in straws and two members working with droppers. Take notes in your journal about what you find. Use the special journal format.

2. Compare your results and look for patterns that are the same for the two kinds of experiments.

3. Study the colored solutions in other ways. Use the Question Cards for suggestions. Take notes about what you observe and about your theories in your journal.

You will need to communicate with each other while you are working in your groups. After you are done, your groups will need to communicate with all the other groups about what you have found. You can do this by making a poster to present to the class.

Making a poster to communicate

1. Make a plan for your poster. It should be a page in one of your journals showing:
- what ideas and results you are going to present to the class,
- how you will arrange them on your poster.

In addition to words, you might use drawings, charts, tables, or graphs.

2. Show the plan to your teacher and discuss it, then get poster board and markers and make your poster.

3. Two members of your group (will present the poster to the class and discuss your results. (The other two members will present the next poster.)

Whatever you write or draw on your poster needs to be big enough and clear enough for the whole class to understand it. When you make your poster and discuss it with the class, these things are especially important:

- showing that you have observed and described the solutions carefully,
- describing patterns that you see in your results and your theories about how to explain those patterns,
- communicating clearly about your observations and your ideas.

Your Poster Should Include:

1. Both words and illustrations.
2. At least one idea (or special technique or observation) from each person in your group.
3. Something about your techniques. For example:
   - What special techniques or ways of being careful helped you to make unusual stacks or observe interesting things?
   - What are some of the special techniques that you tried that didn't work?
4. Something about your observations. For example:
   - What stacks of two or three solutions did the members of your group make?
   - What are some observations that the members of your group made about floating and sinking or stacks that you are sure are possible or impossible?
5. Your ideas about patterns and explanations. For example:
   - Dropping. Can you list all the possible combinations of dropping one color into another? Is there a pattern to which ones make layers and which ones just mix?
   - Stacks in straws. Can you list all the possible stacks of two colors? Can you make any stacks with three colors? Is there a pattern?
   - Connections. Are there any connections between the patterns for the dropping experiments and the patterns for the stacking experiments?
   - Explanations. What makes each of the different liquids act the way it does?

APPENDIX B

INTERVIEW AND TEST DATA

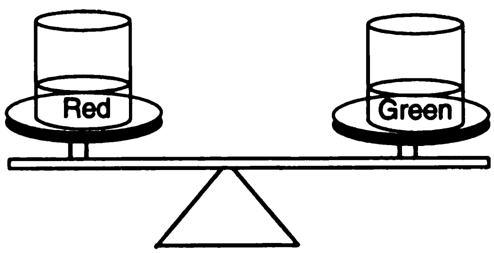
TEST ON COLORED SOLUTIONS, MASS, VOLUME, AND DENSITY

1. Predict whether each colored solution will float or sink in the other solutions below.
   If you disagree with the class prediction, put the class prediction and why you disagree.
   When you drop red solution into clear, the red will __________.
   When you drop green solution into clear, the green will ____________.
   When you drop red solution into green, the red will ____________.

2. Predict whether each of the stacks below is possible or impossible. Write "yes" if the stack is possible and "no" if it is impossible.

			R	R	G
C	R	G	G	C	C
G	G	R	C	G	R
_______	______	_______	_______	_______	________

3. Predict which side will be heavier for each of the balances below and explain your answer.



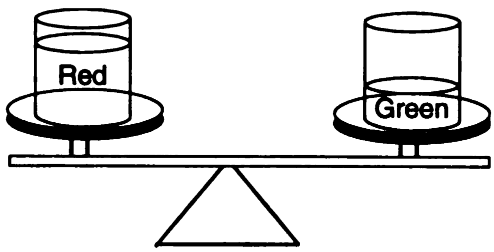
100ml

100ml

Which side will be heavier? ___________ Why?_____________________________

____

____



100ml

200ml

Which side will be heavier? ___________ Why?_____________________________

____

____

4. Fill in the blanks below with the words **mass, volume,** or **density.**

Stones sink in water because they have a greater _________________.

Heavier objects have a greater _________________.

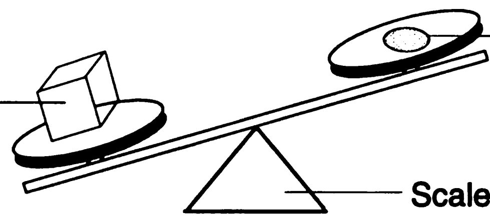
Larger objects have a greater _________________.

We use a balance to measure _________________.

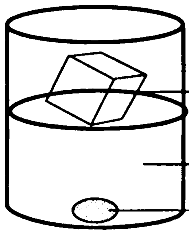
Measuring cups are good for measuring ___________________.

"Weight for the same amount or volume" is _________________.

_________________ does not depend on the amount of a substance. It is the same for a large amount or a small amount of a substance (like green solution).



5.



Look at the two diagrams above, then write three statements comparing the wooden block and the raisin with regard to mass, volume, and density.

Mass:____

Volume:____

Density:____

6. Use the words **mass** and **volume** in your answers to these questions:

What do we mean when we say that a <u>small chocolate bar</u> has "more candy" than a <u>marshmallow</u>?____________________________________

What do we mean when we say that a marshmallow is "bigger" than a small chocolate bar? ____

____

____

7. Use the space below to describe an experiment that will tell me whether alcohol is more or less dense than red colored solution. You can use any equipment that you would like. Draw a picture of your experiment if you would like. If you do, be sure to explain your picture well enough so that other people can understand it. Explain the techniques that you would use and the observations that would help you decide whether alcohol is denser.

My experiment to find the density of alcohol.

8 Which is heavier, a ton of gold or a ton of water?____________________

9. What questions do you still have about what we have studied?________________

10. Demonstration: Use the spaces below to write your responses to the demonstration done in class. You should write one statement about **mass**, one statement about **volume**, and one statement about **density**.

Mass:____________________

Volume:____________________

Density:____________________

GROUP 1 POSTER PLANNING

1 Adam: What are we supposed to do?
2 Nick: Man, I noticed one thing. Red's is never at the bottom.
3 Adam: [taps on mike to test it] What?
4 Nick: Red's never on the bottom. I think it's more buoyant than anything.
5 Lisa: That's what we're supposed to write down. [Adam points something out in Nick's journal.]
6 Nick: That's on stacks we couldn't make!
7 Adam: I knew that. I knew that. [Sandra laughs.]
8 Lisa: Nick, she wants to see you. [Adam comments on how Nick is not supposed to be here.]
9 Nick: I'm the censored person who's not supposed to be here.
10 Sandra: Alright.
11 Nick: Alright. I say red is a more buoyant liquid than anything.
12 Adam: More buoyant? Let me turn back. [flips back in his journal] [Both boys looking at "Whole Class Data" in journals]
13 Nick: It has less buoyance. 'Cause look at the overall thing..
14 Adam: There's stacks we made with droppers, red's always on top.
15 Nick: Yep.
16 Adam: And...
17 Nick: Nuh, ugh. There's one we made with... clear... and red. But, we didn't use red. So you're right. All the one's we used with red...that we used. [he shows his journal to Adam]
18 Adam: Yeah. Not over here in straws. We made one with red in the middle.
19 Sandra: Green is mostly always at the bottom. [not heard]
20 Nick: Yeah, so it's mostly on top.
21 Adam: Red's almost always on top. (to Sandra) Write it down.
22 Nick: And G's almost always... G's always at the bottom.
23 Sandra: (to Adam) I'm smart. I can figure it out.
24 Nick: Except on this...When you're mixing or trying to make a stack and you're using green, green's always on the bottom.
25 Lisa: (to Sandra) Techniques...why are you writing...
26 Sandra: (to Lisa) I don't know.
27 Adam: I don't know though. See the thing is, here's another example of where red's on top too.
28 Nick: Yeah, but um... You have a good point there.
29 Sandra: Did you say at the top?
30 Lisa: Patterns. No Sandra!! Patterns and explanations.
31 Sandra: I'll write it at the top.
32 Adam: The thing is look... Most of the time the stacks we couldn't make, red's on the bottom. But twice it's on the top. Most... oh, look at this, look at this! Clear's almost... on the stacks we couldn't make clear's almost...
33 Lisa: [interrupts Adam] And green's at the bottom. [they ignore her]
34 Sandra: [writing] Red's almost always...
35 Nick: The one's that we couldn't make with straws are always... the majority of them are green on top.

36 Lisa: (to Sandra) No, it's supposed to be "red is almost always" [Sandra had written "always almost." She fixes it.]
37 Adam: And look at this, all the one's that green are in, it's at the bottom.
38 Nick: I know. I noticed that.
39 Sandra: At the top?
40 Adam: (to Sandra) Put, green's almost always at the bottom.
41 Nick: And clear and red are usually in the middle or the top.
42 Sandra: (to Nick) You write! [hands him paper] You're goin' too fast.
43 Nick: Alright... [he starts to write as Adam and Lisa talk] [Lisa goes to say something, opens her mouth and Adam makes fun of her. Lisa giggles.]
44 Adam: Ah, spit it out.
45 Lisa: Green is almost always at the bottom, isn't it?
46 Adam: What is?
47 Lisa: Green is always at the top.
48 Adam: No, green is almost always at the bottom.
49 Lisa: Bottom... Oh, yeah. [Sandra has been looking at notes]
50 Sandra: On this um... [They're too busy listening to each other to listen to Sandra]
51 Lisa: Red is on the top, and clear is in the middle. It goes red, white and clear.
52 MR. V COMES OVER, LOOKS AT PAPER, AND TELLS NATE TO CHANGE HIS HEADING TO "PATTERNS"
53 Lisa: Wait, I mean... [Adam is ignoring her: she stops talking and asks Mr. V if she can go sharpen her pencil. He says yes, and she leaves. Mr. V leaves.]
54 Sandra: You know right here...
55 Adam: Let's put it this way... Red..
56 Sandra: Five out of seven times green is at the bottom.
57 Adam: Okay. (to Nick) Five out of seven times green is at the bottom?
58 Sandra: If you're counting the stacks you made.
59 Adam: Okay.
60 Nick: Five out of seven times...
61 Adam: Green's at the bottom.
62 Sandra: And red's at the top.
63 Lisa: (to Nick) Let me write.
64 Sandra: (to Lisa) Okay, 5 out of 7 times green is at the bottom.
65 Adam: (to Sandra) Look at this, look at this...[no one listens: so to himself] Mix, mix, mix, mix, mix, mix....
66 Sandra: (to Lisa) Do you want me to write it? [Lisa asks her to say it again, and she'll write it.]
67 Nick: (to Adam) We've got to average this up. We've got to add up all the times that red is on the top... and we've got to average it.
68 Adam: No we don't. We don't need to find what percent. [mocks] "Well, sixteen percent of the time..." [Sandra is still telling Lisa that sentence for her to write down.]
69 Nick: (pause) Alright. We had nine different things down here, right? And on mine...
70 Sandra: Let me find mine. Oh, here it is. [All but Lisa (who is writing) check journals.]

71 Nick: One, two, three. Three times. Let's see how many times I got... [All but Lisa looking in their own journals from 1-26]
72 Sandra: (to herself) Red...
73 Lisa: (to Nick) And... what?... the clear?
74 Sandra: (to herself) Red stack... red stack... [counting on fingers]
75 Lisa: Nick, listen up!!!
76 Nick: (to Lisa) Just a sec! [Rex from another group mocks Lisa, and she briefly talks to him.]
77 Nick: [looking at journal from 1-26] Alright, there's one, two, three, four, five, six, seven, eight. There's 8 times we used red in this.
78 Sandra: Are you counting the straws too?
79 Nick: Yeah. [looking in journal] One... two, three... four, five, six. Six out of those eight times red is on top.
80 MR. V MAKES ANNOUNCEMENT ON TIME LEFT
81 Adam: [looking at whole class data] I only had seven. [He looks on Nick's journal.] [Adam puts head down, and then turns journal back to 1-26]
82 Lisa: Why are we..[?]..?
83 Sandra: (to Lisa) Well, we have to hurry.
84 Lisa: Alex, you're a nerd.
85 Sandra: (to Lisa) Just come on, don't fight. (to Nick) Now, what'd you say?
86 Nick: I said, out of my notes there were eight times we used red in the colored solutions, and 6 out of the 8 times red is on top.
87 Sandra: Okay, go ahead, write whatever he said.
88 Adam: We've got enough of that, now we need some... wait a minute; don't we have enough patterns and explanations, now we need some observations and techniques.
89 Sandra: I got seven.
90 Nick: I have a technique. On how to mix, and how to get something on top.
91 Adam: (softly) Oh, boy.
92 Lisa: Wait, we haven't wrote clear yet. It's always in the middle.
93 Nick: Clear. Well, let's look here. [looks in journal] Clear usually it mixes.
94 Sandra: (to Lisa) Clear usually mixes. (to group) Right? [looks in journal] Well, clear stacks on top green on mine.
95 Nick: Well, let's look on this. Let's look on the class data.
96 Adam: I've got red eight times. [he's been looking at his journal for a while].
97 Lisa: No, clear's in the middle. I say clear is in the middle.
98 Adam: Well, pretty much that's what it is: red on top, clear in the middle, and green on the bottom.
99 Nick: [looking at journal from 1-26] Nine different tests. Nine different tests, and out of those... one, two, three, four... [Sandra looking in her journal]
100 Lisa: (to Adam) Clear is in the middle!
101 Adam: (to Lisa) I know, that's what I said.
102 Nick: ...five, six, seven. We had nine different tests, and in seven of those tests... clear mixed. [He's looking at his data wrong-- 7 times clear was used out of 9, but one time it stacked- #8]

103 Adam: (to Sandra) Just put, just put red is the most buoyant and green sinks.
104 Lisa: Listen, listen...
105 Sandra: (arms up to both Adam and Nick) Tell her what to write, okay!!
106 Adam: (to Sandra) That's right you don't have it anymore.
107 Nick: (to Lisa) Red is the most buoyant. [Adam and Sandra look at Lisa]
108 Adam: Put that. [Lisa puts hand over eyes]
109 Sandra: (to Lisa) Write it.
110 Lisa: Somebody else write!

GROUP 1 POSTTEST RESPONSES

Question 2
What happens to the volume of water when it freezes?
A. It stays the same.
B. It increases.
C. It decreases.
D. I don't know.
If you think the volume changes, why does this happen?

Student	Choice circled	Different from pretest? (+,=,-)	Reasons given
Adam	C. It decreases.	Yes (-)	When something gets cold, the volume decreases. When it gets hot, it increases.
Lisa	C. It decreases.	Yes (-)	The volume changes because at first the water is a liquid then it turns in a solid and stays in one spot
Kyle	B. It increases.	Yes (+)	because when the water freese it becomes more packed together.
Sandra	A. It stays the same.	Yes (-)	*No reason given.*

Question 10C
Why do you think that helium balloons rise in air?

Student	Response
Adam	Because the pressure outside the balloon is greater than the pressure outside the balloon.
Lisa	I think they rise in the air because there is so much helium in the balloon.
Kyle	because the moucles move fast and rise the balloon.
Sandra	*No answer given.*

GROUP 2 POSTTEST RESPONSES

Question 2

What happens to the volume of water when it freezes?

A. It stays the same.
B. It increases.
C. It decreases.
D. I don't know.

If you think the volume changes, why does this happen?

Student	Choice circled	Different from pretest?	Reasons given
Amy	A. It stays the same.	No	*No reason given.*
Ella	C. It decreases.	Yes (-)	Because the molecules move closer together.
Donnie	B. It increases.	No	*No reason given.*
Chet	A. It stays the same.	Yes (-)	*No reason given.*

Question 10C

Why do you think that helium balloons rise in air?

Student	Response
Amy	because it thris to fill the space and raises to doe so.
Ella	The gas is expanding.
Donnie	*No answer given.*
Chet	Helium balloons rise in the air because helium is a much lighter

GROUP 1 PRETEST RESPONSES

Question 2

What happens to the volume of water when it freezes?

A. It stays the same.
B. It increases.
C. It decreases.
D. I don't know.

If you think the volume changes, why does this happen?

Student	Choice circled	Reasons given
Adam	B. It increases.	Because needs more room to contain its consistansy.
Lisa	B. It increases.	Because ice is thicker and its kind of like a pudding.
Kyle	C. It decreases.	it changes because the cold air pushes the water down
Sandra	B. It increases.	The water freezes up and gets heavier.

Question 10C

Why do you think that helium balloons rise in air?

Student	Response
Adam	Because helium is lighter than air.
Lisa	because they have so much preasure and air in them that they just flow up and take off
Kyle	because it is to thin for the gravity
Sandra	They have nothing to weigh them down and helium is lighter than air.

GROUP 2 PRETEST RESPONSES

Question 2

What happens to the volume of water when it freezes?

A. It stays the same.
B. It increases.
C. It decreases.
D. I don't know.

If you think the volume changes, why does this happen?

Student	Choice circled	Reasons given
Amy	A. It stays the same.	*No reason given.*
Ella	B. It increases.	the air molecules bunch together + make the liquid rise
Donnie	B. It increases.	It will get realy hard.
Chet	C. It decreases.	*No reason given.*

Question 10C

Why do you think that helium balloons rise in air?

Student	Response
Amy	beacuse their lighter then the air
Ella	Because helium is lighter than air.
Donnie	Helium is push the balloons up.
Chet	*No answer given.*

LIST OF REFERENCES

REFERENCES

American Association for the Advancement of Science (1989). Science for all Americans: A project 2061 report on literacy goals in science, mathematics and technology. Washington, D.C.: American Association for the Advancement of Science.

American Association for the Advancement of Science (1993). Benchmarks for science literacy. New York: Oxford University Press.

Anderson, C.W., Roth, K.J., Hollon, R.E., & Blakeslee, T.D. (1987). The power cell: Teachers' guide to respiration. Institute for Research on Teaching Occasional Paper 115. East Lansing: Michigan State University.

Anderson, C.W. & Smith, E.L.(1983). Transparencies on light: Teacher's manual. Institute for Research on Teaching Research Series No. 130. East Lansing: Michigan State University.

Anderson, C.W. & Smith, E.L.(1983 April). Teacher behavior associated with conceptual learning in science. Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada.

Anderson, R.C. (1977). The notion of chemata and the educational enterprise: General discussion of the conference. In Anderson, R.C., Spiro, R.J., & Montague, W.E. (Eds), Schooling and the Acquisition of Knowledge. Hillsdale, NJ: Lawrence Erlbaum.

Bakhtin, M. (1981). The dialogic imagination. Austin, TX: University of Texas Press.

Ball, D.L. (1990). Halves, pieces, and twoths: Constructing representational contexts in teaching fractions. National Center for Research on Teacher Education Craft Paper 90-2.. East Lansing: Michigan State University.

Ball, D.L. (1993). With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics. Elementary School Journal, 93, 373-397.

Ball, D.L. (1992). Implementing the NCTM Standards: Hopes and hurdles. National Center for Research on Teacher Learning Issue Paper 92-2. East Lansing: Michigan State University.

Ballenger, C. (1994). Argumentation in a Haitian bilingual classroom. Unpublished report. Cambridge, MA: TERC.

Barnes, D. (1990). Language in the secondary classroom. In Language, the learner and the school.(4th ed.). Portsmouth, NH: Boynton/Cook.

Benson, D.L., Wittrock, M.C., & Baur, M.E. (1993). Students' preconceptions of the nature of gases. Journal of Research in Science Teaching 30(1), 587-597.

Berkheimer, G.D., Anderson, C.W., & Blakeslee, T.D. (1988a). Matter and molecules teacher's guide: Activity book. Institute for Research on Teaching Occasional Paper No. 122. East Lansing: Michigan State University.

Berkheimer, G.D., Anderson, C.W., & Blakeslee, T.D. (1988b). Matter and molecules teacher's guide: Science book©. Institute for Research on Teaching Occasional Paper No. 121. East Lansing: Michigan State University.

Bishop, B.A., Roth, K.J., & Anderson, C.W. (1986). Respiration and photosynthesis: A teaching module. Institute for Research on Teaching Occasional Paper No. 90. East Lansing: Michigan State University.

Blakeslee, T.D., Anderson, C.W., & Smith, E.L. (1987). Teaching strategies associated with conceptual change learning in science. Journal of Research in Science Teaching 30(2), 111-126.

Brehm, S., Anderson, C.W., & DuBay, S. (1986). Ecology: A teaching module. Institute for Research on Teaching Occasional Paper No. 94. East Lansing: Michigan State University.

Britton, J. (1990). Talking to learn. In Language, the learner and the school.(4th ed.). Portsmouth, NH: Boynton/Cook.

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

Carramazza, A., McCloskey, M. & Green, B. (1981). Naive beliefs in sophisticated subjects: Misconceptions about trajectories of objects. Cognition 9, 117-123.

Clement, J. (1982). Students' preconceptions in introductory physics. American Journal of Physics, 50(1), 66-71.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. Educational Researcher 23(7), 13-20.

Cohen, E.G. (1986). Designing groupwork: Strategies for the heterogenous classroom. New York: The Teachers College Press.

Collins, A., Brown, J.S., & Newmann, S.E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In Knowing, learning and instruction: Essays in honor of Robert Glaser. Hillsdale, NJ: Lawrence Erlbaum Associates.

Daiute, C. & Dalton, B. (1993). Collaboration between children learning to write: Can novices be masters? Cognition and Instruction 10(4), 281-333.

Driver, R., Guesne, E., & Tiberghien, A., Ed. (1985). Children's ideas in science. Philadelphia: Milton Keynes .

Eaton, J.F., Anderson, C.W., & Smith, E.L. (1984). Student preconceptions interfere with learning: Case studies of fifth-grade students. Elementary School Journal 84(4), 365-379.

Eaton, J.F., Harding, T., & Anderson, C. W. (1986). Light: A teaching module. Institute for Research on Teaching Occasional Paper No. 92. East Lansing: Michigan State University.

Edwards, D. & Mercer, N. (1988). The development of understanding in the classroom. London: Methuen.

Eichinger, D.C., Anderson, C.W., Palincsar, A.S., & David, Y.M. (1991). An illustration of the roles of content knowledge, scientific argument, and social norms in collaborative problem solving. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago.

Galili, I., Bendall, S., & Goldberg, F. (1993). The effects of prior knowledge and instruction on understanding image formation. Journal of Research in Science Teaching 30(3), 271-301.

Bishop, B.A., Roth, K.J., & Anderson, C.W. (1986). Respiration and photosynthesis: A teaching module. Institute for Research on Teaching Occasional Paper No. 90. East Lansing: Michigan State University.

Blakeslee, T.D., Anderson, C.W., & Smith, E.L. (1987). Teaching strategies associated with conceptual change learning in science. Journal of Research in Science Teaching 30(2), 111-126.

Brehm, S., Anderson, C.W., & DuBay, S. (1986). Ecology: A teaching module. Institute for Research on Teaching Occasional Paper No. 94. East Lansing: Michigan State University.

Britton, J. (1990). Talking to learn. In Language, the learner and the school.(4th ed.). Portsmouth, NH: Boynton/Cook.

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

Carramazza, A., McCloskey, M. & Green, B. (1981). Naive beliefs in sophisticated subjects: Misconceptions about trajectories of objects. Cognition 9, 117-123.

Clement, J. (1982). Students' preconceptions in introductory physics. American Journal of Physics, 50(1), 66-71.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. Educational Researcher 23(7), 13-20.

Cohen, E.G. (1986). Designing groupwork: Strategies for the heterogenous classroom. New York: The Teachers College Press.

Collins, A., Brown, J.S., & Newmann, S.E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In Knowing, learning and instruction: Essays in honor of Robert Glaser. Hillsdale, NJ: Lawrence Erlbaum Associates.

Daiute, C. & Dalton, B. (1993). Collaboration between children learning to write: Can novices be masters? Cognition and Instruction 10(4), 281-333.

Driver, R., Guesne, E., & Tiberghien, A., Ed. (1985). Children's ideas in science. Philadelphia: Milton Keynes .

Eaton, J.F., Anderson, C.W., & Smith, E.L. (1984). Student preconceptions interfere with learning: Case studies of fifth-grade students. Elementary School Journal 84(4), 365-379.

Eaton, J.F., Harding, T., & Anderson, C. W. (1986). Light: A teaching module. Institute for Research on Teaching Occasional Paper No. 92. East Lansing: Michigan State University.

Edwards, D. & Mercer, N. (1988). The development of understanding in the classroom. London: Methuen.

Eichinger, D.C., Anderson, C.W., Palincsar, A.S., & David, Y.M. (1991). An illustration of the roles of content knowledge, scientific argument, and social norms in collaborative problem solving. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago.

Galili, I., Bendall, S., & Goldberg, F. (1993). The effects of prior knowledge and instruction on understanding image formation. Journal of Research in Science Teaching 30(3), 271-301.

Gallegos, L., Jerezano, M.E., & Flores, F. (1994). Preconceptions and relations used by children in the construction of food chains. Journal of Research in Science Teaching 31(3), 259-272.

Gee, J.P. (1991a). Discourse systems and aspirin bottles: On literacy. In Rewriting Literacy: Culture and the Discourse of the Other. New York: Bergin & Garvey.

Gee, J.P. (1991b). What is literacy? In Rewriting Literacy: Culture and the Discourse of the Other. New York: Bergin & Garvey.

Gee, J.P. (1994). "Science Talk:" How do you start to do what you don't know how to do? Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

Heath, S.B. (1983). Ways with words: Language, life and work in communities and classrooms. Cambridge, England: Cambridge University Press.

Hesse, J.J. & Anderson, C.W. (1990). A case study of conceptual change teaching: Teaching the necessity of conservation in physical and chemical changes. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Hesse, J.J. & Anderson, C.W. (1992). Students' conceptions of chemical change. Journal of Research in Science Teaching 29(3): 277-299.

Hewson, M.G. (1986). The acquisition of scientific knowledge: Analysis and representation of student conceptions concerning density. Science Education 70(2), 159-170.

Hewson, P.W. & Hewson, M.G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. Instructional Science 13(1), 1-13.

Holland, J.D. (1994). Appropriating scientific discourse in a sixth grade classroom: The case of Juan. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Anaheim, CA.

Hollon, R.E.& Anderson, C.W. (1986). Heat: A teaching module. Institute for Research on Teaching Occasional Paper No. 93. East Lansing: Michigan State University.

Hollon, R.E.& Anderson, C.W. (1986). Teachers' understanding of students' scientific thinking: Its influence on planning and teaching. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco.

Hynd, C.R., McWhorter, J.Y., Phares, V.L., & Suttles, C.W. (1994). The role of instructional variables in conceptual change in high school physics topics. Journal of Research in Science Teaching 31(9), 933-946.

Kesidou, S. & Duit, R.(1993). Students' conceptions of the second law of thermodynamics--An interpretive study. Journal of Research in Science Teaching 30(1), 85-106.

Kollar, G., Anderson, C., & Palincsar, A. (1994). Power, status, and identity in small group problem solving: The effects of social and task specific agendas. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Anaheim, CA..

Kurth, L., Anderson, C., & Palincsar, A. (1994). The case of Carla: Dilemmas of helping all students to understand science. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Anaheim, CA..

Kurth, L., Anderson, C., & Palincsar, A. (1995). Pursuing multiple reform agendas in middle school science teaching. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco.

Lampert, M. (1985). How do teachers manage to teach? Perspectives on problems in practice. Harvard Educational Review 55(2), 178-194.

Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. American Educational Research Journal 27(1), 29-63.

Lampert, M. (1992). Practices and problems in teaching authentic mathematics. In Effective and responsible teaching. San Francisco: Jossey-Bass.

Latour, B. & Woolgar, S. (1986). Laboratory life: The construction of scientific facts. Princeton, NJ: Princeton University Press.

Lee, O. & Anderson, C.W. (1993). Task engagement and conceptual change in middle school science classrooms. American Educational Research Journal 30(3), 585-610.

Lemke, J. (1990). Talking science: Language, learning and values. Norwood, N.J.: Ablex.

Michaels, S.& Bruce, B. (undated). Discourses on the seasons. Unpublished manuscript. Newton, MA: Bolt, Baranek, & Newman, Inc.

Michaels, S. & O'Connor, M.C. (1990). Literacy as reasoning within multiple discourses: Implications for policy and educational reform. Paper presented at the Council of Chief State School Officers Summer Institute.

Miller, M. (1987). Argumentation and cognition. In Social and functional approaches to language and thought. Orlando, FL: Academic Press.

Minstrell, J. (1984). Teaching for the development of understanding of ideas: Forces on moving objects. In Observing science classrooms: Perspectives from research and practice: 1984 Yearbook of the Association for the Education of Teachers in Science. Washington, D.C.: AETS.

Minstrell, J. & Stimpson, V.C. (1990). A teaching system for diagnosing student conceptions and prescribing relevant instruction. Paper presented at the Annual Meeting of the American Educational Research Association, Boston.

Moses, R.P., Kamii, M., Swap, S., & Howard, J. (1989). The Algebra Project: Organizing in the spirit of Ella. Harvard Educational Review. 59(4), 423-443.

Newmann, F., Ed. (1992). Student engagement and achievement in American secondary schools. New York: Teachers College Press.

National Science Teachers Association (1991). Project on the scope, sequence and coordination of secondary school science. Washington, DC: National Science Teachers Association.

Nussbaum, J. & Novick, S. (1982). Alternative frameworks, conceptual conflict, and accomodation: Toward a principled teaching strategy. Instructional Science 11(3), 183-200.

Nystrand, M. (1992). Diagologic instruction and conceptual change. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco.

Ogbu, J. (1992). Understanding cultural diversity and learning. Educational Researcher, 21(8), 5-14.

Palincsar, A.S., Anderson, C.W., & David, Y.M. (1993). Pursuing scientific literacy in the middle grades through collaborative problem solving. The Elementary School Journal 93(5), 643-658.

Palincsar, A.S. & Brown, A.L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction 1, 117-175.

Pintrich, P., Marx, R., & Boyle, R. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. Review of Educational Research, 63(2), 167-199.

Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education 66(2), 211-227.

Rogoff, B. & Lave, J. Ed. (1984). Everyday cognition: Its development in social context. Cambridge, MA: Harvard University Press.

Rommetveit, R. (1990). On axiomatic features of a dialogical approach to language and mind. In I. Markova & K. Foppa (Eds.) The dynamics of dialogue. New York: Harvester/Wheatsheaf.

Rosebery, A., Warren, B., & Conant, F. (1990). Appropriating scientific discourse: Findings from language minority classrooms. Cambridge, MA: Bolt, Baranek and Newman, Inc.

Roth, K. & Rosaen, C. (1990). Writing activities in a conceptual change science learning community: Two perspectives. Paper presented at the Annual Meeting of the American Educational Research Association, Boston.

Roth, K.J. (1985). The effects of science texts on students' misconceptions about food for plants. Unpublished doctoral dissertation: Michigan State University.

Roth, K.J. (1985). Food for plants: Teachers' guide. Institute for Research on Teaching Research Series No. 153. East Lansing: Michigan State University.

Roth, K.J. & Anderson, C.W. (1987). The power plant: Teachers' guide to photosynthesis. Institute for Research on Teaching Occasional Paper No. 112. East Lansing: Michigan State University.

Roth, K.J. & Anderson, C.W. (1988). Promoting conceptual change learning from science textbooks. In Improving learning: New perspectives. London: Kogen-Page.

Roth, K.J., Anderson, C.W., & Smith, E.L. (1987). Curriculum materials, teacher talk, and student learning: Case studies of fifth grade science teaching. Journal of Curriculum Studies 19(6), 527-548.

Schauble, L., Klopfer, L.E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. Journal of Research in Science Teaching, 28(9), 859-882.

Schoenfeld, A. (1990, in press). Reflections on doing and teaching mathematics. Forthcoming in Mathematical thinking and problem solving.

Schoenfeld, A.H. (1985). Mathematical problem solving. Orlando, FL: Academic Press.

Schwab, J.J. (1976). Education and the state: Learning community. In Great ideas today. Chicago: Encyclopedia Brittanica.

Slavin, R.E. (1990). Cooperative learning. Englewood Cliffs, NJ: Prentice Hall.

Smith, E.L. & Anderson, C.W. (1984). Plants as producers: A case study of elementary school science teaching. Journal of Research in Science Teaching 21(7), 685-695.

Smith, E.L. & Anderson, C.W. (1987). The effects of training and the use of specially designed curriculum materials on conceptual change teaching and learning. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Washington, D.C.

Smith, E.L., Blakeslee, T.D., & Anderson, C.W. (1993). Teaching strategies associated with conceptual learning in science. Journal of Research in Science Teaching 30(2), 111-126.

Stewart, J.H. (1982). Difficulties experienced by high school students when learning basic Mendelian genetics. The American Biology Teacher 44(2), 80-89.

Strike, K. & Posner, G. (1992). A revisionist theory of conceptual change. In Philosophy of science, cognitive psychology, and educational theory and practice. Albany, NY: State University of New York Press.

Swales, J.M. (1990). The concept of discourse community. In Genre analysis: English in academic and research settings. Cambridge, England: Cambridge University Press.

Toulmin, S. (1972). Human understanding, Vol. 1: The collective use and evolution of concepts. Princeton, NJ: Princeton University Press.

Vellom, R.P., Anderson, C.W., & Palincsar, A.S. (1993). Scientific reasoning in school contexts. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Vellom, R.P., Anderson, C.W., & Palincsar, A.S. (1994). Developing mass, volume, and density as mediationa means in a sixth grade classroom. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco.

Vellom, R.P., Anderson, C.W., & Palincsar, A.S. (1995). Constructing facts and mediational means in a middle school science classroom. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans.

Vygotsky, L. (1967). Thought and language. Cambridge, MA: MIT Press.

Warren, B., Rosebery, A.S., & Conant, F. (1989). Cheche konnen: Science and literacy in language minority classrooms. Newton, MA: Bolt, Baranek, & Newman, Inc.

Watson, B. & Konicek, R. (1990). Teaching for conceptual change: Confronting childrens' experience. Phi Delta Kappan 71(9), 680-685.

Wells, G. (1991). Talk for learning and teaching. Presented address at the International Convention on Language and Literacy. University of East Anglia, England, April.

Wells, G. (undated). Reevaluating the IRF sequence: A proposal for the articulation of theories of activity and discourse for the analysis of teaching and learning in the classroom. Unpublished draft manuscript posted to electronic bulletin board. Ontario Institute for Studies in Education.

Wertsch, J.V. (1985). Vygotsky and the social formation of mind. Cambridge, MA: Harvard University Press.

Wertsch, J.V. (1991). Voices of the mind: A sociocultural approach to mediated action. Cambridge, MA: Harvard University Press.

Wertsch, J.V., & Bivens, J.A. (1992). The social origins of individual mental functioning: Alternatives and perspectives. The Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 14(2), 35-44.