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ABSTRACT

This study examines thought, language, and related action in sixth-graders working to understand concepts related to mass, volume, and density. Students from a heterogeneous urban classroom worked in various social contexts including individually, in pairs, in groups of four, and as a class. Their work was examined via videotapes, field notes, written work and group products, conceptual tests, and clinical interviews. Two groups of four students formed the target population that was studied closely within the context of the larger class. Research questions focused on how concepts develop across public and private arenas, and on ways the teacher's "privileging" of particular ideas, strategies, and actions played into the students' overt goals, their use of mediational means, the connectedness of sequences of discourse and action, and the standards they employed for determining the acceptability of claims made by their classmates. Concepts developed in stages, across social arrangements, as students focused on developing techniques, making observations, finding patterns in data, and developing explanations. Teacher privileging greatly influenced standards and the strategies students employed even when the teacher attempted to focus decision-making around consensus. This study ties sociocultural and cognitive research approaches. Findings indicate that group work does not adequately support already marginalized students who have difficulty entering into group negotiations in meaningful ways. (Author/PVD)

# Developing mass, volume, and density as mediational means in a sixth grade classroom

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## ABSTRACT

This study examined thought, language, and related action in a sixth-grade heterogeneous urban classroom as students worked to understand concepts related to mass, volume, and density. Students worked in various social contexts, including individually, in pairs, in groups of four, and as a whole class, and their work in these settings was examined via videotapes, field notes, copies of written work and group products, conceptual tests, and clinical interviews. Two groups of four students formed the target population that was studied closely, within the context of the larger class. Research questions focused on the way concepts developed across public and private arenas, and in what ways the teacher's *privileging* (Wertsch, 1991) of particular ideas, strategies, and actions played into the students' overt goals, their use of mediational means, the connectedness of sequences of discourse and action, and the standards they employed for determining the acceptability of claims made by their classmates.

Concepts were seen to develop in stages, across social arrangements, as students focused on developing techniques, making observations, finding patterns in data, and finally developing explanations. Teacher privileging was seen to greatly influence standards and strategies students employed, even when the teacher attempted to focus decisionmaking around consensus. The study ties sociocultural and cognitive research approaches. Findings support earlier studies indicating that groupwork does not adequately support already marginalized students, who have difficulty entering into group negotiations in meaningful ways.

## I. INTRODUCTION

Recent research in science education shows that student learning of science involves more than the acquisition of concepts, skills, and dispositions. Rather, in learning science, students mus take on and master what Gee (1989) refers to as the "identity kit" of scientific discourse. He defines *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"(3)

This conception of the goals of science teaching implies that science classrooms should become *discourse communities* (Swales, 1990) built around scientific discourse. Swales proposed the following six criteria for a discourse community (ibid, pp. 24-27):

1. A discourse community a broadly agreed set of **common public goals.**
2. A discourse community has **mechanisms of intercommunication** among its members
3. A discourse community uses its participatory mechanisms primarily to provide **information** and **feedback.**
4. A discourse community utilizes and hence possesses one or more **genres in** the communicative **furtherance of its aims.**
5. A discourse community, in addition to owning genres, has acquired some **specific lexis.**
6. A discourse community has a **threshold level of** members with a suitable degree of relevant content and discoursal **expertise.**

This paper describes a sixth grade science classroom in which the teacher attempted to develop a *discourse community* in interactions around the activity of describing substances. At the outset, the classroom was not a discourse community in Swales' sense. Instead, it was characterized by interactions born of its memberships' home cultures and the social institution of the school. The discourse community had to be developed over time, as the teacher sought to assist students in taking on the *identity kit* (Gee, 1989) of science discourse. The following graphic (Figure 1, below) illustrates how we think about the development of a classroom discourse community.

At the outset of the instructional sequence, students came to the setting and task with a variety of cultural and academic backgrounds, which led them to describe the observed phenomena in a range of ways. Taking the class as a whole, the range was relatively large, including vernacular constructions as well as some that sounded "more scientific". Over the course of the instructional sequence, the teacher sought to scaffold students towards more scientific language and action, as they worked together to describe substances in more precise and useful ways. The movement towards scientific forms was pushed by the teacher's and students' needs for resolving ambiguity in data collection and verification procedures, and the discourse that both formed and accompanied them.

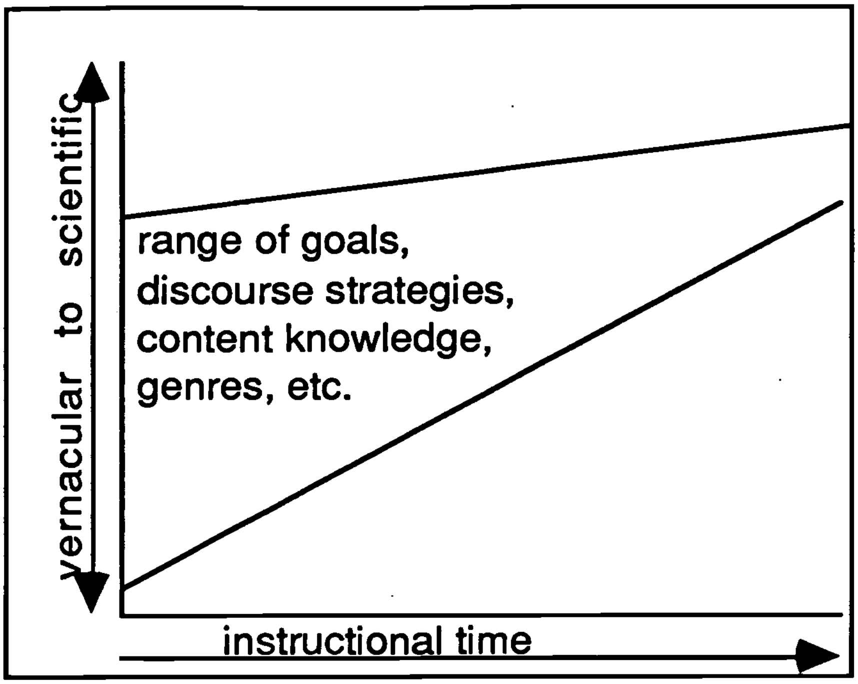



Figure 1: A representation of the goals of discourse-based science instruction

This graphic was initially drawn by the teacher (who is also the researcher in this study) as a tool for conceptualizing his goals in teaching from a discourse-based perspective. Over time, it has taken on some analytical significance, as well. Analysis indicates that as the instructional sequence unfolded, the students and teacher came to critical points at which exact meaning was important in order to move forward in the process of describing substances. At these points, the rules for language use sometimes underwent modification, as the students and teacher together developed *standards* for reporting and discussing observational data. The graphic illustrates that, as these standards developed and certain forms were *privileged* (Wertsch, 1991), the range of acceptability for any mediated action (in the eyes of students and teacher) narrowed for the entire class. Students who failed to take on the privileged forms may have found themselves outside of the range, and thus may have been denied access to meaning-making interactions in the whole-class setting, and in small-group interactions as well.

## Theoretical Background

This study seeks to trace the development and use of mediational means (or cultural tools, (Wertsch, 1992) in the collective setting of the classroom community. These tools include 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). In order to trace the use of these tools, I chose to pay attention to particular aspects, or *dimensions*, of classroom discourse (described fully in Data Analysis, below). Because of the varied nature of the tools, and the multidimensional nature of the emergent discourse, I selected and refined dimensions that I thought would cut across traditional lines of analysis, in order to reflect a more dynamic and realistic view of the interactions under study.

Two traditions currently characterize much of the observational research in progress in science classrooms today. These are the conceptual change tradition, which takes a cognitive approach to analyzing teaching and learning situations, and the sociolinguistic tradition, which examines language and interaction in social settings. These two forms of analysis have been viewed in most circles as competing, since they make different claims about what is important in examining teaching and learning situations, and thus make distinctly different recommendations for improving science teaching. 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, contrary to the common one-or-the-other approach, 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 rationale for the complementary view he suggested, Cobb cited Ball's (1993) analysis of her own teaching of mathematics, in which she elaborated 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.

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. Furthermore, 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. In this effort, I chose to foreground the sociolinguistic approach, while landmarking the analysis with views of individuals' conceptual work. This approach enabled me to consider the ways that each of Swales' aspects of a discourse community developed as instruction proceeded. I did this by examining the discourse for evidence of each of the dimensions that Swales proposed.

We expected that we would be able to track the development of other aspects of the community as defined by Swales: mechanisms of communication for information and feedback, genres as the community's goals dictated needs for them, a specific lexis, and levels of content and discoursal expertise. Our methods of describing the development of the community are discussed in the section on data analysis, below.

## PURPOSES FOR THE STUDY

My aim in this study was to develop a rich description of the development of a classroom discourse community around concepts that are typically difficult or foreign to many students. I wanted to select concepts that represented abstractions from examples, rather than simple descriptors used in observations. The concepts of mass, volume, and density are often taught using multiple representations; initial conceptions are usually 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 out these concepts 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 involved 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 examine these privileging actions, which in some cases established new standards for acceptability. I wanted to see what happened-- whether students took on newly privileged forms, and whether some were marginalized by virtue of not doing so. In doing this, 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 descriptions of the developing discourse system and the individuals who comprised it.

This 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? Trace the construction of these concepts in the public discourse of the classroom during the instructional sequence.
2. How was the emerging discourse system of the classroom community and collaborative groups facilitative (or not facilitative) of individual students' participation in the activity of describing substances, and especially their understanding of Mass, Volume and Density?

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 in the instructional sequence.

The second question focuses more on individuals as they operated within the collective. Here, I examined how 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 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.

## II. METHODS:

### SETTING AND INSTRUCTIONAL CONSIDERATIONS

The setting for this study was a single sixth grade classroom in an urban middle school (grades 6-8). The school, located in a midsize city in the Midwest, serves a population that is notably diverse in terms of ethnicity and socio-economic status. The class studied herein was mainly European-American and African-American students, with small populations of Asian-Americans and Latin-Americans. Some students came from relatively affluent homes, while slightly more than fifty percent of the students at the school qualified for free or reduced-price lunch assistance. Classes included students with a full range of academic backgrounds, including some that had been designated as "gifted" according to state guidelines, and a handful of others that qualified for specialized learning support.

I entered the classroom in January, as the students were finishing a state-mandated unit on health, hygiene, and personal management. I took over complete responsibility for planning curriculum and teaching this class. The regular classroom teacher observed most lessons, taking notes and participating in discussions at times. Weekly meetings with her, the university researcher who gathered data, and myself were held to plan and discuss curriculum. During these meetings, I typically proposed activities and approaches for the coming week, and a free-flowing discussion emerged about priorities, equipment needed, setup and cleanup, and conceptual issues. These meetings were characterized by the development of more detailed plans for the week. In these meetings, as in all activities during the eleven weeks of instruction, I purposely deferred any consideration of research issues, choosing to live the role of teacher and leave these potentially conflicting issues to the university researcher.

One important feature of the classroom was the collaborative groups of four students that the teacher had established before I entered. She had done this 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 episodes reported herein are a part of a larger, eleven week sequence of instruction on describing substances. These episodes do not necessarily reflect the sequence or flow of the larger instructional unit, which forms an important context in which these episodes should be considered. Generally, the sequence unfolded in these ways:

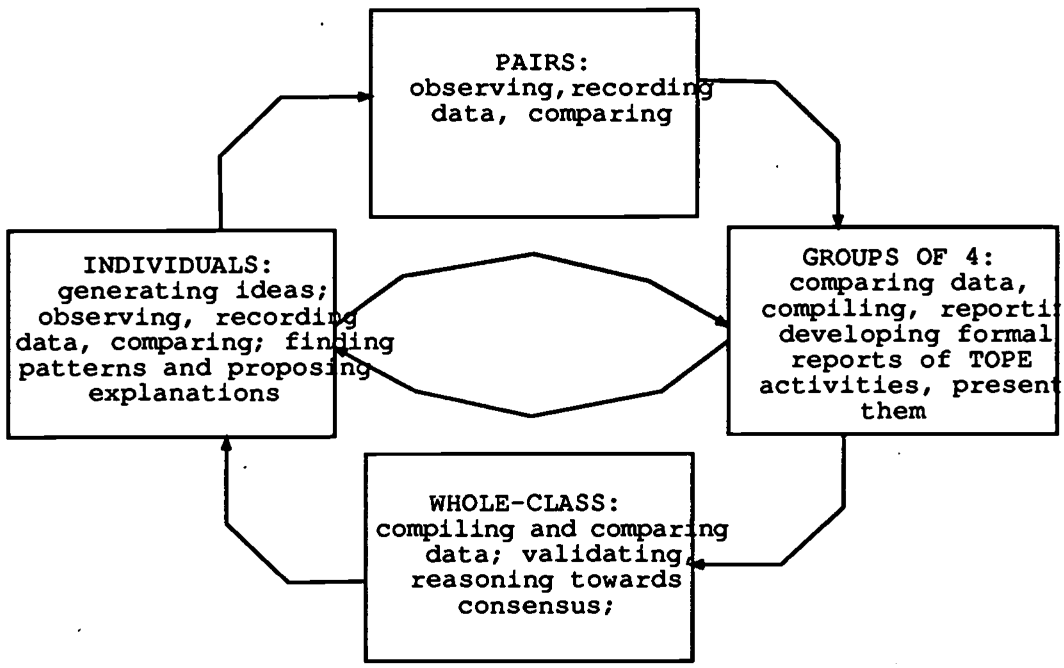



Figure 2: Activities related to describing substances in each of four social configurations in the classroom

This diagram shows that students often worked in pairs and groups of four on particular aspects 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 in terms of what counted as data, what counted as good data, and 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 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.

## Data Sources and Collection

The data collected and used in this paper were a subset of data collected for The Collaborative Problem Solving Project. Data reported herein represent the fourth year of this project. Sources of data for this study are listed below with brief methodological notes.

Pre-instruction and post-instruction clinical Interviews were conducted with each of the eight target students in the class. 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.

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. 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. 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.

These records were augmented by fieldnotes, which were recorded by a researcher using a standard Classroom Observation form developed by the project.

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.

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.

A university researcher was present in the classroom each day to set up and run the video and audio recorders, and to take fieldnotes. The researcher also participated in weekly meetings with the regular classroom teacher, at which curriculum was detailed and practical considerations discussed. The researcher assisted with setup of laboratory materials for many activities.

## Data Analysis

Because of the enormity of the data set, promising classroom sessions were first identified from the classroom observation sheets. These sessions were then viewed, and larger segments of activity were catalogued, as were interactions that seemed particularly promising or rich. As these catalogues were developed, identified segments were viewed one or more additional times, in order to more closely characterize the story lines running through them. In concert with these catalogues and viewing, copies of written work from logbooks, worksheets, and group posters were examined. In this way, notes were attached to the catalogues that indicated some of the non-verbal mediated actions, as well as important referents in conversations. Next, a number of segments were identified for close transcription, and transcripts were developed by repeatedly viewing segments in conjunction with examination of the aforementioned artifacts. In all cases, care was taken to maintain accurate sequencing of transcripted segments within the larger sequences of action in the classroom. Finally, these sequences with transcript were elaborated into the more complete episodes that comprise the data in this study.

The primary unit of analysis for this study was *(an) actor(s) acting with mediational means in a setting or context*. Proposed by Wertsch (1991), this unit allowed consideration of both individual and concerted action across a variety of contexts, using any number of mediational means. This was particularly appropriate for the study of instructional sequences, which are characterized by their complexity and their fluid nature. Using this unit of analysis, while freeing me from some of the constraints of solely individual or entirely collective views, necessitated careful definition of the features that I was looking for in the classroom discourse as students and teacher worked to describe substances. I wanted to select aspects of the discourse that would reflect the important processes that I saw going on in the collective, such as privileging and the development of standards, as well as giving a sense of the goals and logic inherent in mediated action. I also wanted to reflect some of the cognitive work that was being done, work that is particularly valued in more traditional views of science instruction.

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 below, 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.

## The scientific 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 <u>variables</u> 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 <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.

Many of these techniques, observations, patterns, and explanations are summarized in the table below. This table 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 included in the analysis describes all or part of the classroom community working on either one of the specific activities described in this table, or on the connections among them.

## Dimensions of each activity

The analysis of each episode characterizes its place within the general set of activities associated with describing substances outlined in the table above. Each episode can also be analyzed in terms of four <u>dimensions</u> 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.

| | MASS | VOLUME | DENSITY |
|---|---|---|---|
| T | • Weighing substances using a balance.<br>• Comparisons of mass can be made using a double pan balance. | • Measuring liquid volume using volumetric containers.<br>• Measuring volume by linear or displacement means.<br>• Comparisons of volume can be made by height of liquids in identical containers. | • Comparing density of substances by floating and sinking<br>• Calculating density from measures of mass and volume |
| O | • Measured in units, gram is standard unit<br>• We say that objects with more mass are heavier, while objects with less mass are lighter. | • Measured in units, liter is standard unit<br>• Comparing volume of liquids leads us to say we have more or less of one.<br>• 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.<br>• Calculated and referenced to standard (water = 1g/ml)<br>• 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.<br>• Mass is independent of gravity | • Volume is dependent on sample size for solids and liquids. | • More dense liquids sink, less dense liquids float<br>• Floating and sinking is independent of sample size<br>• Floating and sinking is independent of shape or size of container<br>• 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.<br>• Measures of density assume samples are uniform |

Table 1: TOPE activities in describing substances in terms of mass, volume and density

These dimensions represent a somewhat simplified scheme that bears significant similarity to Swales' six criteria for discourse communities. For instance, my asking what *goals and purposes* the students brought to the activity relates closely to Swales' first criterion, *a broadly agreed set of common public goals*. Swales' *genres* and *lexis* relate directly as particular kinds of *mediational means*. The *threshold levels of expertise* of which Swales speaks have much to do with the developing *standards* that I sought to characterize. The others of Swales' criteria have more to do with the kind of classroom environment that is established, wherein intercommunication between members is common, there are mechanisms that provide for this, and many of the interactions have the purpose of providing information and feedback.

Notice, however, that Swales' criteria are found in the collectives; in this case, as the discourse community develops. While communities are composed of acting individuals, several of these criteria are difficult to apply to individuals. Because of the individual and collective focus of this study, I needed to be able to examine discourse events across settings, which would necessarily include individual writings, relatively private conversations within pairs or groups of four, and the more public whole-class events. The dimensions of discourse described above largely correspond to Swales' criteria, but enable examination of individuals and collectives as actors with mediational means. Both Swales' criteria and my dimensions of discourse cover significant ground in analyzing discourse-based interactions, as they attend to the cognitive and interactive aspects of the emerging discourse within the classroom.

The four dimensions of discourse listed above have the additional characteristic that they reflect, in more direct and specific ways, some of the essence of scientific activity. While Swales' six criteria certainly apply to the development of a discourse community around the scientific description of substances, and thus each of these features will be found in this community as it develops, I sought an analytical scheme that would more closely track students' attempts to master scientific discourse, which values certain features, strategies, and intellectual tools. I wanted to keep track of the students' work in taking on this discourse, in order to try to better understand how the instructional sequence worked for these students.

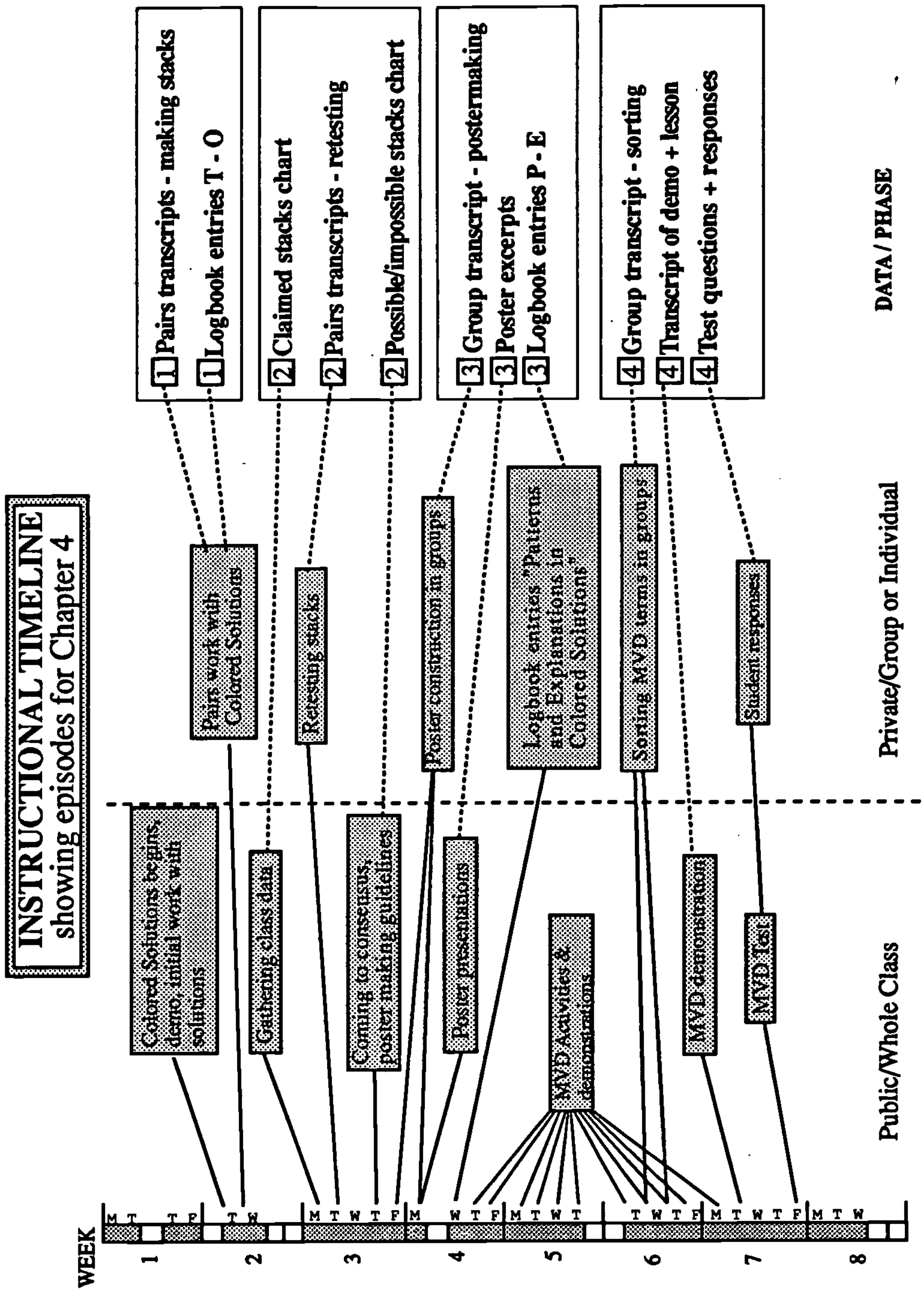
Ways in which the language and action associated with each dimension were identified and analyzed are described below.

Analysis of segments of mediated action tells 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?" This question was posed in analysis of each successive segment, in order to consistently build pictures of the relatedness of mediated actions over time.

## III. Results

Analysis of classroom episodes and artifacts below is characterized in terms of four phases, named to reflect the main thrust of the activity; these phases are intended to help the reader keep track of the larger progression of activity, and the place of each episode within it. The phases are named as follows:

- Phase I: Getting Data in Colored Solutions
- Phase II: Getting Good Data in Colored Solutions




- Phase III: Patterns and Explanations in Colored Solutions
- Phase IV: Developing the Concepts of Mass, Volume, and Density

As noted above, the data analyzed in this study is part of a larger set of data described in the timeline above. The timeline shows the kinds of data that were analyzed, the setting and activity from which each came, and where each activity fell in the overall instructional sequence.

## Phase I: Getting and Recording Data in Colored Solutions

The instructional sequence examined here is part of a larger unit designed to teach students about the kinetic molecular theory, after the model of Berkheimer and colleagues (Berkheimer et al, 1988). 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.

The first part of this instructional unit, which is most closely examined in this paper, was a modified version of the ESS Colored Solutions problem (Education Development Center, 1966). 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. A timeline of this instructional sequence is presented below, showing how the Colored Solutions problem fit into the larger unit of instruction. The timeline also shows the kinds of data that were gathered from different social settings within the classroom.

Once the students had been exposed to these activities of scientists, the teacher 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>

1/19/9

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

Setting the table up before the activity began had the effect creating an organizing framework for the work that would ensue. The teacher 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.

Once the logbook page was set up, the teacher 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". The teacher 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 the teacher 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. Nevertheless, the teacher chose to move on to the student work with solutions, in an attempt to maintain their interest in the phenomenon and to maximize their time with the solutions. A tray of materials, including supplies of red, green, and clear solutions, droppers, vials, soda straws, and a waste container was given to each pair of students.

The students then proceeded to work with the solutions for the remainder of the period, and all of the next day. During this time, the teacher circulated between groups, supplying materials, answering questions, and encouraging students to record trials and observations. Included in this sequence was a handout which discussed some techniques using droppers and some using straws; it also encouraged assiduous recording. Although students were repeatedly encouraged to work together and to make records of their trials and observations, they each had the freedom to chose how they carried out these aspects of their work.

## 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 investigated, figuring out what to do as they went:

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.

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 effected by turn-taking rather than by equally distributed joint responsibility for each test. Lisa's first statement here (move 1) is actually a restatement of the 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 then 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 proscribed 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. In completing the task, Adam and Lisa recorded the following information 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.*

Note the 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 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 differ from one another in seemingly small ways.

One entry that is different for these students is 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 (which was the routine), reflects attention to which liquid was on top. This observation stands out among all others made in this pair of students because it moves from the general "mixed or didn't mix" formulation to one of greater specificity. The initial formulation is still there, but Adam has begun to gather data that will be meaningful in figuring out the relative density of the liquids. While there is 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 puts Adam in a potentially better position to focus on density as the causal feature for the stacking behavior of the solutions.

The observations of these two students represent common approaches from early in the instructional sequence, as represented by their use of common language in routine ways to describe their tests and their observations. Their first two observation statements resulted in gross estimations of color; in their third trial Lisa suggested a pattern statement, which could also be taken as a progressive description of what they saw. They then switched to using straws, in which their first trial resulted in another gross statement of color. Finally, when they got a stack, they carefully recorded the stacking order. They 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, since 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 the teacher, 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. (She writes 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
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?

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 easily heard by all members. Both Chet and Donnie explored for several minutes without recording trials in their logbooks. Chet's initiating statement (move 1) above announced his intentions to others who were doing their own trials. Emma's response (2) and Donnie's rejoinder (4) were given as they held their own vials and droppers. In these responses, they indicated that Chet's effort was nothing new to them, and perhaps prejudiced his interpretation of results by telling him what should happen. From this, however, Emma made a generalization (6), which she quickly recorded in her logbook. Then, in successive turns, Chet announced a stack (7), Donnie corrected himself on the order in which he was to add the solutions (8), Emma challenged Chet's stack (9), Donnie defended it (10), and Chet urged her to look more closely at the top of the solution (11). Chet then spent some time trying to make the stack more visible for Emma (14), while Donnie initiated his own (unsuccessful) trial (20). Chet coached Donnie to squirt the solution in slowly (23), then asked for advice on dumping his solutions out (24). Meanwhile, Donnie made another visual effect with bubbles, which he bid for Chet to look at (25).

In this exploration, the 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:

*1-19-92* *Colored Solutions* *Donnie*

| *Techniques (What I 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*<br>*Put the red, then he put the clear on the top* | *The red didn't mix with the green.* |

*Colored Solutions*

| *What I did*<br>*1-19-93 Techniques* | *Things I saw*<br>*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* | |
| *5)* | |

Beyond the first trial (which is a record of the demonstration done by the teacher), the Technique and Observation statements of these students are markedly different. 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 attempt to outdo one another in visual effect. One interesting result of this was the attention each paid to carefully examining the resulting solutions. 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 the teacher, Chet asked "why does it do that?". The teacher explained the illusion 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.

## 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 (see Table 1, above). In testing different combinations of liquids and attempting to make stacks, they were practicing techniques that would eventually allow them to compare the densities of the liquids and they were 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, 1994). 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, 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, we saw 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 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 the teacher 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 the teacher'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. Their routine exhibited features that set it apart from the work of Chet and Donnie. 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.

Chet and Donnie, however, 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.

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 (p. 24), Chet suggests, 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 technique 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. Thus, his vocalization was a reflection of this technique standard for successfully stacking liquids.

## 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 do 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, in which technique is much less of an issue, did they make a stack. Instead, their actions seem to reflect a common 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 benefit 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 lot more 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.

As Day 2 ended, students cleaned up their materials, and the teacher encouraged them to begin looking back over their logbooks, making sure that the records they had made 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.

### Differences in status and participation among students

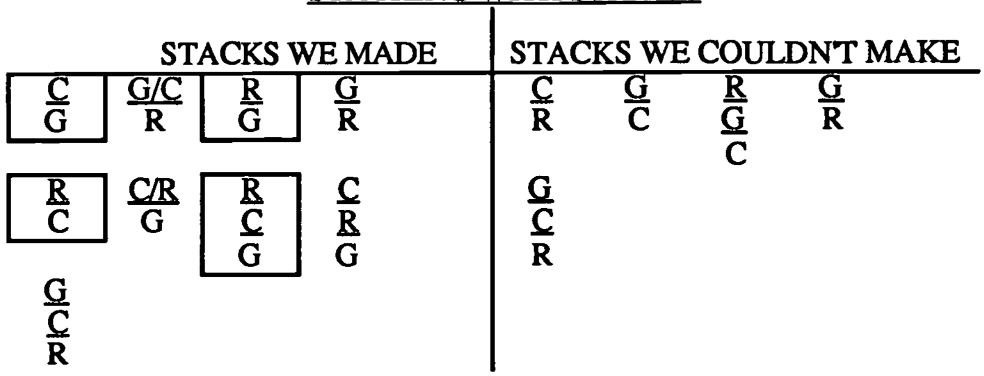
The students' work during Phase I was notable for the general absence of differences in status, participation, and engagement among the students. This was probably due partly to the absence of stated standards that would have privileged some approaches to experimenting with the solutions. We have also noticed that the relative absence of status differences and high levels of engagement are generally apparent when students are working in pairs (see Kurth, Anderson, & Palincsar, 1995).

It is notable, however, that some students are spontaneously acting in ways that will later be privileged, while others are 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.

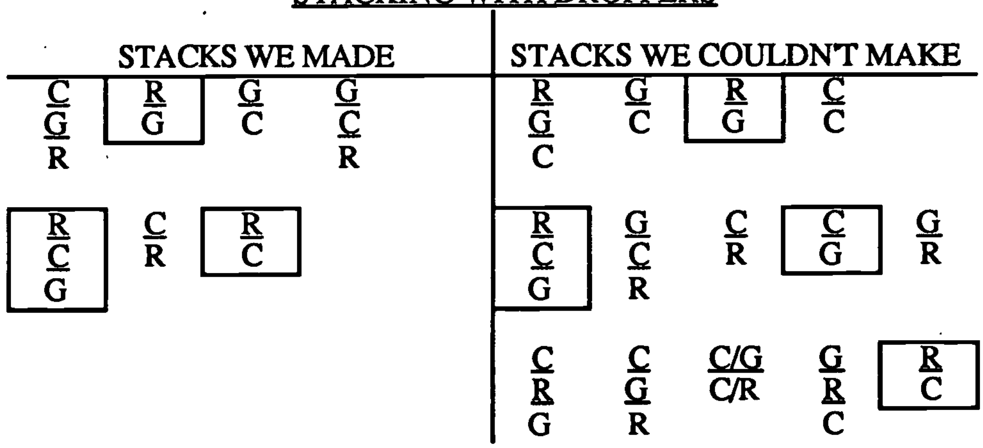
## PHASE II: GETTING GOOD DATA IN COLORED SOLUTIONS

At the beginning of the third day, the teacher quickly reviewed the TOPE activities framework in a quick question-and-answer format, and then asked the students to set up a page in their logbooks to record group and class data concerning "stacks" of one liquid on top of another, including those that they had made and those that they had tried to make and failed. The students moved into groups of four and completed the data-compiling process quickly, with most groups appearing to take this task as simply an additive process in which all claims within the group were to be recorded, and then moved their desks back into rows for the whole-class data gathering session. In the reporting process, Mr. V recorded all verbally made claims on an overhead transparency. He then moved in succession to each of the other columns. No evidence or explanation was required in this process, so the class ended up with charts with the following stacks on them:

STACKING WITH STRAWS




STACKING WITH DROPPERS




## A. Significant Features of the Class Data Set

In straws, the class "Stacks we made" included all four of the possible stacking orders (indicated by boxes on the chart), and that only two stacks appeared on both sides of this chart (G/R and G/C/R). At the same time, this chart included definitive statements from some students about stacks they couldn't get to work; all of these statements accurately reflected impossible stacks.

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 claimed to have made four stacks that are impossible. These results reflected, by my estimation, a number of factors that play into the difficulty of making and observing stacks in vials (that are not present with straws). These include how one solution was introduced into another, visual criteria for claiming a stack, and the students' perceptions that relative amount and the order in which the solutions were added made a difference. In any case, at this point, I judged that much of what the students reported about droppers was suspect. Some kind of validation process was needed.

At the end of this episode, the teacher and the class had filled in the chart that contained all of the reported claims (data); at this point, the problem became figuring out which data to believe. Once the data had been recorded in tabular form, Mr. V turned their attention to the quality of the data that they had recorded:

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?
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?
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....

Mr. V began this session by asking students to examine the data and find patterns. Jeannie's first response (move 2) reflected the very feature he had hoped they would notice. In allowing further responses, he invited other students to become invested in the process, and also learned more about the approaches that these students took to looking at the data.

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.
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.

The second half of this transcript shows Mr. V encouraging students to explore possible explanations for the anomalies in reported data. Jeannie again made a suggestion, and at this point Mr. V changed the course of the task to the present dilemma: what to do next. He quickly framed a situation for the students that served notice that the students could suggest ways of ironing out the disagreements. 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 re-test 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 both possible and impossible to make. There were nine of these, which he suggested they re-test. 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. The teacher did this at the same time 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 re-testing 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.

## 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). 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, the teacher 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 for the dimensions of discourse below.

### Goals and Standards in Phase II

The teacher'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. The teacher's request for recorded data was also consistent with Adam and Lisa's care in writing down their techniques and observations.

However, the teacher's request for observations about stacks recognized only one of the many possibilities inherent in the students' initial explorations. The students' initial explorations could equally well have led in a variety of other directions. For example, they could 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 the teacher was using his authority to privilege some of the students' goals at the expense of others. From the array of possibilities the teacher chose one goal as a "common public goal" (cf., Swales, above). for the emerging classroom discourse community. The teacher's reasons for doing this were not made explicit to the students at this time.

Prior to this point, any observations that students had made in doing a "trial" (in a straw or using dropper and vial) could (and should) have been recorded. There had been no distinction between kinds of data. All were equally valid; the emphasis was on performing trials and recording carefully. At this point, however, the teacher made a choice that valued one particular kind of observational data, in the form of stacks of two or three solutions. This choice was to influence the kinds of data that were reported in the immediate sense, but it also had the effect of establishing a standard that would influence all future work with Colored Solutions in this class, by focusing their efforts exclusively on producing data that described stacks that could or could not be made. It pushed students away from reporting ambiguous data, of the sort "Red and green worked". This consistent way of reporting also ensured that the data appeared in a form that itself would not obscure patterns that might be found in it. And, the larger sample reported in a consistent format was intended to enable pattern-finding with minimal difficulty.

The teacher used a standardized form to record the students' observations: the representation of stacks with stacked letters as in the illustrations above. This form was introduced by the teacher; it was not apparent either in the students' journals or in their oral reports. In other respects, though, the teacher depended on the students to suggest problems with the data and develop standards. It was a student (Jeannie in line 2) who 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.)

During the course of this discussion another subtle shift in public goals was occurring. 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, 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.

At this point in the unit the evidence indicates that the teacher was striking this balance successfully. The students accepted the new goals and standards as their own and worked on them with enthusiasm.

### 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 that they had previously paid attention to. (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 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.

### Status and Participation in Phase II

It is significant that the teacher accepted all claims made in the whole-class session. 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.

Yet, even in privileging data about stacks, the teacher set no other threshold for what constituted good data. He accepted all of the claims as valid, just as a researcher might take each of them as a data point. At the same time, his acceptance of each claim 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. 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, the teacher did not make this distinction).

## 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 next page). 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?

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

The process of creating a poster was intended to give each group occasion to participate in two kinds of concept-based processes. 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 side by side with 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. 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.]

Here, Nick made an initial suggestion of a pattern (move 2) to be included on the group's poster; this was the first time we saw a student present a pattern, although the teacher had given one example of a pattern statement earlier. When Adam asked him to repeat it, he added an explanatory mechanism, using the idea of buoyancy. Lisa, meanwhile, attending to the need to get the poster done, noted that this was the kind of thing that should be written down. The boys did not act on her suggestion, instead looking at Nick's data to verify the claim.

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 logbook] [Both boys looking at "Whole Class Data" in logbooks]

Move 6 resolved the claim as false, at least in terms of the data Nick and Adam were looking at. Then a series of social agendas arose, but in move 11 Nick repeated his claim, this time in comparative terms. Again, he and Adam turned to their logbooks to verify the claim. This pattern, in which Nick claimed a pattern or explanation, and then he and Adam examined their logged data to verify the claim, reflects that each of them held a standard for claims, and had the mediational means to check themselves and each other before the claim went any further. In the ensuing sequence, Nick said "less buoyance" in examining his data, but in showing it to Adam, his actions indicated that this was a mistake--that he meant "more buoyance". He and Adam quickly agreed on the pattern suggested by the attribute of "buoyance" thereafter, again using their 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.

In move 17, Nick talked his way through examining some data, eventually concluding that Adam was right. Adam suggests that the pattern is different with straws, which results in a less precise formulation from Nick (move 20), including the word "mostly". Meanwhile, Sandra's bid for a pattern went unheard. Finally, Adam formalized the statement for Sandra as she wrote. The 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". However, in this negotiation, the pattern already recorded for Red was questioned again several times, as students examined their data. 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.

Later on in poster planning, Lisa was writing as 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 the move to quantify, which is one way that accumulated data may be reported. Sandra proposed "Five out of seven times Green is at the bottom." This statement undergoes validation in which Sandra notes 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. It was a statement that numerically summarized the findings of the group in regards the position of the Green solution, which was a comparison of Density. And, it was clearly data-based. Later on, Lisa pointed out that the group had no statements about the Clear solution, and suggested a pattern:

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 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.

Nick's response to Lisa's comment was to examine his data to see what pattern he could find in the Clear's behavior. Nick suggests that, "Clear usually mixes", a formulation that does not fit the earlier class standard that privileged stacking data over other kinds of observational information. Sandra (move 94) looks for verification from the group, then finds an instance in which Clear did not mix, in her logbook. Adam was still considering data from an earlier question about Red (see move 62 above). Lisa stuck to her pattern, reiterating, "Clear's in the middle", twice. Nick again went to his data, counting aloud as Sandra also looked at her data. Adam agreed with Lisa (move 101), but in the face of Nick's conflicting data, finally crafted a statement for Sandra to write that omitted Clear altogether.

Notable here is that Lisa found her pattern from looking at her logbook, but she did not use her recorded trials to try to convince her peers. Instead, as they examined their data, she lobbied to keep the issue alive while they sought the pattern in their own records. While it was clear that Lisa understood the value of data as a root for claims, she did not use her own data as a persuasive tool.

## Dimensions of Discourse in Phase III

The transcripts in this phase provide a good opportunity to illustrate the development of the classroom discourse community because the students have moved from the public domain of whole class discussion guided by the teacher to the private domain of work in groups of four, where the teacher had no direct influence. These transcripts indicate that the students have to a substantial degree appropriated the goals, standards, and mediational means that were privileged in the public domain. The classroom discourse community was beginning to function!

The discussion in this group also expanded the scope of inquiry from the upper right-hand corner of the TOPE x MVD table to the entire right-hand column. Adam, Lisa, Sandra, and Nick were considering density-related patterns and explanations as well as discussing how to report their techniques and observations. 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 "main goal" of the unit is evident in this transcript. The students focused exclusively on the stacking data.

The standard of replicability as necessary for separating good data from "noise," however, seemed to be less thoroughly understood and accepted by the students. Although this discussion took place after they had replicated the tests for stacks that were reported as both possible and impossible, 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 it much more difficult for them to decide what data to report and how to word their claims about patterns.

Careful attention to the data played a role in the group's decisions about what to report, but the overall picture was more complicated than that. In particular, the group struggled with the issue of what to report as a valid pattern, an issue not addressed in the previous class discussions. The students sometimes went back to data to resolve disputes, but not always. The limits of this strategy were socially determined, and can be seen in Adam's conciliatory statement. Laying logbooks side by side would mean someone was wrong, in the end. The group processes observed here were a kind of informal consensus mode in which Nick, Adam, and Sandra held sway, but Lisa could get her concerns attended to, as long as someone else picked them up. She did not use her logbook to try to convince the others that she was right.

### Mediational Means and Connections in Phase III

In general the group used the mediational means for communicating about techniques and observations that had been developed in earlier class discussions. They also struggled to develop a language for deciding on and describing patterns. 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.")

As they moved from techniques and observations to a discussion of patterns and explanations, the group began to consider more connections among their experiences. Although they had trouble finding language to express their consensus, the group did come to agreement about the most important pattern, and Nick suggested an explanation. His explanation anticipated the next step in the unit in that he suggested that the observed pattern was caused by a property of the solutions: buoyancy.

### Status and Participation in Phase III

In contrast with the work in pairs during Phase I, a clear status hierarchy was evident in this group (and most of the other groups) when the groups of four worked on posters. 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 is a pattern that we have seen in many other case studies of group work (e. g., Holland, Anderson, & Palincsar, 1994; Kurth, Anderson, & Palincsar, 1994, 1995; Striley & Richmond, 1993). It seems to be especially salient when the students are working in groups of four.

## 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 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 the teacher 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..

Jumping directly to formal instruction in Mass, Volume, and Density seemed ill-advised, based on the range of mechanisms that students in the class still believed responsible for the stacking behavior of the liquids. Instead, he chose to promote a discussion of the terms that students had been using to represent these concepts, while still working on the problem of clarifying what mechanism was operating when liquids stacked. This two-pronged approach was meant to value the conclusions that a variety of students had reached about the Colored Solutions while moving them along towards a better understanding of how systems of liquids that layer work. At the same time, Mr. V hoped to raise issues of ambiguity in the ways that the students had been talking about Colored Solutions in order to encourage a move to language that included some of the finer distinctions (like those between properties of substances like Mass, Volume, and Density) that enable scientists to describe substances precisely.

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 diffusion demonstration consisting of 5 liquids (corn syrup; the Green, Clear, and Red colored solutions; and vegetable oil) layered in a large graduated cylinder. Students predicted changes in layering they thought would occur over one month's time. The stacking order of the liquids used in the demonstration was an issue that paralleled and extended the questions students had about the mechanism that would explain the stacking order of the Colored Solutions.
- Negotiation about some of the terms that the students had used in describing properties of the liquids in the course of writing explanations for the stacking patterns in Colored Solutions. Students and the teacher ran tests and discussed meaning to distinguish between these terms, and to figure out which might have a bearing on stacking behavior::

  | | |
  |---|---|
  | • heavier | • thicker |
  | • dense | • less buoyant |

  Over the course of 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. Formal instruction in these terms was tied to the four vernacular terms for which the students had been developing and running tests.
- Sorting Terms for mass, volume, and density in which students worked in pairs, then groups to sort a variety of terms into columns and then presented their group's results to the class using an overhead transparency they had made. 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.

Mr. V saw this teaching sequence as an opportunity to further engage students in investigations that arose from their own previous work, while working towards contexts that would support formal instruction in the part of the scientific canon having to do with the concepts of Mass, Volume, and Density. Important in this instruction was a process of helping students to make distinctions between concepts and terminology that was often the same in the vernacular, but not so in scientific settings. An example of the activities that represented significant privileging of these forms is included below.

## Making Distinctions: The Brass Weight and the Film Can

One of the demonstrations that Mr. V included in this instructional sequence had to do with the distinction between Mass and Volume. During the interchange, Mrs. P, the cooperating teacher (who was in the classroom most of the time), interjected comments periodically.

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.

This demonstration occurred after the students had worked through several other demonstrations involving comparisons of mass, volume, and density. At this point, Mr. V wanted to move from a group-response pattern that had been common, towards an individual statement mode that would give each student practice in writing statements about these comparisons. Having shared in the planning for this activity, Mrs. P helped frame the writing task for the students. After a brief pause, Mr. V continued:

6 Mr. V: Alright, 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.) 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.

8 Mr. V: 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). 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.(Points to Emma)

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 this segment, Mr. V has accepted four different formulations. The first three involve direct comparisons, and name both objects. These responses show use of mediational means that are important in scientific endeavors: naming both objects being compared, naming the feature or property that is the basis for the comparison, and holding the basis for comparison constant across both objects. Emma's statement, in contrast, just included one object, and used the vernacular "more space". Mr. V gently corrected Emma with the addition of the word "volume", allowing her to still understand that her statement was correct, as far as it went.

15 Alan: (unintelligible)

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... 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. (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.

In this segment, Mr. V moved to a comparison of mass, which was complicated by many students' inability to see the balance from their seats. Mort, being one of these, made a judgment that one side of the balance was lower. Mr. V did not allow this, referring to his earlier statement that the pans were balanced. Again, he accepted statements in varying forms that still demonstrated understanding and recognition of the distinctions that were being made. In the turns below, he accepted a statement that included the idea of mass and weight being the same; the distinction between these properties had not been made yet, and this equivalency had been accepted (but not suggested) by Mr. V in some of the previous demonstrations.

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.

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.

This activity was intended to bring each of the students in the class along towards understanding appropriate uses for the terms involved, as well as making conceptual and practical distinctions between them. Mr. V wanted to constrain the discourse in support of these goals, and in keeping with this adopted a much more teacher-centered mode of conducting the lesson. As evident in the transcript above, he placed himself at the center of interaction, becoming a channel through which student responses were controlled.. In contrast to some demonstrations in which student responses had been accepted as valid (sometimes leading to negotiations about meaning), in this case he held goals of giving good linguistic and conceptual models for the students to hear and appreciate. Thus, he did not allow Mort's statement to stand without correction, believing that doing so would confuse other students. He continued to ask for statements until he had heard a number that were acceptable.

At the same time, he wanted each individual to participate in writing comparative statements, believing that this was one way to encourage students to attend to the distinctions between the concepts of Mass, Volume, and Density. In asking for several students' versions of each statement, he hoped to keep the interest of the class and provide a range of acceptable responses to which each student could compare his or her response.

Over the next couple of days, Mr. V ran several of these tests, 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 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 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.

## 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 of the whole-class discussion excerpted above, 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 the goals, standards, and mediational means that scientists use for describing substances. Each of the dimensions of discourse is discussed below.

### Goals and standards in Phase IV

During this phase, we saw 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 other substances in terms of properties such as mass, volume, and density.

Alongside this shift in public goals we noted that 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, highlights 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.

Seeing (and hearing) students using scientific-sounding terms and formulations, and attempting to generalize their understandings to other settings brings out underlying questions about the effectiveness of this kind of instruction. Has the class successfully constituted a discourse community around this kind of discourse, or were students 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 appears to vary with individual students. Some, like Adam and Tess, were successfully using mass, volume, and density in both public and private settings, while others' statements and actions were less convincing.

### 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 here expanded to include work on terms themselves, as well as work which 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 above 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.

### Status and patterns of participation in Phase IV

The main change that we detected in this final phase involved something that we didn't see, more than any single thing we saw. Briefly, we noted that Lisa, Donnie, and other low-status students were largely silent in whole-class discussions and activities which required public nomination. We see this as related to their limited understanding and use of mediational means that had become privileged forms.

We saw similar mixed results 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.

Significant in this process was Mr. V's choice to move to a teacher-centered model of instruction. 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. It 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 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. I suspect that this generally was also the case in the pairs work on these terms; coming from this setting with strong understandings would bode well for 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.

## IV. Discussion

The theme of this symposium is "Constituting Discourse Communities around Scientific Problems," and this paper describes an attempt to constitute a discourse community around the scientific problem of describing substances in terms of mass, volume, and density. We feel that the story we tell here illustrates both the complexity and the importance of this goal.

The complexity lies partly in the difficulty inherent in even apparently simple scientific problems. Describing substances, for example, is a superficially simple activity. The scientific activity of describing substances, however, is difficult and initially inaccessible to many students. The difficulty lies partly in the ways that scientific description is deeply embedded in a culture that is foreign to many students. It seems "natural" to scientists that we would approach the task of describing something by identifying a set of specific properties (in this case, mass, volume, and density), then specifying values for those properties in absolute or comparative terms. For many students, who are used to more metaphorical or analogical modes of description, this approach to describing substances is anything but natural.

Even for students who are comfortable with the basic approach of describing substances in terms of their properties, the knowledge that they must master in order to do so successfully in scientific terms is complex and detailed, encompassing new concepts, specialized techniques, new uses of language, and an understanding of underlying patterns and connections.

Thus constituting a community around the scientific problem of describing substances poses multiple challenges to a teacher. In most classrooms with diverse student populations, this means helping a wide range of individuals with unique needs and cultural backgrounds form a community that reflects Swales' criteria. The method we've described above involves constituting such a community around scientific discourse.

Students are challenged to appropriate scientific goals, standards, and mediational means, while still having an opportunity to populate the discourse of the community with their own ideas and purposes. In this way, students develop and use more scientific forms of language in situations that have some meaning for them. This instructional goal stands in contrast to the alternative, the ritualized use of scientific vocabulary seen in many classrooms today.

Still, one of the biggest challenges in this and other instructional approaches is dealing with diversity among the students. Even in constituting discourse communities, some forms of mediated action will inevitably be judged more useful than others. When the players have a stake in their actions, the question becomes one of bringing a diverse group of people together around common goals in inclusive, rather than exclusive, ways. This is perhaps the biggest challenge that remains.

The story we've told here is one of partial success. We think that our work has more clearly outlined some very daunting problems. But in this work, we see enough promise to count working towards constituting discourse communities around scientific problems as a worthy goal.

Inherent in this goal is the difficult nature of even simple concepts like mass, volume, and density. Our analysis shows much of this difficulty lies in the differences between common, everyday ways of thinking about similar concepts, and the more precise and controlled approaches that scientists take. This dynamic, as well as those listed above, describe well the difficult balancing act that teachers must perform in attempting to constitute discourse communities in which the goal is meaningful learning for all.

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