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ABSTRACT

This paper describes a sequence of lessons based on a modified version of the ESS Colored Solutions problem posed in an urban multicultural middle school setting in which students often worked in collaborative groups. As students encountered observable phenomena, they were encouraged to record techniques and observations, search for patterns in their data, and eventually develop explanations. The researchers examined discourse and interactions in working pairs, groups of four, and individual logbook entries to see how various tasks, settings, and interactions influenced engagement for each of the members of the group studied. Each member of the student working groups was observed to be fully engaged in the activities of developing and recording techniques and observations and finding patterns. The activity of developing explanations, however, revealed differential engagement based upon whether or not each student had focused on properties of the solutions as the salient feature of the system being studied. The researchers hypothesize that this differential may have substantial consequences when students encounter formal instruction in related scientific concepts. Those more engaged in generating explanations appear more ready to appropriate and use concepts as intellectual tools to explain observed phenomena. (Author)

Constructing facts and mediational means in a middle school science classroom

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ABSTRACT

This paper describes a sequence of lessons based on a modified version of the ESS Colored Solutions problem, posed in an urban multicultural middle school setting in which students often worked in collaborative groups. As students encountered observable phenomena, they were encouraged to record techniques and observations, search for patterns in their data, and eventually develop explanations. The researchers examined discourse and interactions in working pairs, groups of four, and individual logbook entries to see how various tasks, settings, and interactions influenced engagement for each of the members of the group studied. Each member of the student working groups was observed to be fully engaged in the activities of developing and recording techniques and observations, and finding patterns. The activity of developing explanations, however, revealed differential engagement based whether or not each student had focused on properties of the solutions as the salient feature of the system under study. The researchers hypothesize that this differential may have substantial consequences when students encounter formal instruction in related scientific concepts; those more engaged in generating explanations appear more ready to appropriate and use concepts as intellectual tools to explain observed phenomena.

Mass, volume and density are concepts that scientists use as powerful tools to describe substances, and to predict and explain many phenomena involving interactions among substances. These tools are held as common in the scientific community, as a result of their construction within that community by negotiation according to community standards. Scientists use the terms mass, volume, and density in precise ways. In general, since a precise and common understanding of these terms is prerequisite to membership in such a community, the variance in the meanings of these terms is minimal across the community *writ large*, so that they form part of a common conceptual and linguistic base shared by scientists who describe and explain phenomena having to do with matter. Many scientists use these terms in situations where conversational rejoinder is neither expected nor possible, such as published reports of research or in proposing and justifying new theories. In these situations, common and precise understandings of these terms and the underlying concepts they represent help make the work of the community generative and efficient. Little time is wasted negotiating and renegotiating meanings at this foundational level, and the community is able to build quickly on the work or findings of its members.

These terms represent concepts that, in themselves, cannot be directly "discovered" by interactions with the material world. Instead, mass, volume and density are historical artifacts of the community within which they were created. Their utility and applicability rests on the strength of a set of commonly held assumptions about the nature of matter and the world around us. They are constructs that help those seeking to describe and explain the nature and behavior of matter to do so in powerful and efficient ways.

In Voices of the Mind, James Wertsch (1985) calls these terms and the constructs they represent *mediational means*. For us, these are intellectual tools which emerge from and shape scientists' interactions with and about matter. Wertsch parallels the concept of mediational means with Vygotsky's *psychological tools*:

> "...the following can serve as examples of psychological tools and their complex systems: language; various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and mechanical drawings; all sorts of conventional signs; and so on" (Vygotsky, 1981).

Wertsch's contribution is to connect these tools to actions in specific contexts. He qualifies this view for abstract concepts, looking again to Vygotsky:

> Furthermore, within the most important form of mediational means in his account--human natural language--he recognized the possibility of decontextualization as manifested in scientific concepts...(Wertsch, 93)

For mass, volume, and density, one indicator of this decontextualized nature is their status as concepts. When one does not know the meaning of mass, for instance, it is not possible to directly observe a single instance or phenomenon that clearly delineates the concept. However, one might build an understanding of this concept across a variety of contexts in which it is useful in describing a feature of various samples of matter, and in talking about those samples in comparative terms.

> To explore the idea that concepts are both situated and progressively developed through activity, we should abandon any notion that they are abstract, self-contained entities. Instead, it may be more useful to consider conceptual knowledge as, in some ways, similar to a set of tools. Tools share several significant features with knowledge: They can only be fully understood through use, and using them entails both changing the user's view of the world and adopting the belief system of the culture in which they are used (33) (Brown, Collins, & Duguid, 1989)

Like tools that a carpenter might use, intellectual tools such as mass, volume and density can have tremendous power when they are appropriately applied in particular contexts. Yet, the power of these tools depends on matching their application to an appropriate situation, and employing them in useful and accepted ways within that situation. The cultural norms and standards of scientific working groups (proposing theories, backing them with evidence drawn from replicable tests, developing explanations based on accepted logic and evidence) determine, in large part, which situations are appropriate and how these tools are to be employed.

A central feature of the kind of scientific discourse that we refer to here is its precision. In appropriating and crafting this kind of discourse, necessarily, students must also develop understandings of the particular instances in which concepts like mass, volume, and density are most useful, and the range of uses for which they are acceptable. So, simply put, we are not talking about just "trying on some new terms" here, but rather attempting to create discourse events which reflect accepted understandings and usages of these concepts within the disciplinary community of science. While students may understand vernacular versions of concepts for which scientists might use these terms, these common versions usually have a wider range of uses and meanings. As noted above, mass, volume, and density are powerful in scientific circles because their meanings are universal and precise in these settings.

This, then, is a central tension in teaching students about these concepts; the classroom context may not require such precise usages for these intellectual tools at the outset of instruction (and in fact the student collaborative groups may never represent this kind of a context for the students, regardless of the instruction). But, we might characterize one of the initial goals of discourse-centered collaborative work as giving students access to these intellectual tools by providing situations in which they are encouraged to work out more precise understandings of these concepts than they might have brought to the instructional setting. Beyond this, a second goal is to provide situations which encourage students to use these mediational means in further attempts at describing substances and solving problems.

In the instructional sequence described below, as students encounter phenomena (first-hand), they are invited to observe carefully and describe what they observe to others. Then, in the course of group negotiations about conflicting data, students are encouraged to develop explanations for the observed phenomena. In our analysis of this instructional sequence, we noted that how students chose to participate in these negotiations seemed to directly influence the kinds of explanations they proposed, and thus their readiness to appropriate and use terms (and the named concepts) like mass, volume and density in their explanations of the observed phenomena.

Purpose of the Study

This study investigates the ways that some of the foundational concepts in physical science, namely mass, volume and density, find their way into the discourse of middle school students who are learning about properties of matter, changes in matter, and the kinetic molecular theory. We trace the development of these concepts in a class of sixth grade students as they struggle to describe and explain patterns of interactions among a variety of substances. Specifically, we will:

1. Trace the ways in which four individual students who are members of a collaborative group participated (or failed to participate) in classroom and group discourse about mass, volume, and density.
2. Examine ways in which the emerging discourse of the classroom community and the group within it was and was not facilitative of student engagement, student understanding of mass, volume and density, and student participation in scientific reasoning.

Methods and Data Analysis

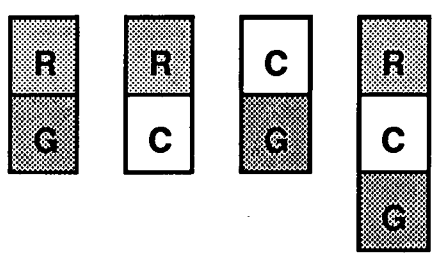
The study followed one group of four students (mixed with regard to ethnicity and gender) as they learned about matter and molecules over a ten-week period. The class was taught by a researcher who is an experienced classroom teacher. Data in the form of videotapes of whole-class and small-group classroom observations were collected, augmented by field notes, pre- and post-instruction conceptual tests, pre- and post-instruction interviews, and copies of students' written work and group projects. Analysis focused on tracing individual and group understandings over time, as well as close examination of the uses of evidence in argument, and the occurrence of common linguistic constructions in explaining phenomena within the group. We chose to study a small group over a long period of time, noting that within this group the students shared and proposed ideas, and negotiated standards. We wanted to understand both how students began these negotiations and how the character of discussions in the group changed as the students became more familiar with each other and with the mediational tools associated with the unit. Wherever possible, videotapes and written products were examined together in order to retain the rich nature of classroom interactions throughout our analysis.

This study is part of a larger 4 year study which focused on collaborative problem solving in middle school science. The larger study involved two classrooms of sixth grade students in one urban middle school setting (as well as a number of classrooms in a second site in a nearby city). Our collaborating teacher at this site, who had participated in this project from the outset, taught one class while a university researcher taught the class reported here. University observers attended each class daily; curriculum was negotiated in weekly meetings between the cooperating teacher and the teacher-researcher.

The Curriculum:

This study focuses on an instructional sequence within the ten-week unit on matter and molecules. This a nine day sequence which spanned weeks 2, 3, and part of 4; the students were working on Colored Solutions (a unit developed as a modification of the ESS Colored Solutions problem; for details of this activity, see Vellom et al, 1993). During this investigation, students worked in pairs with red, clear, and green solutions of differing density. Given vials, soda straws, and droppers, they were challenged to stack the liquids one atop another in as many different ways as they could. Then, working in groups of 4 students, they were asked to create and present posters which shared what they had learned and the stacks they had made (possible stacks are shown below). Once this was done, discrepant data from the groups were highlighted, and suggestions taken from the students on how best to proceed. Emerging standards for replicability came into play as a few students suggested repeating the tests, and relying on written records of the tests only (as opposed to verbal accounts). Once discrepancies were resolved, students wrote individual journal entries about the patterns that they had found in the data, and their explanations for them.

POSSIBLE STACKS



Instruction in this and other sequences within the unit was framed by a set of four activities which we characterize as typical of scientists seeking to build new knowledge about substances. These were denoted in class by the acronym TOPE, and presented to the students as follows:

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

Within the instructional sequence on Colored Solutions, students were periodically reminded that the day's activities should include or focus on particular elements of this scheme, and that in this way their activities might approximate those of scientists in working groups. (This scheme was the product of several years' attempts to engage students in the activities of scientific working groups, and the felt need for a relatively simple and easily remembered characterization of these activities.)

Some of our students' responses showed us that their first inclinations were to treat these four activities as a list of operations that scientists perform during investigations. They took them as discrete and to be done in the order listed. Thus, to many this was a 'recipe'. The teacher responded by emphasizing the flexible and often cyclical nature of these activities throughout the remainder of the unit. For example, students were taught that the first two of these activities, *developing techniques* and *making observations*, go hand-in-hand whenever scientists investigate substances or phenomena. *Finding patterns* was contextualized as an activity that occurs while scientists are investigating, as well as while they are organizing, thinking and talking about their data with others. We noted that *developing good explanations* (the fourth activity) included being able to remember the techniques and experiment well, and making good use of readings, notes, the ideas of others working on similar investigations, and the patterns that they had found. So, while our students may have initially treated these activities as discrete and ordered, in emphasizing the dynamic nature of the work of scientists, we hoped to paint a much richer and more realistic picture for them. We did so by making the nature of our classroom activities a subject of attention and discussion, and by exploring options for action with our students as the investigations proceeded.

One Collaborative Group:

The members of the group reported here are*:.

- Sandra: African American girl, quite academically successful. Also very socially successful. Well-respected by others in the class. Influential among her classmates.
- Kyle: African American boy. Less academically successful. At times very social, at others quite reserved. A follower, especially in social terms. Tries hard to please others, likes to be in alliance with respected others.
- Adam: European American boy. Academically successful, largely as a result of careful and diligent attention to detail. Very quiet, somewhat overweight and appearing self-conscious. Seen as a solid group member by peers.
- Lisa: European American female. Less academically successful. Often seen by other group members as "slow" or "ditzy". Also known as "nice" by almost everyone. Socially, often marginalized. Sometimes demands that she be treated with respect by other group members.

*physical characteristics and academic prowess as observed. Behavioral and social notes are impressions of researcher/observer or author.

Colored Solutions as Construction Zone

The teacher began the activity by making a stack of red over clear in a vial for the students, and passing it around. After brief instructions, our students (in pairs) quickly set about trying to make "stacks" of their own. Because of experiences in the previous year of this project, students were asked to focus on techniques and observations (the "T-O" of TOPE) during this exploratory phase of the investigation. Students were reminded at the outset, and often during the initial work with the solutions, that scientists in working groups generally have to make accurate records of their work in order to be able to figure out what patterns might exist later. In addition, students were encouraged to share findings with their partners (within pairs) as they made stacks. To further these ideals, students were asked to set up a page in their logbooks in two columns, titled Techniques and Observations, respectively. The teacher modeled writing the test that was performed (and how it was done) in the first column, and the observed results (what the solutions looked like) in the second. So, each attempt to make a stack of two or more solutions in a particular order was to be recorded before students moved on to a new trial. Adam's journal entries for the first two trials can be found in figure 1 below.

This organizing format, together with the dynamic of working in pairs during this part of the investigation (as opposed to groups of four) had definite and observable benefits in terms of moving our students away from rapidly exploring without making records, which had been a source of frustration in previous years. We observed pairs of students meticulously discussing, performing tests, observing vials from different angles, showing vials to partners and discussing what they saw, and negotiating wording for their records. We noted the careful and considered way that

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.

Figure 1: Adam's first two entries in two-column format

most of our students approached this task. This appeared much more mature and "scientific" than the approaches of students in previous years; we did observe a slight increase in the accuracy of results that students reported from these initial forays into testing the liquids. In our target group, Adam and Lisa (a working pair) performed four tests in vials and three in straws, with one success in each. Sandra and Kyle ran nine trials in vials and one in a straw, reporting three successes in vials.

Below, Adam and Lisa were exploring with the solutions, attempting to make them stack:

Lisa- The observation is that it turns olive green. (passes materials to Lisa)

Adam- What do you want to do?

Lisa- Is this how you dump it?(Adam describes how to use dropper, then shows her.)

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.)

Adam- (to himself) It turned olive green. (to Lisa) Is that olive green again?

Lisa- It turned colors. (they both write)

Adam- You put red in first, right?

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.

Adam- Okay

Lisa- Now....

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.

Lisa- What happened? What'd we do?

Adam- (as writes) We put green in straw, we put red in straw... it turned clear.

Note in this excerpt that both Adam and Lisa were fully engaged in the problem of making the liquids stack, and that the conversational dynamic of turn-taking supported this engagement. Each of these two students expected the other to be a full partner in the investigation, including the manipulation of the liquids, observing and interpreting the results, and recording those results in a way that was mutually acceptable. While it is evident that Adam was more adept, it is equally the case that he did not choose to single-handedly run all of the tests, relegating much less of the task to Lisa. Instead, he chose to assist Lisa in her attempts, teaching her the techniques that he knew so that she was able to perform the manipulations as well. In so doing, Lisa's engagement was ensured.

In the following transcript, Sandra and Kyle were working with solutions in vials:

Sandra: It mixed together

Kyle: Uh-Uh, it's a layer at top

Sandra: Oh, OK, it's down in there...gee...so it stacked?

Kyle: I put green and red, green and clear

Sandra: Clear stacked on top of green (they write)

Kyle: OK, number four

Sandra: Put some green in vial, red and clear...can't use this (she's holding a vial) because it's got some clear in it

Kyle: You gotta get the clear out of it

Sandra: How do you get clear out of it...oh, gosh...OK, oh, god. Actually, it's kinda out...OK, well some red in...me turn, me turn, me turn...what are you doing?

Kyle: red goes into green

Sandra: put some green in a vial and put an eyedropper of red in (she does).

Kyle: go

Sandra: (to herself) Sheez, don't start makin' all your mistakes...(to Kyle) OK hold on...Nothin happened, it mixed together (showing Kyle)

Kyle: it got darker...it's like brownish red

Sandra: a very light brownish red/put a very light brownish red (both write)... Put clear in vial... clear in vial, eyedropper of red... I should, shouldn't I?

Kyle: you don't have the number of eyedroppers in there.

Sandra: How's that?

Again, we see that Sandra and Kyle had mutual responsibility for all aspects of the task, as described above. While this pair's interactions were characterized by each of the students talking their way through the manipulations (i.e. they talked almost constantly as they worked), their talk showed joint custody of the tasks and full engagement, even though Sandra was characteristically the one who decided on the wording of what was recorded, and Kyle clearly deferred to her in situations where this was the object. So, while there was some differentiation among the students in each of these pairs in terms of the academic requirements of the task, this did not create a dynamic in which some students were more engaged and others were less so. During this exploratory phase 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. And, while they were working on this two-column format in their logbooks, we believe that they were also involved in less overt ways in figuring out what patterns might exist in the liquids. While we do not have direct evidence of this, the ease with which most members were able to suggest patterns a day after this interaction leads us to believe that this was a vital part of the territory in these interactions.

While the two-column recording format appears to have had a positive effect in terms of orderliness and results, this gain was not realized without cost. We did note that one of the academic features of the task, recording trials in their logbooks, occupied a greater portion of the activity for the two students (Lisa and Kyle) who were each the less academically successful student in their respective pairs. In both pairs, when time required to record events impeded progress in running the trials, the more successful students simply loaned their logbooks to their partners, who copied verbatim as the next trial was prepared.

Adam- Number four. That's what we're on. (He reads and motions her to do. He reads her through it.) Green, dropper of clear.

Lisa- Clear in what?

Adam- In the vial. And put a dropper of red. (she's not careful at all.)

Adam- Okay, what happened.

Lisa- (She holds it up so he can see.) It did not mix.

Adam- Where's the red at?

Lisa- I mean, it mixed. (Video note: He says red and green mixed, and there's clear on the top. She says it's just a reflection.)

Adam- No, it's there.

Lisa- Okay, what do we put down? (He reads his answer and she writes.)

Initially, we assumed that this pattern meant that the more academically successful students were in charge of what tests were run, and dictated what should be written in each case. However, this assumption was not supported fully by our data, as there were instances in which Kyle or Lisa determined which test was to be run, voiced the wording for Sandra or Adam to record, ran the test, and spoke first about what they observed in the vial or straw. Instead, we now view this dynamic as indicative of a shared sense of responsibility for the task and products which, in our experience, is much more frequently found when pairs of students work together (as opposed to larger groups of students).

Thus, where groupings of three or four students have often resulted in different levels of engagement and differences in role and status (see Eichinger et al, 1991; Kollar et al, 1994; Kurth et al, 1994; Vellom et al, 1993) our experience with students working in pairs was much more positive in terms of equity and management (within the pair). Every student seemed to have equal opportunity and stake (was on equal ground) in deciding which stacks were possible, and in making claims. We observed students initiating and sustaining conversations in which one member taught another. We also noted each member of the pair performed a greater range of tasks than he/she might have in a larger group, where roles tended to be socially defined (and thus less flexible) often by majority assent. In short, in our pairs we saw a true sharing of responsibility for the task and the products, as well as a willingness to offer help and to discuss on an equal footing; these positive aspects were either fleeting or not present in larger group and whole-class contexts.

Once each pair of students had performed a number of tests on the liquids, these pairs brought their data together in established groups of four students, in which they were challenged to create a poster that presented their data to the class. Guidelines for the posters stated that they should include important techniques, observations about stacks that were possible or impossible, and that groups should tell about patterns that they had found. Initially, most students seemed to have some difficulty imagining just what a statement of patterns might look like. Since finding patterns is not a well-defined activity (in relation to observing, for instance), the teacher chose to model just what kinds of activity this might entail, as well as the kinds of statements that students might make about the solutions that would represent patterns. Once the teacher modelled these statements and activities, though, we noted that all four of the target students were able to participate in pattern-finding in the data. In the following transcript, Nick (a European American boy who is somewhat of a social gadfly, but is academically successful) was a new member to this group, placed here due to the absence of his other group members. The group was preparing a poster plan, a preliminary step to actually producing it:

Sandra- Okay, how 'bout if we have like techniques, and you (Nick) you all have some techniques. We have at least five techniques because we have five people here. And we'll have a little square and we'll write all your techniques down... then let's see...

Adam- I don't have any techniques.

Sandra- Patterns.

Lisa- I like Nick's idea. I like Nick's idea.

Sandra- Nobody in this group is creative.

Nick- (to Sandra) Oh, shut up.

Kyle- He can draw.

Nick- I can not draw... (unintelligible)

Kyle- What do we have to draw, what do we have to draw?

Sandra- (simultaneously) We have to draw vials, um... I know... in each corner we'll have a little beaker or something. (to Aaron, a student in a neighboring group) I'm not talking to you. (to her group) This is going to be a straw okay? Now, this isn't going to look right.

Adam- Now, why is that going to be a straw?

Sandra- That's not a straw...(draws) anyway.

Nick- What's your idea?

Adam- Aaron, shut up.

Sandra- In every corner we have like a beaker or a vial or something and write like, our techniques in it.

Nick- Use MY idea!
Sandra- No it's not, it's different.
Nick- Just "use it" I said.
(Adam tells other group to shut up, whoever is listening.)
Kyle- (to Nick) Ain't nobody good enough to draw, okay?
(Sandra and Nick repeat "okay" the way Kyle did.)
Sandra- I'll color. (laughs)
Kyle- I can color great, but I just cannot draw.
Nick- (mocks) I cannot draw.
Sandra- Okay, so we have a vial. This is going to be a vial, right? So you make a big vial and you put all your patterns in it. All the patterns you know. Then you make like a beaker or something.

Note that in this series of interchanges, the responsibility for the task was shared, but much less equally than in the pairs. In this larger group setting, Sandra and Nick, and to some extent Adam, formulated and discussed features of the poster. While Lisa and Kyle were still very much socially involved, and still involve themselves in group activity and production by taking part in the conversation around the poster plan, they were clearly less involved in suggesting what might go on the poster or how they might best represent it. While it is a truism of groups that generally someone must take leadership roles of some sort in order for the group to get work done, in this instance we observed that three (out of five) students participated in the intellectual work of creating the poster, in terms of the content and design. When the poster from this group was completed, we noted that the design features that Adam, Nick, and Sandra had worked out were evident. We also observed that Kyle and Lisa participated in actual creation (drawing, coloring, and writing) of the poster, but that they looked to these other group members for direction and approval of their work.

The next sequence in our instructional schedule focused on the "E" of the T-O-P-E instructional frame, developing explanations. After all of the posters were presented, the class was prompted (by a series of questions) to first discuss (in pairs) and then write a logbook entry about the patterns that they had recorded (from the poster presentations), and their explanations for why the liquids behaved as they did. One way of looking at the explanations proposed here is to think in terms of the mediational means , or intellectual tools, of which Wertsch (1991) writes. These intellectual tools, in this case the ideas of heaviness and density, are concepts that help scientists and those familiar with their ways of acting, thinking, and communicating, to describe and explain the behavior of phenomena like our Colored Solutions.

So, the challenge to write about why the solutions acted the way they did was intended to draw students into consideration of causes for the observed phenomena, and away from the earlier focus on defining the phenomena themselves. The realm of cause (the "why" to the "what" that they had worked out) is where these mediational means, including understandings of the precise ways that scientists use them, are most powerful and useful. Of our students, Sandra and Adam attended to the salient feature of the system (an inherent property of the liquids themselves) that made them ready to learn about these mediational means. So, one striking difference that we noted between these two students and their partners might be stated in terms of their readiness to learn about these intellectual tools.

The four journal entries from our target group are reproduced below (recall that Adam & Lisa were a working pair, and Sandra & Kyle were another). Each of the students discussed patterns first, then proposed an explanation, as requested by the teacher.

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

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

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

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

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

The task of proposing an explanation of the pattern, however, seemed to forebode some difficulties for Kyle and Lisa. While Adam and Sandra had both proposed explanations that focused on which liquid was "heaviest" or "most dence" (constructions that we take to be equivalent, since at this point the distinction between mass and density had not been a topic of discussion or instruction in this class), Kyle proposed that the liquids stack the way they did because of the way that they were put into the vials, a matter of technique. Clearly, Kyle had not settled on the liquids themselves (their properties) as the factor determining which liquids would stack on top of which others. Unlike Sandra and Adam, Kyle focused on issues of technique rather than properties inherent to the liquids.

Lisa's writing presented a much less clear picture, one in which she may have come close to an appropriate focus on the liquids. She wrote, "Clear probaly dozen't have as much chemicals in it as red. But where does green stand? Green dozen't really have a place it's just kind of hanging". Figuring out exactly what was going through Lisa's head is impossible, but two plausible explanations for the "clear probaly dozen't have as much chemicals in it..." statement come to mind. First, Lisa might have some idea that more chemicals make a solution float. While possible, we could find no evidence of this thinking in previous or subsequent interactions (including post-instruction interviews). A second possibility is that Lisa based her idea of "chemicals in it" on color. Thus, the red would have more chemicals than the clear. Lisa's subsequent statement about the green being "hanging" simply said that she had not reasoned through where the green solution fell in this plan. This discontinuity might (again, we cannot be sure) have been related to Lisa's attaching observations about color to her understanding that green goes to the bottom, unlike red.

Discussion

The initial focus on figuring out which stacks could be made and how to go about making them we liken to the construction of facts in scientific working groups, described by Latour & Woolgar (Latour & Woolgar, 1986). This process begins when a scientist makes a statement or claim related to his or her data. This claim can be a summary of the data, a feature or pattern of it, or any of a number of extensions from it. The claim may initially appear with qualifiers, which are removed in a process of validation within the working group and the larger community.

In our classroom, our students attempted to stack liquids, and their recorded observations became the basis for claims (many first stated verbally within the working pairs and later presented on posters made by groups of four) about which stacks were possible, and how they could be made. These became the "facts" around and about which subsequent negotiations occurred. The initial qualifiers in our class consisted in some cases of the identities of the claimants, in others a specialized technique (also a claim!) and in some cases an immediate counterclaim. These claims were then subjected to intensified scrutiny within working groups as well as in the larger arena of the classroom. Those upon which there was class consensus were accepted as true stacks; those upon which there was disagreement or a lack of consensus were then tested by each pair of investigators (and thus the entire community). This step resulted in each pair of students running nine additional tests as a part of the validation process, which took another whole day. When these results were reported, consensus was reached quickly on seven of the claims. The other two were retested publicly by a pair composed of a claimant and a counterclaimant. In both of these cases the claimed stacks could not be replicated, leading to a class consensus that the stacks were impossible.

This classroom process of validation bears significant similarity to the process of social construction of facts described by Latour & Woolgar. We note that the initial claims were recorded by anywhere from one to thirteen pairs of students, and that the first step taken was an attempt to remove qualifiers within the classroom community-- to find claims that were universally acceptable. The claims accepted at this phase then became a part of "what was known to be true" by the members of the community, and their energies then turned to the stacks in contention. Replicability, an important principle for validation in scientific working groups, was employed in a process in which each pair had some say. In scientific communities, the reputation of the claimant is sometimes enough to sustain a claim in the face of a lack of replication. This was not so in our classroom, where "seeing is believing" was the bottom line for our students. Claims which could not be replicated were often abandoned by the claimant, and, lacking a proponent, fell from the list. We did not observe instances in which possible stacks were dropped, nor did the teacher intercede in defense of claims that the class rejected. In short, the validation process described here worked. It ran smoothly, and all claims were sorted according to these procedures. In the end, the class had settled on a list which included all four possible stacks, and no others.

Once claims for which stacks were possible were resolved, discussions about patterns in the data and possible explanations for them became the currency of group and classroom interactions. In this transition, we saw the emergence of different levels of engagement within the groups of four working on the posters. Those students who had been judged most academically successful prior to this instructional sequence generally took on the weight of the conceptualization tasks related to the poster, and thus most often involved themselves in discussions that were directly related to the concepts of mass, volume and density. In these interchanges, we noted that other group members were rarely completely uninvolved, but more often took roles which facilitated producing the poster rather than generating explanations.

Subsequent attempts at writing explanations for the behavior of the liquids revealed that the students who had been most involved in the conceptual work of creating explanations were more likely to propose explanations that focused on what scientists consider the salient features of the system, namely the properties of the liquids themselves. Thus the differences among Adam's, Kyle's, and Lisa's "incorrect" explanations are highly significant. Although Adam lacked a specific conceptual tool (the distinction between mass and density), his choice of features of the system to attend to and his approach to writing an explanation signaled his readiness to participate in scientific discourse. We use the term "discourse" here in the way it is defined by Gee (1989). A discourse is not merely a way of talking, but an entire *identity kit*.

> 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).

Although Lisa and Kyle (and other less academically successful students) maintained active social involvement in the work of the group, they did not approach the "identity kit" of discourse in the same way as Adam and Sandra. Instead, they took marginal and supporting roles with respect to the key activity of generating explanations. We saw these students as being at a distinct disadvantage in the next few days of instruction (beyond the sequence under examination here), where the concepts of mass, volume, and density were formally taught. Since these students had not focused on properties of the liquids as the main determiner of their behavior, this instruction did not focus on questions or issues that Kyle and Lisa had identified as personally salient. Similarly, their roles in the group discussion had given them little practice in the discourse strategies, terminology, and ways of thinking that would allow them to use the concepts of mass, volume, and density as powerful intellectual tools.

We would like to suggest that our initial conception of a continuum between the vernacular constructions that students bring with them to the instructional setting, and the precise constructions that scientists use to describe and explain their world, crystallizes some of the challenges that we face in attempting to better educate all students. In the sequence of lessons examined for this paper we experienced mixed success in helping students to move along this continuum. All the students in the class made significant progress in constructing facts about colored solutions. They developed new experimental techniques, more precise and powerful ways of communicating about their techniques and observations, and social processes for deciding which reported observations to accept as "true", as well as an accurate consensus about which stacks were possible. We observed working pairs sharing substantial responsibility for the task, and noted that in situations where establishing the facts was the focus, full engagement for all students was the rule.

We were not uniformly successful, however, in helping the students to construct the concepts of mass, volume, and density as mediational means for scientific reasoning. This lack of success seems intimately tied to our students' readiness to try on the 'identity kit' that comes with scientific discourse. Scientific explanation is a specialized genre, quite distinct from the other kinds of explanations that students are likely to encounter in social situations. So, a part of the challenge for us is figuring out how to make these explanations more accessible and valuable to them. Whether specialized scaffolding structures, including meta-views of their own work, can assist these students is a subject worthy of investigation.

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