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ABSTRACT

This study investigates the fate of claims made by middle school science students working in collaborative groups in a multicultural urban classroom and the concomitant effects on engagement and understanding. Given problems of a complex and open-ended nature in a learning community setting, students were challenged to establish group positions and to explain these positions to the classroom community. In the negotiation and collective validation processes that ensued, consensus as the basis of acceptability was held as the standard. Individual claims often became the claims of groups of students as the class worked together to separate data from "noise". The study shows how groups of students and individuals within groups came to understand a number of science concepts relating to the kinetic molecular theory and how their understanding related to the ongoing bargaining process surrounding roles within each group. The researchers noted that students who were active in a wide range of group negotiations tended to develop deeper and more meaningful understandings of concepts, while less active students displayed a more limited understanding characterized by their ritualized use of scientific language. Student working groups each established its own unique patterns of interaction which often served the social aims of some group members. In general, collaborative activities appeared to best serve students who were already academically successful. (Author)

Scientific Reasoning in School Contexts

(formerly Creating Social Contexts That Encourage Students' Scientific Arguments)
Presented at the Annual Meeting of the National Association for Research in Science Teaching
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ABSTRACT

This study investigates the fate of claims made by middle school science students working in collaborative groups in a multicultural urban classroom, and concomitant effects on engagement and understanding. Given problems of a complex and open-ended nature in a learning community setting, students were challenged to establish group positions and to explain these positions to the classroom community. In the negotiation and collective validation processes that ensued, consensus as the basis of acceptability was held as the standard. Individual claims often became the claims of groups of students, as the class worked together to separate data from "noise". The study shows how groups of students, and individuals within groups, came to understand a number of science concepts (having to do with the kinetic molecular theory), and how their understanding related to the ongoing bargaining process surrounding roles within each group. The researchers noted that students who were active in a wide range of group negotiations tended to develop deeper and more meaningful understandings of concepts, while less active students displayed a more limited understandings, characterized by their ritualized use of scientific language. Student working groups each established their own, unique patterns of interaction, which often served social aims of some group members. In general, collaborative activities appeared to best serve students who were already academically successful.

Scientific concepts and theories are intellectual tools. These tools enable us to describe, explain, and make predictions about the natural world with a precision and power that far exceeds what we could do without them. Scientific concepts and theories are also used in technological design processes that allow us to influence or control the natural world in increasingly powerful (if also ever more problematic) ways.

Science teachers generally recognize at least two types of goals centered on scientific concepts and theories in their teaching. The first goal (traditionally labeled *science content*) involves helping students to control the intellectual tools of science and use them for their intended purposes. The second goal (traditionally labeled *the scientific method* or *science processes*) involves helping students to understand how concepts and theories are developed in scientists' attempts to explore and understand the world. Teaching toward this second goal has often involved the reduction of scientists' activities to lists of discrete skills (science processes) or to a clearly defined sequence of steps (the scientific method). These approaches to teaching about scientific investigations are problematic because they transform the complex, socially embedded processes of scientific sense-making into traditional school tasks-- "bits" of curriculum that can be easily managed in teacher-centered classrooms.

Recent efforts to reform science teaching have featured classroom environments which are less teacher-centered, and which model many of the ideals and processes of scientific communities. Significant features of this kind of classroom include valuing of student ideas as currency for classroom interactions, teacher as co-learner, shared responsibility for maintenance of the learning environment, and evolving standards for collective validation of ideas. Often called a *learning community*, (Ball, 1990; Lampert, 1990; Roth & Rosaen, 1990) this kind of classroom holds promise for instructional situations in which the teacher values modeling student efforts after the working ideals of scientific communities.

This paper describes an episode from a curriculum in which we attempted to involve sixth-grade students in activities that more closely approximated scientific data gathering and theory development. In particular, we had *three* goals. First, we wanted students to gain an appreciation of the power of collective efforts to understand the world--of how groups of people can develop collective understandings that are more powerful and systematic than any of them could achieve alone, even when there are no books or experts to tell them the answers. Second, we wanted to help students develop the social and intellectual tools and skills that would allow them to participate in these kinds of collective reasoning processes. Third, we wanted students to begin gaining an understanding of the cultural and epistemological status of scientific concepts and theories. As products of a rigorous process of collective validation by scientific communities, they are deserving of attention and respect, but they remain human constructs that retain the perspectives and prejudices of the communities that produced them.

Within this context, our study examined the kinds and nature of arguments that students made, what they learned in the process of negotiating content and process issues, and the nature of the interactions within their collaborative groups. This last focus became an increasingly important point of analysis as we attempted to understand the interplay between group interactions and individual understandings, and how these determined or were determined by interactions in whole-class discussions. We saw all of these issues as intimately tied to (and perhaps partially determinant of) the levels of investment that our students were willing to make in order to solve problems in a collaborative classroom setting.

The Problem

A key problem for students in these negotiations, as well as for scientists in their working relationships, concerns how one views and treats data that one has gathered in any investigation. This problem can be simply put as a question: How does one separate the data from the "noise"? How the students resolved this issue within their collaborative groups, and how the issue was characterized and resolved in the whole-class setting is the central theme of this report. Just as student and teacher decisions about this issue affect the students' views of the nature of the scientific enterprise, so too do we see the way that scientists answer this question as a key feature of reasoning and negotiation in working relationships among and between scientists.

When scientists talk together about data that they have gathered, and when they have as their purpose decisions about the veracity and application of the data in question, there are a number of standards and conventions that prevail. These standards and conventions are a product of the social and intellectual history of the scientific endeavor. They include, for instance, the standard that data must be replicable in order to be accepted within the community. This standard is of such importance in scientific communities that individual efforts are generally not reported until this standard has been met. There are numerous examples of the pitfalls of reporting data that has not met this standard, notable among them the cold fusion debacle of recent years.

Underlying replicability as a standard for judging data is another, deeper value of scientific communities, which has to do with consensus as the basis of acceptability of data and theories. Unlike, for example, political democracies, scientific communities do not resolve issues involving the acceptability of data and theories by majority vote. Rather, these issues are treated as unresolved until there is a broad consensus among those scientists who are judged by the community to be knowledgeable about an issue. Sometimes, as in the case of cold fusion, this consensus is achieved in a year or two. In other cases, achieving consensus may take decades. As Kuhn (Kuhn, 1970) suggests, sometimes consensus is achieved only when the adherents of one point of view retire and fail to recruit new followers in the next generation. Given the need for consensus, replicability emerges as an important standard for data because, for scientific skeptics as for other people, "seeing is believing."

Though this standard could be considered to be a critical and necessary underpinning of any negotiations about data in the scientific community, it is not a standard in the everyday social negotiations outside that community. Here, arguments based on hearsay, persuasive acumen, social status, hyperbole, and any of a number of extensions of logic are common and acceptable. In science classrooms, too, the problem of deciding which data are replicable is usually dealt with in ways quite different from those of scientific communities. In most classrooms, acceptable data are those that approximate the results the teacher knows to be "correct." In other "discovery-oriented" classrooms, virtually all claims are accepted uncritically. In either case, students gain little appreciation for the nature or the complexity of negotiations about data that take place in scientific communities.

Thus, for students, the problem of "separating the data from the noise" encompasses both understanding and accepting the standards of consensus and replicability so important to scientific reasoning, and learning also that a variety of arguments which are acceptable and useful in other contexts carry little weight in negotiations about making sense of observed phenomena. Given that this problem is so important in scientific working groups, and so complex in nature, studying how it plays out in classroom collaborative settings provides us with examples of the grounds on which students make decisions about what is important, especially in an endeavor where the commonly understood bottom line for many students is that "in science, you have to be able to prove things with your data."

Common approaches to this problem in the school setting might include teaching students algorithms for the "correct" methods for handling data, or to present the standards and conventions of the community of scientists as arbitrary, but still useful and necessary. These approaches have their strengths, especially in terms of their use of historical examples ("classic experiments"), and the typical modeling of scientific processes that they include. This paper, though, is a case study of a different approach, in which we sought to help students to see the underlying rationale for these conventions as a way of teaching them. Our goals, which include appreciation of the power of collective efforts, and understanding of the status and importance of concepts and theories, and developing social and intellectual tools and skills for collective reasoning, seem best fitted to this third approach.

In this approach, consensus without coercion is a key idea around which negotiations about data are structured. We have chosen this path as the most promising in terms of students making meaning and use of these conventions and standards. In our classrooms, students first identified discrepancies in the data reported by groups of students, and asked questions that established and defined conflicting claims. Though this process was not as even or well-directed as we might imagine it to be among scientists, eventually students returned to the phenomena to try to "prove" their claims, and the resulting discussions focused on whether sufficient data existed for proof. We suggest that such discussions, in the social (rather than individual) domain, establish and help students to experience the value of the standards and conventions that are so important to scientific communities, within the classroom context.

The Lessons

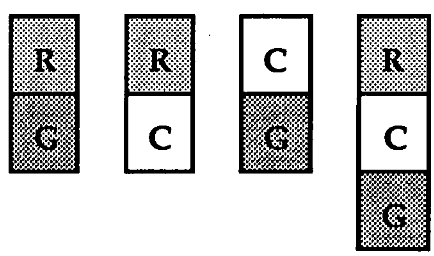
The lesson cluster described here, a modified version of the ESS Colored Solutions Unit (for details of this activity, see Anderson & Palincsar, 1992) was the first science activity in the instructional unit. Students had been working in collaborative groups for less than two weeks. We viewed examination of these episodes as an opportunity to learn more about how students' responses may be shaped by previous social and classroom experiences, and also to examine how social arrangements for work and discussion can contribute to the emergence of new patterns of interaction in these situations.

Students were first introduced to three colored solutions:

Color	Symbol*	Ingredients
RED	R	water, food coloring
CLEAR	C	weak salt water
GREEN	G	strong salt water, food coloring

(herein we will use these symbols* to refer to the solutions, for clarity's sake). These solutions differ in density, and with care can be layered or "stacked" one atop another according to density. Thus, the order in which three solutions would stack in our lessons (from the top down) was Red/Clear/Green (R/C/G); other stacks of two solutions could be made as well, following order of density (R/C, C/G, and R/G). These are the only possible stacks.

POSSIBLE STACKS



The sequence of events for the entire lesson cluster appears below (Figure 1). The teacher (Mr. A) introduced the lesson cluster by showing students two phenomena: if the Red solution is dropped (with a dropper) into a vial of Clear solution, it floats to the surface; students were also shown that a Red solution will stack on top of a Clear solution in a soda straw. The students were then challenged to make as many different stacks as possible.

They next spent two sessions working in their groups of 4 to explore the colored solutions. Each group received colored solutions, vials, droppers, and soda straws, as

Figure 1:

Calendar for Colored Solutions Activities

DAY	LESSON SEQUENCE	STUDENT ACTIVITY
Description of problem, students explore with solutions		
1*	• Introduction	• T-led demo of R/C
2	• Introduction • Group work	• T gives instructions • S's explore with solutions
3	• Class discussion of norms • Group work	• S's reflect on previous day • S's explore with solutions
4	• Group work	• S's finish working with solutions
Students plan and make posters, and present them		
4	• Preparing poster plan	• S's gather and report data
5	• Class discussion of poster plans • Preparing poster	• S's examine poster plan • S's negotiate reporting of data
6	• Preparing poster • Grading groupwork	• S's negotiate reporting of data • S's reflect and evaluate their group
7	• Preparing poster • Preparing presentation	• S's complete posters • S's practice poster presentations
8	• Poster presentations	• S's present posters
Class works towards consensus on possible and impossible stacks		
8	• Poster presentations	• S's and T ask questions, record data
9	• Resolving conflicts in data	• T-leads class in gathering/verifying data • S's recheck stacks to verify reported data
10*	• Resolving conflicts in data	• T-led attempt to resolve G/C/G, students vote 50/50
11*	• Resolving conflicts in data	• T-led attempt to resolve G/C/G, students vote 28-1
12*	• Recording final data set	• S's record stacks, discussion of predicting new stacks

* indicates partial day spent on this activity. S=student, T=teacher.

well as a set of cards with prompting questions guiding students to describe, find patterns, explain, and ask questions. One question, for example, asked students to describe what happened when each color of solution was dropped into each other color. Another question asked which "stacks" of solutions were possible and which were impossible. A third question required students to explain why the solutions floated, sank, and stacked in the ways that they did. Although students were encouraged to clarify their evidence and conclusions, and were informed when different groups were arriving at different conclusions, they were not told how to do the investigations, nor were they told whether their conclusions were correct or not.

At this stage the students each worked on making stacks by themselves, even though they were seated in groups of four and had common materials to share. Interactions centered on showing each other the results of different trials, particularly if the results were something other than a brown mixture. Results were noted by other group members summoned to do so, and then quickly discarded and a new trial begun. We did not observe students demonstrating how they made particular stacks, nor did we see evidence that students recorded stacks that they had not been able to make, but that others had shown them. In short, the interactions within groups in this part of the activity were minimal and tentative, and the actions of individual students within groups could best be described as *parallel* to those of their peers, rather than *in concert* with them. There was little or no collaborative effort during this exploration phase, even though the students were seated together in groups and had been given a group set of supplies and guiding questions, and despite repeated suggestions by the teacher.

Beginning on day 4, the students met in their collaborative groups to compare their information and to create a poster reporting what they had found. This was the first time that most of the students found out in any formal way what stacks the other members of their groups had made. Many students had few (or no) stacks recorded, and participated by making verbal claims about stacks. Faced with the task of creating a poster which presented the group's data (written guidelines stated that each poster should contain something from each of the four group members creating it), each group worked out its own procedures for getting the task done. Most groups, as mentioned above, made the poster a repository for all claims. Yet, even in doing so, very different methods evolved across groups; these seemed to depend heavily on who was in the group, and what the bottom line was for them. In making their posters students were encouraged to work from the observations that they had made and recorded as they worked with the solutions. Issues of verification and replicability of data were left to the groups, and the solutions were made available in case groups needed them to resolve conflicts in reported data.

Few groups returned to using the solutions to settle claims about which stacks should go on the posters. In fact, challenges within groups were rare during this activity. Many of the groups did not formulate a cohesive plan for deciding which data to report. Instead, several of the groups simply made sure that the poster contained all of the stacks that anyone in the group reported as possible. In this way, the posters became repositories for individual claims of possible stacks; each of these claims was reportedly backed by individual observations, but no groups were observed excluding data from the posters on the basis of disagreement about its truth value. None of the groups' public repertoires appeared to include standards for replicability of data like those that are critical in scientific working groups.

One further result of this activity was that each of the seven posters reported at least one stack that was not possible. When the posters were presented, the teacher and class listened to each group report the possible stacks from their poster, and recorded these in their notebooks. At the end of each presentation, students observing the presentation were encouraged to ask questions of the presenters. Several of these questions had to do with whether certain stacks were possible, and some students asked how particular stacks had been made, but none expressed direct doubt about claims made by other classmates. Thus, only <u>after</u> the posters had been created and presented did verification of data become an issue for the majority of the students, and then only because the teacher signaled that this was the next part of the lesson.

The remaining four days spent on Colored Solutions were characterized by attention to the central problem reported here. Through a series of whole-class discussions and repeated attempts to replicate stacks that had been claimed on the posters, the class and teacher eventually came to consensus about which stacks were possible and which were not. It is to the stories of three of these stacks that we now turn. In them we see graphic examples of the kinds of arguments that our students made and their struggles to establish standards within their classroom community. In these examples we also see evidence of the critical nature of the role of the teacher in shaping these negotiations, and hence in influencing the messages that students get about the nature of the scientific enterprise.

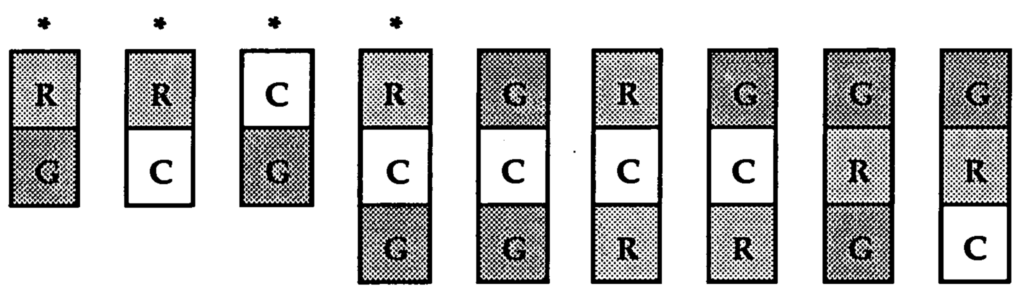
In light of these considerations, we will examine each of the three stories from the perspectives of the emergence of standards, as well as the social bases for action. Specifically, we will focus on consequences experienced by individual students as well as groups of students in the reporting and negotiation about each stack. In addition, we will note examples of social pressure to allow non-replicable data, and the students' failure to use patterns in data as the basis for challenging claims about stacks.

We also chart the emergence of replication and reasoning from patterns as standards in the class and in the small groups.

<u>The stories of the stacks</u>:

When all posters had been presented, the teacher made a public list of all of the stacks claimed (see below). Note that only four of these stacks are possible (those with asterisks above), and that virtually no verification of data had occurred by this time.

<u>CLASS LIST OF STACKS</u>



Mr. A then asked groups to work on answers to the question cards (see p. 10), which focused the students on summarizing and clarifying what they had learned about the solutions. One of the questions was "What are all of the possible stacks of two and three solutions?" When this group later reported their answer to the class, they noted that there were many conflicting claims about which stacks were possible, citing some stacks that were claimed on most of the posters, and others that only appeared on one.

> Mr. A: So how are we going to answer this question since there are a couple different opinions?
> Carrie: Could we do another experiment and see if all the different ones they said you could do really can be done.
> Mr. A: I like that idea so lets talk about how we can do that experiment.

> Emily: I've got an idea for, uh, well you make a chart for each group, for what things they think are possible, and then you could check and see which ones everyone had...

In Carrie's suggestion, we see our first evidence of a standard of replicability; Mr. A picked up on this suggestion, making retesting each claim a central feature of the validation procedure. Emily's suggestion was to add order, or systematicity, to the testing procedure--a feature that became equally critical in keeping track of the many claims and additional data that was to ensue. In taking these students up on their suggestions, Mr. A valued the ideas of these students, and helped others in the class to see (in their use) how scientists use these same methods to solve problems in data collection and validation. He accepted standards held by two members of the classroom community; as the stories below illustrate, though, most of the members of the class did not understand how to use these standards at this point.

Green/Red/Clear

This stack was claimed by just one group on their poster (recall that this is not a stack that can be made). In the class session in which Mr. A was taking nominations for stacks to be tested, Walter (a member of that group) nominated this stack. He was then designated as the tester, and went to the counter at the back of the room to attempt to make G/R/C. After repeated attempts in which he added the liquids in different order, he reported to Mr. A that he could not make the stack. Meanwhile, several other students were attempting to test stacks that they had claimed. Those who made the claimed stacks brought them forward to be shown to the class as proof. Some of these were then passed around for students to examine. The class period ended with several tests remaining incomplete, and some complete but unreported to the whole class.

The next day, testing continued. When all tests were complete, Mr. A returned to the original list of claimed stacks, and focused the class on recording the results of the many tests that had been performed over the last two days. He systematically asked each of the testers what results they had found. Here, students got verification of the stacks the testers had made, and also the results of the negative tests (the ones for which no positive result existed). When asked what he had found in testing G/R/C, Walter reported that this stack was not possible.

Mr. A's choice to accept all claims as equally tentative is a significant one, both in terms of maintaining student engagement in the central problem of validating data, and in terms of creating an atmosphere where the ideas and work of each student could be valued. Each of the students who made a claim (and many who did not, but were in claimants' small groups) held a stake in what ensued by virtue of their ownership of claim. Many then bid to test their claims (and those of others); initially one student for each claim was appointed to test. Some of the later claims were countered by other students who argued that they were not possible. In these cases, one claimant and one opposer were sent to work together on testing. Here again, Mr. A effectively maintained student engagement by allowing claims and counterclaims, and following an emerging standard for data: that seeing is believing, and that all claims could be verified by this standard. In the case of G/R/C, the initial claim was tentatively accepted until it was tested in a public way; when it could not be substantiated by the claimant, it was dropped. Note that this is generally close to the ideal in scientific working groups, in which individuals usually subject their own claims to rigorous retesting. In scientific communities, standards of replicability have evolved over many years; in our classroom, we attempted to help students understand and value these standards by facilitating their emergence as a function of the students' own needs to make sense of the data.

Red/Clear/Green

As previously mentioned, the one possible stack of three liquids is Red/Clear/Green. When the group posters were presented to the whole class, six out of the seven groups reported R/C/G as possible. In fact, this was the most commonly and prominently reported stack of three solutions, although neither students nor teacher tallied the number of times stacks were reported in class. We do not have evidence of arguments about this stack within groups. As noted above, challenges of this type were rare in the time before posters were presented. And, as the posters were presented, this stack was not challenged directly. Once the class had begun the process of nominating stacks for further verification, this stack was mentioned pretty quickly:

> Mr. A: OK, so let's see if we can summarize what people were saying, and I'm going to try to follow through on Emily's idea. We're going to make a chart of all the ones that different groups think are possible, and then we'll see how to test out that. Here are the four that are on these two posters over here. Who says that any of these are impossible? (adjusts overhead projector so that all can see) Are these ones that everyone agrees are possible, or is there somebody who says that one or more of these is impossible? (barely audible--individual students nominate three of the four as impossible, Mr. A marks each with a question mark as it is nominated) Everyone agrees about red/white/green?
>
> Student: Everybody agrees about, some people agree about all of them...
>
> Mr. A: (Happily) Alriigghhtttt! Everyone agrees about red/white/green!

In this interchange, R/C/G became the first stack accepted by the whole class as a true and possible stack.

In scientific communities, when data is presented that seems to "fit", it is the lack of public objection to it that signals consensus in the community ("fit" in these communities seems to depend on replicability, consistency with currently held theories, and the reputations of the claimants). While we saw the same lack of public objection here, and while Mr. A could not be sure of the basis for this lack of objection, he modeled consensus in scientific communities by noting the lack of objection and voicing the point of consensus (it is possible that this stack was sped along its track by the way that the question was posed).

Students who did disagree with this stack might have chosen to avoid the public risk of speaking up about it, given that none of the stronger, more vocal students had picked up the gauntlet. Though we cannot be absolutely sure about this particular instance, we have seen compelling evidence at other times in the same classroom that would lead us to believe that quite often, less successful students lack the confidence to take such risks. So, when a teacher asks for such a response, there are times when social factors may outweigh academic ones in determining student responses (or lack of them) for a sizable portion of the classroom population. Still, this was the only time that we saw acceptance of a claim without public testing.

A far more positive way of looking at the acceptance of R/C/G in this class is to assume that a majority of the students had indeed made this stack, and that its acceptance by the class validated their claims. It may be safe to assume that at least six students had made this stack (one in each of the groups reporting it), and in fact the number could be twice or three times that. It <u>is</u> clear to us that the acceptance of this stack had no negative consequences for individuals (in terms of engagement) <u>in the public arena</u> of the classroom. There were no vocal counterclaims and no complaints about its acceptance.

The teacher's decision to allow the class to accept this stack and to move on to others was clearly the result of his judgment about the best way to approach teaching the underlying social rules and standards that go with such an activity. For instance, he might have taken the class to task about agreeing to something without evidence or proof. Playing devil's advocate, he might have posed the question, "How do we know that this stack is actually possible....what have we seen that convinces us as a class?" Yet, calling the class up short can have its consequences, and in doing so he might have risked their enthusiasm and involvement. Instead, he chose to go with the choice they made, leaving the issues of proof and replicability for later.

Green/Clear/Green

The third stack that we will trace here is Green/Clear/Green, a stack that was presented on the poster of just one group. This group was comprised of two male and two female students. The two females were African American and best friends, and were generally moderately successful in science class, Laurie being more academically successful than Leticia. Both of these students were socially adept and good-natured about group work. Ernie was Hispanic, less academically successful than his groupmates, and was sometimes socially ostracized as well. He spent much of his time in the group bidding for acceptance on a variety of levels, and although he often had good ideas, he seldom had an impact on what the group decided. The fourth member of this group was Jack, a highly successful Caucasian student who was also socially adept (the following year, he was elected president of the Student Council). He and Laurie agreed that this stack should go on their poster, along with the companion Red/Clear/Red.

We describe G/C/G and R/C/R as companion stacks for several reasons. Based on the densities of the solutions, these are not stacks that can be made. Yet, they *appear* to have been made whenever a colored solution, in this case Green, is stacked only with Clear. This is because the Green reflects off of the meniscus of the Clear solution, giving the appearance of a thin layer of Green solution riding atop the Clear (for Red, the reflection is off of the bottom of the vial). Interpretation of this green color as either a reflection of the Green solution below, or as a separate thin layer of Green solution, formed the basis for one of the most interesting and sustained debates that we encountered in this lesson cluster. In this case, the students were arguing about what they *saw*, and what they saw was subject to individual interpretation. This is one instance in which the evidence itself was confounding, and the resulting disagreement was resolved only after long arguments and many attempts at bringing in evidence to settle the dispute.

When the group was making their poster, Jack and Laurie agreed readily on this stack as something that was important for their poster. There was no discussion here of the correctness of the stack, only how it should appear on the poster. Laurie was clearly the leader in terms of what would go on it. She was the one that took the markers and began to outline the sketched figures with them. Leticia asked her permission to work on the letters, and also asked for instructions. The poster was physically arranged on the girls' desks, away from Jack and Ernie. Ernie was completely uninvolved in the poster on this day, and Jack made periodic bids, but the topics most discussed were radio stations, cable TV, and other social agendas. Jack's complaint below focused on how the stacks were represented on the poster (that he later presented to the class), not on the content of them:

Laurie: (referring to what she has drawn) This is our first Red level, second is...(pointing)...and the rest is all White, then Green, White and the Green is on the bottom.
Jack: There's only 3 layers! (indignant complaint)
Laurie: That is 3 layers! 1, 2, 3! 1, 2, 3! (Pointing out layers on poster illustrations.) 3 Layers!
Jack: You shoulda put'm up higher. One big thing.
Laurie: (writing on poster) This is the first level.......first level.....
Jack: I'm not going to show that! I don't see no elevator there or anything.

Later on, while they are still working on their poster, Laurie told the teacher, Mr. A., about the stacks that she had drawn.

Laurie: ...there's a little G on top, C in the middle, and G on bottom.
Mr. A: You made one like that?
Laurie: Yes.
Mr. A: G on top?
Laurie: (nods)
Mr. A.: OK.

Mr. A's response here is typical of his willingness to accept claims that students made about which stacks they had seen, even though he was surprised at the claim. His role in this part of the activity was to help students to clarify and report (by creating a poster) what they saw within their groups. As a result, this particular group then presented G/C/G as one of the 3 stacks that they believed possible (the others were the similar R/C/R, and the correct R/C/G). The presentation (in which Jack coupled the presentation of R/C/R and G/C/G) went like this:

Jack: (Pointing to the R/C/R stack) You have to have a certain order to do it, like if you had Red first it wouldn't work. So you always have to have Clear first and then you can put Red, you will have Red on top and a little bit on the bottom and then (pointing to the G/C/G stack) put Clear and then Green, it will be Clear in the middle and Green on the bottom.

Note here that Jack focused on *how* these stacks could be made, rather than explanations of *why* the liquids stacked as he claimed, a distinction that Schauble and her colleagues (Schauble, Klopfer, & Raghavan, 1991) characterize as an *engineering agenda* rather than a *scientific agenda*. We found that when students detailed how they made specific stacks, their descriptions carried the weight of explanations with their peers. They were readily accepted as justification for claims, even though they did not focus on the patterns inherent in the system, the common stuff of explanation and theory in scientific circles.

The class had no questions or challenges to this stack when it was presented. Later, when the class set about making a chart to figure out all of the stacks that people said were possible, Mr. A asked if anyone wanted to disagree with a stack that was on the posters. Jack disagreed with C/G, saying "some of the Green goes to the top." Later, when students were asked to nominate stacks for testing, Jack nominated G/C/G as well as R/C/R. A little later, Jack was sent to the back with Pauline, who claimed that G/C/G was impossible, to do the tests. When they brought their stacks forward, each claimed victory. Mr. A noted that there was "disagreement about what you see" in the vial. He restated the question while holding the vial up:

> Mr. A: Pauline is saying that this looks like just Green on the bottom and White on the top; ah, Jack is saying it looks like Green on the top and bottom, and Clear in between. And the question again is, is this green color you see on the top a reflection, or is it actual Green that is up there? OK, so that's an interesting question. How are we going to resolve this? (No responses from class here, Mr. A waits 2-3 sec.)

At this point, the standard of replicability had been well established in a number of tests already run by other students. Clearly, though, replication of the stack was not enough; this was a special case. Mr. A sent Jack and Pauline to do further testing, and asked them to watch each other very carefully, and to be sure to run their tests using both straws and vials. Later, Jack brought a stack in a straw up to Mr. A. In the process of showing it to him, Jack's finger slipped and the Green dropped out of the straw:

> Mr. A: ..."it looked to me like, when the Green dropped off the bottom, the green disappeared from the top, too. If that was true, that would mean it was a reflection. Try that again! Jack, try it with more stuff, especially with more Clear. See what happens when the Green drops off the bottom, when the Green's all gone, does the green disappear from the top, too." (Jack goes to do it.)

Ten minutes later, Jack came back up to Mr. A, holding a stack in a straw. An all-school announcement was being made over the public address system, so he showed the straw to Mr. A. Pauline came up with a vial as well, and Jack and Mr. A and Pauline all examined each of the stacks. Class ended a minute later, so the stacks were not shown to the rest of the class or discussed.

Mr. A had several choices for intervention at this point. He could resort to his authority as teacher and scientist, and tell the "right" answer, something that a student had already suggested. Or, he might leave the question unresolved and move on. A third option, the one Mr. A chose, hinged on his judgment that Jack and Pauline were making very little headway in resolving the disputed claims. Mr. A decided to suggest additional tests, in the public arena of the class, and to carry them out for all to see. In doing so, he avoided trivializing the difficulties that Jack and Pauline were having in resolving their claims, and he upheld the emergent standards of replicability so important to the work that the students were doing. His choice valued Jack and Pauline as holding essentially equal claims, deserving of thoughtful and careful validation.

The next day, Mr. A brought in a turkey baster and showed it to the class, saying "this is like a big dropper," and a graduated cylinder "this is a big vial". He then gave a description of Mitch, a class member, who came in after school the previous day to work with the solutions more. He characterized Mitch as carefully squirting solutions into each other, and watching what happened. Then he reminded the class of the debate from the previous day, and set the stage by having Jack and Pauline come to the front of the class to help him run the test. Mr. A put plenty of Clear in the graduate, and instructed Jack to slowly squirt the Green in. Jack did this, watching closely. Mr. A noted that he saw the Green just going to the bottom. He asked Jack if he saw any going to the top. Jack said he thought he saw a little going to the top. The baster was leaky, which made the experiment hard to do. Another class member then suggested a procedural modification. She wanted Mr. A to put all of the Green in at the top. Mr. A defended putting it in the middle, explaining that watching where it goes as it comes out of the dropper is important, because the end result always looks like G/C/G. Then, he asked for a show of hands for those who saw it all go to the bottom, and those who saw some go to the top. The result was a slight majority for going to the bottom, but not by much. Mr. A then emptied the baster and graduate and ran a similar test with Red and Clear, and the resulting show of hands was equally split. Class ended with no resolution to either question.

The following day, Mr. A brought in a syringe with a length of clear tubing attached, and used large amounts of Clear and Green again in a large graduate. With the Clear solution already in place, he gathered the class around and lowered the tubing/syringe to the midpoint of the Clear solution. Again he prompted students to watch carefully to see which way the Green solution went, reminding them that if they saw Green going up and down, that there would be two layers of Green; if they only saw it going down, then they would know that the green on top was only a reflection. The students watched intently, and then some proclaimed "reflection!" loudly. A tally of what they saw was taken, with 28 students reporting that they only saw the Green go down, and one (Jack) reporting that he saw a little of it go up. Mr. A then explained that the class would accept that the green color on top was a reflection, since all but one agreed. He then noted that Jack was free to bring in evidence to the contrary at any time, and the class would consider it, noting that this is how scientific communities handle disagreements about data.

Notice that this claim was initiated in one group, and was sustained by the continued enthusiasm of one student, Jack, backed by others in the class. Mr. A's acceptance of this enthusiasm was critical, and his methods of checking to see where the claim stood with other members of the class indicated his willingness to work towards consensus with them, without coercion. When it was clear that there was no clear consensus among class members, he first worked to ensure that the problem was stated clearly. In fact, on every occasion that the class discussed G/C/G or ran a new trial, Mr. A restated the two views of what was going on, or asked students to do so. This attempt to involve every class member in the decision about what was actually happening was a key component in the process of coming to consensus. In this process, Jack and Pauline became potential adversaries, though Mr. A's focus on evidence took the personal element away, and focused the class on the phenomenon rather than the players involved. Throughout this process, individual consequences for being "right" or "wrong" were deflected to questions about the data. In fact, there was a point at which Jack got frustrated, and his complaint was one about a lack of proof rather than any comment about an individual. This sustained effort to examine and re-examine a phenomenon in order to come to consensus-- to be sure about what one sees and knows-- is a hallmark of Mr. A's teaching.

It is noteworthy that during this long debate, which continued through parts of four class periods, the students did not spontaneously suggest any of the mechanisms that scientific communities use to achieve consensus in times of controversy. Thus, students did not suggest new and more precisely controlled experiments, nor replication of existing experiments to settle the dispute. And, no students made attempts to reason about the feasibility of the G/C/G stack from patterns that they had seen in other stacks.

This finding clearly sets the kinds of reasoning we observed in the classroom community apart from the kinds of reasoning that working groups of scientists often do. While expecting students to make this kind of connection is clearly expecting quite a lot, this kind of reasoning is still a key aspect of the culture of scientific working groups that we hoped to establish in the classroom. Though students did not reason from previously accepted stacks to verify or deny new claims, we did see evidence of other kinds of reasoning about patterns. We now turn to a discussion of these and other significant findings, framed by each of the three goals we held for our students.

Discussion

Scientific communities have well-established social mechanisms for validating claims, and a rich interchange around problems of data generation and interpretation. In our classrooms, social mechanisms like these are not a given. For this reason (and others), scientific problems posed in school contexts often beg collaboration in the best sense--students putting their heads together to work out possible solutions that are better than those that most individuals could come up with, because they make best use of the varied efforts and approaches of all of the players. Our three goals for our students aimed at the kind of collaboration described here. So, how did our students fare in achieving these goals, which were essentially aimed at them developing a new kind of literacy, an "identity kit" (Gee, 1989) for scientific problem solving? There are ways in which our students made progress toward each goal and other ways in which these goals were not achieved. We discuss each of our goals in turn below.

Goal 1: Gain an appreciation of the power of collective efforts to understand the world.

The kind of collaboration described above is distinctly different from what most students experience in other contexts. Most are familiar with classrooms in which the teacher mediates democratic votes, or in which the teacher is the ultimate authority for right answers. They are also used to the kinds of discussions and arguments that they have in peer groups outside of the classroom, in which social status and verbal acumen are often the deciding factors in what is valued and what is not.

In general, we noted that students made significant progress in understanding the nature of the problem we posed, and in figuring out how to respond to unexpected barriers to solving it that arose in the course of classroom activities. While several of the techniques and standards that they used originated with the teacher, or other individuals within the class, we saw these ideas and standards being upheld by some class members in arguments about what should be done, why, and what it meant.

While most students made progress, we are aware that much of what they did accomplish was in a classroom setting in which individual ideas were valued-- which, relatively, is a pretty safe environment. We are confident that the majority of students came to a richer understanding of the power of groups in problem solving, of understanding how theories and concepts are grounded in observable phenomena, and in developing social and intellectual tools that enabled them to participate in collective reasoning processes. Yet, we are still deeply concerned that these goals remained least fulfilled for those students who have difficulty in school settings. While students who find success in school tended to appropriate the discourse and practices of the community as their own, we saw less evidence of this kind of appropriation from students already marginalized.

We have learned from our observations that, left to their own devices, groups of students only rarely "collaborate," unless the tasks given them are carefully structured to demand such collaboration. We have seen evidence that much consideration must also be given to the ways that students in classrooms typically approach science tasks, especially those involving manipulation in the study of a system such as the Colored Solutions with which our students were working. Our findings here are complementary to those of Schauble (Schauble, et al., 1991) -- that students tend to approach such tasks with goals of seeing what they can make happen, (engineering agenda) rather than the goal that a teacher or scientist might hold for the activity, which is developing an understanding and appreciation of the underlying rules or patterns in the way the system works (scientific agenda).

Goal 2: Develop the social and intellectual tools that enable participation in collective reasoning processes.

We noted above that we did not observe any instances of students reasoning about new claims from previously verified stacks. However, the absence of evidence of such reasoning in verbal discourse does not necessarily mean that students didn't make these connections. A more reasonable guess, in our estimation, is that some students did see these patterns and make these connections, but that this occurred in the nonverbal realm of their thoughts. And, in fact, since they may not have had experience talking about these patterns, they may have developed an implicit sense of them, a sense never formalized by speech or action.

Our only evidence for this hunch comes from the plight of some of the stacks that students claimed early in the process, which later found no support and were dropped. These stacks were never tested in the public arena, and no evidence for or against them was ever presented. We have previously mentioned the possibility that their being dropped was due largely to social factors. Further investigation of these hunches may be a fruitful avenue for understanding what social factors are at play in determining individual students' participation in class activities.

It is also clear that our students were frustrated by the lack of consensus, but themselves saw only two possible solutions to this problem. They could accept the majority vote (which varied in this case as new evidence became available), or Mr. A could tell them the answer. Failure to suggest scientific mechanisms apparently had more to do with lack of experience than with lack of understanding of their usefulness. Students did change their minds and achieve consensus when Mr. A engaged them in scientific procedures.

Goal 3: Gain an understanding of the cultural and epistemological status of scientific concepts and theories.

Our students clearly fell short of making substantial progress on this goal. Few if any indicated deeper understanding of what makes theories and concepts so important in science--their explanatory power, simplicity, connectedness, or predictive power. Yet, this is not the kind of thing that most middle schoolers do, in public or private discourse. At best, we would like to suggest that experiences like these can form the basis for students' future understanding and appreciation of these constructs and their value. Our students learned that they had the power to discover "the truth" without being told, but this did not lead them to inquire more deeply about the nature of scientific knowledge.

Conclusion

These stories remind us of how complex and multifaceted classroom interactions often can be. Here we have vivid pictures of how much common knowledge of rules, procedures, and standards is embedded in classroom discussions that appear, at first glance, to be relatively simple and routine. It is clear to us that the social aspects of the classroom environment, and the groups in it, bear careful consideration by teachers who plan collaborative activities. The kind and nature of the social norms that are established, and the ways in which whole-group activities are structured have much to do with student engagement, and hence understanding.

Whether or not students see their own ideas as important and valued can, in large part, determine the messages that students get about school science, and the nature of the scientific enterprise, as well. Understanding that one can gather evidence to solve problems, and that evidence can help to resolve disputes about how things in the natural world work is a central part of this process. Though we do not characterize what went on in our classrooms as an exact model of the ways that scientific communities work, we do believe that replicating significant features of scientific working groups in our classrooms serves students well as they learn what science is all about.

It is our contention, then, that the better we do at helping them to see their own ideas as valuable, the better we have done in giving them a dynamic picture of the scientific enterprise. When they feel free to propose, elaborate, modify, and sometimes withdraw these ideas, then they are better equipped to do the same in other situations outside of classroom contexts. This is what teaching science should be about--empowering students to use scientific knowledge to understand the world around them.

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