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Comparing Classroom Enactments of an Inquiry Curriculum: Lessons Learned From Two Teachers

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Examining how teachers structure the activities in a unit and how they facilitate classroom discussion is important to understand how innovative technology-rich curricula work in the context of classroom instruction. This study compared 2 enactments of an inquiry curriculum, then examined students' learning outcomes in classes taught by 2 teachers. The quantitative data show that there were significant differences in the learning outcomes of students in classes of the 2 teachers. This study then examined classroom enactments by the 2 teachers to understand the differences in the learning outcomes. This research specifically focused on how teacher-led discussions (a) helped connect the activities within a curriculum unit and (b) enabled deeper conceptual understanding by helping students make connections between science concepts and principles. This study examined the role that teacher facilitation played in helping students focus on the relations between the various activities in the unit and the concepts that they were learning. The results point to important differences in the 2 enactments, helping to understand better what strategies might enable a deeper conceptual understanding of the science content.

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Current design-based and project-based approaches to enhance science learning (Kafai, 1994; Kolodner, 1997; Krajcik, Blumenfeld, Marx, & Soloway, 1991; Reiser et al., 2001) have often been characterized by opportunities for students to engage in extended inquiry lasting for several weeks, and consisting of many activities and events. For example, students are required to generate questions for exploration, plan and carry out investigations, collect data, gather information, and apply it to analyze and interpret the data (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Kolodner, Fasse, Gray, Holbrook, & Puntambekar, 2003; Roth, 1995). Students often use electronic resources in the form of hypertext and hypermedia systems (e.g., Azevedo & Cromley, 2004; Shapiro, 2000) as well as digital libraries (e.g., Abbas, Norris, & Soloway, 2002; Hoffman, Wu, Krajcik, & Soloway, 2003) to explore topics and conduct research. Small group collaboration and whole class discussions are typical, requiring teachers to facilitate classroom discussions. These characteristics are quite unlike traditional text-based science and even hands-on science, and require teaching strategies and practices that are significantly different (e.g., Borko & Putnam, 1996; Sandoval & Daniszewski, 2004; Schneider, Krajcik, & Blumenfeld, 2005). Examining how teachers structure the activities in a unit, so that they are not linear, discrete events but are seamlessly combined into a coherent whole, and how they facilitate classroom discussion is important to understanding how innovative curricula work in the context of classroom instruction.

The ways teachers "enact the instructional discourse and mediate the environment" (Cohen & Ball, 2001) is an important aspect of understanding learning in a classroom environment. In recent years, researchers have analyzed small group and whole class discussions (e.g., Tabak & Baumgartner, 2004; Tabak & Reiser, 1997) as well as discourse patterns of different teachers (Sandoval & Daniszewski, 2004; Schneider et al., 2005). For example, Schneider et al. analyzed classroom interactions by four teachers, examining three aspects of their interactions: presentation of science ideas, opportunities for student learning, and how teachers supported those opportunities. Tabak and Reiser (1997) analyzed how teachers can support small group and whole class discussions so that students share what they have learned in their groups with the rest of the class. Although each of these studies analyzed classroom interactions and identified successful strategies that teachers have used in an inquiry classroom, most studies have examined how teacher-led discussions have affected students' contributions to the interaction. There have not been studies that have investigated how differences in enactments of instructional discourse might impact students' learning outcomes. As described by Sandoval and Daniszewski (2004), "a missing piece of the puzzle, however, is how different activity structures and discourse strategies contribute to students' learning" (p. 177). Do differences in enactments—most notably in the ways in which teachers orchestrate a unit and facilitate classroom discussions—have an impact on student performance? This exploratory study is designed to address this issue by examining the relation between classroom enactment and learning outcomes. Specifically, we examine how teacher-led discussions can help (a) connect the activities within a curriculum unit and (b) enable deeper conceptual understanding by helping students make connections between science concepts and principles. We analyzed students' learning outcomes in classes taught by two teachers. We then conducted a qualitative analysis of classroom enactments by the two teachers, to understand the differences in the learning outcomes. We examine these issues within the context of the CoMPASS project (Puntambekar & Stylianou, 2002; Puntambekar, Stylianou, & Hübscher, 2003). This project consists of a hypertext system, CoMPASS, and accompanying curriculum modules broadly based on the pedagogical principles of Learning By Design (LBD) (Kolodner et al., 2003).

This article is organized as follows. We first discuss the background and design of the study in which two teachers implement the simple machines unit in sixth-grade classes. We then discuss the results of the learning outcomes in the form of the quantitative data from the two implementations. Next, the qualitative data comprising classroom interactions in classes taught by the two teachers are presented to understand how the two enactments differ, in an effort to understand what might have affected student learning in the two classes. Finally, we discuss the lessons learned from the study in terms of providing students with opportunities to enable a richer understanding of science phenomena.

UNDERSTANDING CLASSROOM ENACTMENTS

Ball and Cohen (1996) emphasized the importance of studying *enacted curricula,* which according to them are "jointly constructed by teachers, students and materials in particular contexts" (p. 7). They also noted that teachers' perceptions about the students, their understanding of the material, their choice of materials, and instructional resources influence enactments. Teacher content knowledge as well as their pedagogical knowledge and beliefs are critical to the success of an intervention (Ryder, Hind, & Leech, 2003; Songer, Lee, & Kam, 2002). Often, the intervention, as intended by the designers varies greatly in its enactments by different teachers in their particular contexts. Sometimes modifications of curricula are so different that although the "surface procedures" are followed, the pedagogical principles on which the intervention are based are completely lost resulting in a "lethal mutation" (Brown & Campione, 1996, p. 292). Therefore, examining the complexities of how a curriculum module is enacted by different teachers who come with different understandings can help understand the factors that contribute to success, eventually enabling us to arrive at design principles that might be common across contexts. Our focus is on understanding two aspects of the classroom enactment. These are (a) helping students make connections between activities—how classroom discussions and structuring of activities help build connections between activities in the unit—and (b) helping students make connections between concepts—how teacher facilitation supports the making of connections between concepts during each of these activities.

Helping Students Make Connections Between Activities

Several researchers have documented the challenges that teachers face in orchestrating inquiry-based science in their classes. Inquiry-based approaches require that students engage in several activities such as brainstorming, generating questions, finding and applying information, and justifying data and results. Teachers in this environment are simultaneously managing content and process that requires them to be masters of both. One particular challenge that teachers face is helping students understand how the activities in an inquiry unit are integrated, so that they are not carried out as disconnected tasks. In their discussion of teacher practices in the Learning By Design™ (LBD) approach, the LBD research team noted that fostering inquiry requires teachers to support students through the process of inquiry rather than providing them with information automatically (Holbrook & Kolodner, 2002). They also noted that teachers are often unfamiliar with the inquiry approach and are not used to being facilitators.

The importance of connecting activities in a unit is especially critical when students use information resources (e.g., books, CD-ROMS, hypertext systems) as part of inquiry. When using resources, students need to connect other parts of their investigations, such as generating questions, to their exploration using resources. One of the problems is that they seek to find the right answer instead of thinking about how the information will help them in their projects (Soloway & Wallace, 1997). Research in cognitive science has long emphasized the importance of asking questions as an integral part of inquiry (Bransford, Goldman, & Vye, 1991; Palincsar & Brown, 1984) and the need to help students ask "how" and "why" questions so that they are able to reason about evidence and causal relations between scientific phenomena (e.g., Graesser, Person, & Hu, 2002; Otero & Graesser, 2001). The importance of having students ask deep questions is also recognized in project and design-based science activities, in the form of learning issues (Kolodner et al., 2003) or questions to drive investigations (Hoffman et al., 2003; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Wallace et al., 1998). Research has indicated that the depth of student generated questions improves over time as they gain more knowledge (Roth & Roychoudhury, 1993; Scardamalia & Bereiter, 1992). Krajcik et al. (1998) discussed the need for scaffolding for students to generate good questions and the need for feedback from teachers so that they can generate better questions. They recommended that students need support to "determine the meaningfulness of their questions" (p. 342), so that the questions are related to their investigations, instead of merely finding the "right answer." Students need to make meaningful connections among such activities in a unit as generating questions, finding information and applying it to their investigations (Schneider et al., 2005).

An inquiry unit in which students are required to learn through hands-on investigations, as well as text resources, necessitates that students are able to connect knowledge of abstract principles in a text to observations of real-world events that are examples of the abstract concepts (e.g., Krajcik et al., 1998; Wood, 1999). Such translation requires students to relate the real-world, dynamic representations of scientific phenomena to the more abstract representations of science formulas and principles. When multiple representations are used, experts are known to describe scientific phenomena based on the underlying generalizable principles, whereas novices often focus on their experiences and "what they saw" (Kozma, 2001). Furthermore, novices often seem to focus on single entities, whereas experts tend to explain scientific phenomena in terms of relations between entities and generalizations across phenomena. As White (1993) described, "the semantic distance between the formulas and their real world applications is too great, and thus the relationship between the formulas and the physical world they model is often not clear to students" (p. 178).

For students to build integrated knowledge from their science learning experiences, teachers need to make the goals of science investigations visible to students (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000) and help them make connections between activities. Research has indicated that if students are not supported to understand the connections between activities, they often follow a set of procedures to complete an activity or a series of exercises, without understanding the overall goal and structure of the activities (Schauble, Glaser, Duschl, Schulze, & John, 1995). In a curriculum unit consisting of different activities, teachers themselves need to understand the cycle of activities and how they are tied together (Davis & Petish, 2001; Fasse & Kolodner, 2002) to effectively help students understand how the activities are related to each other.

Helping Students Make Connections Between Concepts

A key aspect of science understanding is the integration of knowledge into a framework consisting of relations among concepts and principles (Hiebert & Carpenter, 1992; Newton & Newton, 2000; Ruiz Primo & Shavelson, 1996). According to Glynn, Yeany, and Britton, (1991), "without the construction of relations, students have no foundation and framework on which to build meaningful conceptual networks" (p. 6). Research on differences between experts and novices has indicated that they differ in the ways in which their knowledge is represented (Chi, Hutchinson, & Robin, 1989; Chi & Koeske, 1983). Specifically, expert learners' knowledge is represented in ways that show richer organization; often organized around the central principles of the domain that can be generalized (Cheng, 1999; Kozma, 2001; Pearsall, Skipper, & Mintzes, 1997).

However, building deep conceptual understanding does not occur by simply transmitting knowledge. Students need to make connections themselves—a process that can be fostered by instructional materials and teacher facilitation. Discourse that promotes an understanding of relations and reasoning enables a deeper knowledge representation (Newton & Newton, 2000). Well-designed science instruction plays an important role in enabling students to connect science ideas for deeper understanding so that they can apply them in different contexts (Linn, Eylon, & Davis, 2004), and teacher-led discussions are an important aspect of such instruction. If a teacher "shrinks" from discourse that will enable students to make causal connections, students simply focus on the acquisition of factual information (Newton & Newton, 2000).

Our aim in this study was to understand the role that teachers play in facilitating learning by focusing on connections for deeper conceptual understanding. In multifaceted inquiry units consisting of several activities, our questions were as follows:

- How do teachers facilitate classroom discussions to enable students to make connections between the activities?
- How does the nature of teacher's facilitation support (or not) students' understanding of the connections between science concepts?

METHOD

Participants

The study was implemented in a middle school serving 670 students in grades five through eight located in a university town in Connecticut with a population of approximately 20,000 residents (Connecticut State Department of Education [CSDE], 2003). Within the school, 9.5% of the student population is eligible for free or reduced price meals, and 10% of the students come from homes in which English is not spoken (CSDE, 2003). All of the classrooms have Internet access and there are two students for each academic computer. In the 2001–2002 academic year, 77% of the sixth-grade students met the state goal in reading on the Connecticut Mastery Test, 72% met the state goal in writing, and 79% met the state goal in mathematics (CSDE, 2003).

A total of 146 sixth-grade students participated in this study. The students were from different ethnic backgrounds, academic abilities, and socioeconomic levels. This sample represented all of the students enrolled in sixth grade. The students were from seven classes taught by two teachers, Jane and Linda.[1] Jane taught four classes ($N = 77$) and Linda taught three ($N = 69$). All students used laptops in their science classes throughout the year. Students worked in groups of three or four, resulting in an average of five groups per class. Each group had access to a laptop

[1]Teacher and student names are pseudonyms.

computer with wireless capabilities. Students used the CoMPASS hypertext system and the accompanying simple machines curriculum in the 10-week unit.

The two teachers who participated in the study had different backgrounds. Jane, a Psychology major, had been teaching for 2 years. Linda, a Science major, had been teaching for 4 years. The two teachers were selected because they were willing to participate and were excited about implementing the 10-week unit on simple machines. A few months prior to the study, two researchers observed the two teachers and found that their teaching styles are very different. Jane incorporated an inquiry approach in her teaching, often giving a lot of freedom to students. Linda followed a structured approach, often giving instructions to students on how to complete each activity. She was therefore new to implementing an inquiry curriculum, although she had been teaching longer than Jane.

Both teachers took part in a weeklong workshop in the summer preceding the implementation and came back again for a 1-day meeting before the beginning of the unit. In the summer workshop, the project team worked with the teachers to develop the simple machines curriculum. We also worked with the teachers and discussed issues such as allowing students to raise their own questions, exploring and finding information, and the importance of open-ended questions so that students would not look merely for the “right” answers. The teachers spent 2 days on the CoMPASS system itself, familiarizing themselves with the software, reading the text, and giving feedback to the project team.

Materials: The CoMPASS System

The CoMPASS hypertext system (Puntambekar & Stylianou, 2002; Puntambekar et al., 2003) is designed so as to make the relations between science concepts and principles more visible to students.

CoMPASS uses two representations—concept maps and text—to enable multiple passes and to support navigation and learning. Each page in CoMPASS represents a conceptual unit, such as force or work. A conceptual map of the science concept and other related concepts takes up the left half of the CoMPASS screen, and a textual description takes up the right half of the screen (see Figures 1 and 2). The maps are dynamically constructed and displayed with the fisheye technique (Bedersen & Hollan, 1995; Furnas, 1986) every time the student selects a concept. The selected (focal) concept is at the center of the map, with the most related concepts at the first level of magnification and those less closely related at the outer level of the map. The map representation is not static, but the maps are drawn by retrieving concepts from a database every time the student clicks on a concept. The fisheye view is organized such that the concepts that are most related conceptually to the focal concept are displayed close to each other spatially. In CoMPASS, we used relation strength, established in consultation with physics experts, to determine the spatial proximity of the concepts. Spiro, Feltovitch, Jacobson, and Coulson (1991) argued that multiple representations and

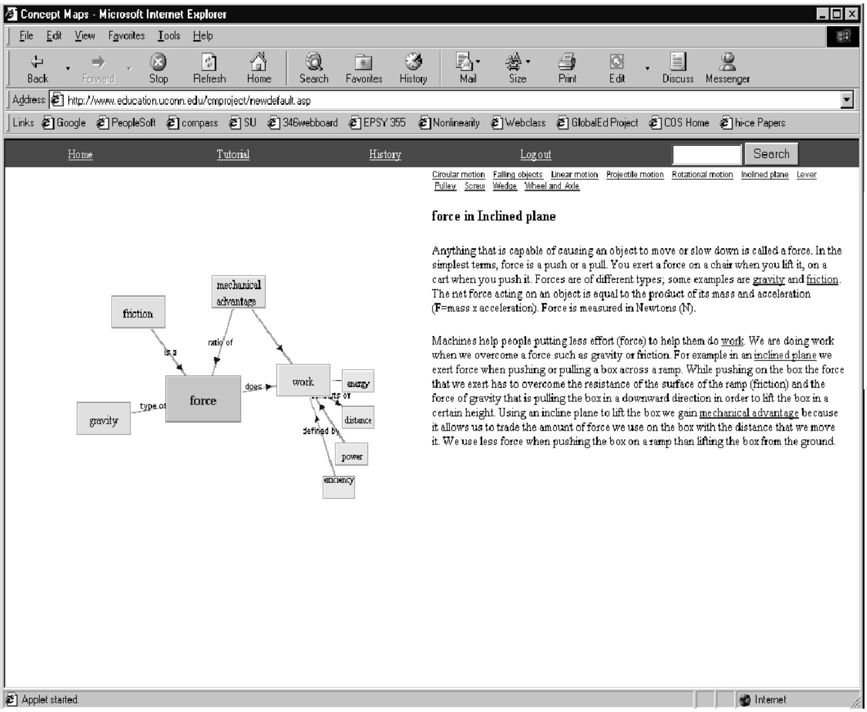

FIGURE 1 Fisheye with force as the focus.

multiple passes through the same material enable students to build richer knowledge representations. The maps in CoMPASS mirror the structure of the domain to aid deep learning and are designed to help students make connections, by seeing how different phenomena are related to each other, and enabling students to select alternative paths to pursue for any particular activity.

Materials: The Simple Machines Curriculum

The topic for this implementation was simple machines. Students used the simple machines module in CoMPASS along with the corresponding design-based curriculum unit lasting approximately 10 weeks. The entire unit was taught by Jane and Linda; even though members of the research team were present in the classes, they did not interfere with the teaching. Figure 3 shows the way in which the unit was structured. After the pretests, students were presented with the can-lift challenge,[2] in which they had to build a device using simple machines to lift a 16-ounce can of

[2]Modified from the Learning by Design™ curriculum at Georgia Tech.

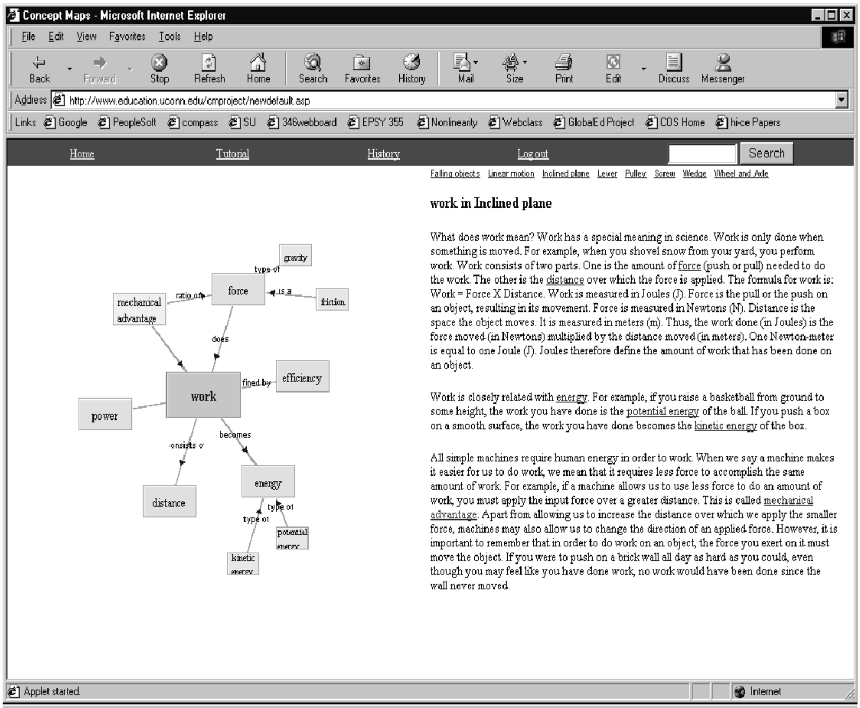

FIGURE 2 Fisheye with work as the focus.

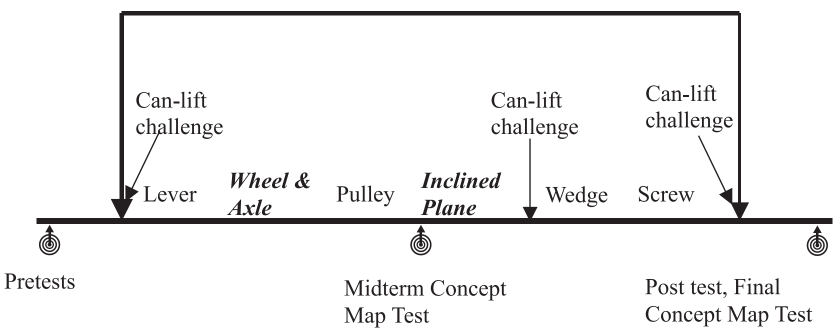

FIGURE 3 Structure of the simple machines unit.

food. In the first couple of days of the unit, students brainstormed their initial design ideas and drew plans of their designs. After this, they were introduced to each of the simple machines by way of activities such as balancing a ruler with different weights and with different positions of the fulcrum, or using a ramp to get a heavy object up a certain height. Each activity was based in a real-world scenario; for example, for the ramp activity students were given the problem of moving a pool table from a friend's house to their own. Students went back to their can-lift designs approximately halfway through the unit and again at the end, with a posttest at the end of the unit. Students used CoMPASS throughout the design process. For example, after the initial brainstorming, students referred to the information in CoMPASS to refine their questions. Once they generated questions, students used the system again to find information and apply it to their designs. They used the software again as they were working on their designs to find out more about the specific topic so that they could revise and optimize their designs and interpret the data that they were collecting.

The unit was comprised of five investigations. The three longer investigations—levers, pulleys, and inclined planes—each lasted 2 weeks, and the two shorter investigations—wheel-and-axle and wedge–screw —lasted 1 week each.

PART 1: UNDERSTANDING STUDENT LEARNING

In this section, we discuss the data and results of students' learning outcomes. The data reflect student learning from the entire unit. The data for learning outcomes consisted of a pre- and post-physics knowledge test and a concept-mapping test.

DATA: STUDENT LEARNING

All participants took the pretest at the beginning of the unit, and a posttest at the end of the unit. The pre- and posttest was administered online and included 17 multiple-choice items and 3 open-ended questions (see Appendix A for examples). Evidence for the content validation of this instrument was accomplished through 10 experts in the field of science education (8 science teachers and 2 advanced doctoral students in the Physics department). Students' responses to the open-ended questions were scored based on a 3-point scale ranging from 0 (*incorrect response*), to 1 (*partial correct response*), to 2 (*correct response*). Two raters who were trained to use the scoring scheme scored the open-ended questions. The interrater reliability was found to be 97%.

Students created two practice maps before the start of the unit and also throughout the unit. The teachers provided them with feedback only on the practice maps. Although students drew maps for all the machines, we scored students' midterm and final maps.[3] For the midterm and final concept maps, students were asked to draw a concept map with explanations for each concept, make connections among concepts and describe how they are related. We analyzed students' concept maps (Appendix B), taking into consideration three aspects of the maps: the number of concepts in the map, the number of accurate connections among the concepts, and the explanation provided for the connections. Each connection was scored based on a 3-point scale ranging from 0 (*no descriptor on an arrow*), to 1 (*a correct but simple connection*; e.g., "type of" or "is a"), to 2 (*higher level of understanding demonstrated in a connection*). Some examples of 2-point connections were "increases" or "decreases." A 3-point connection (*one that demonstrated in-depth knowledge and application of this knowledge*) was, for example, a connection between power and work that said, "[power] tells you how fast it's done, (rate)." We converted the scores for the maps into ratios to get the richness and depth of student understanding. First, we calculated the richness ratio by dividing the number of connections with the number of concepts. This ratio was a measure of the relations or knowledge of the interconnections between concepts. A higher value indicated that the map was very rich and that the student had demonstrated knowledge of the interconnectedness of the concepts used in the map. A second ratio, the depth ratio, was calculated by dividing the score that was given for the explanation of the connections with the number of connections in the map. This ratio was a measure of the depth of the connections between the concepts. A higher value indicated a higher level of understanding of the way in which the concepts were connected.

RESULTS AND DISCUSSION: STUDENT LEARNING OUTCOMES

As mentioned earlier, a pre- and posttest with multiple-choice and open-ended items, and a midterm and a final concept map provided us with data on students' learning outcomes. We analyzed the pre- and posttest physics and concept-mapping scores to understand whether the two groups taught by the two teachers differed in their learning gains and in the quality of the concept maps they constructed. For this discussion we refer to Jane's classes as Group 1 ($N = 77$) and Linda's classes as Group 2 ($N = 69$).

We started our analysis of learning outcomes by examining whether the two groups performed significantly better in the posttest (Table 1). One-sample t-tests

[3]Students in both the teachers' classes created three practice maps before the midterm map. The idea of concept maps was introduced before the start of the unit, and students created two maps in another science topic. Thus, a total of five maps were drawn by students in each class, before the midterm map. The importance of students' familiarity with concept maps has been emphasized in research on using this technique as a form of assessment (e.g., Shavelson, Lang, & Lewin, 1994). Therefore, maps drawn before the midterm maps were not used in the analysis to allow students sufficient practice drawing concept maps.

TABLE 1
Posttest Scores (Unadjusted) in the Multiple-Choice and Open-Ended Items

	Pretest		*Posttest*		*Difference*	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Multiple choice questions						
1[a]	6.44	1.67	9.64	2.33	3.22	2.04
2[b]	6.46	2.04	9.25	2.47	3.69	2.52
Open-ended questions						
1[a]	3.38	1.69	5.36	1.44	2.02	1.48
2[b]	3.21	1.48	3.40	1.61	0.19	2.27

[a]$N = 67$. [b]$N = 53$.

were conducted to test the significance of difference between the pre- and post-scores on the multiple-choice items and the open-ended items for each of the groups. We found that students in Jane's classes (Group 1) performed significantly better on the posttest in both the multiple-choice part of the test, $t(66) = 4.84$, $p < .001$, as well as the open-ended questions, $t(66) = 5.98$, $p < .001$. Students in Linda's classes (Group 2) performed significantly better on the multiple-choice questions on the posttest, $t(52) = 8.04$, $p < .001$, when compared to their pretest scores. However, there was no significant difference between their pre- and posttest scores on the open-ended items, $t(66) = 1.15$, $p = .256$. A one-way analysis of variance was conducted to examine whether the two groups differed in their pretest multiple-choice and open-ended scores. The results show that there was no significant difference between the two groups in the scores on the multiple-choice portion of the pretest, $F(1, 118) = 2.21$, $p = .139$. Similarly, there was no significant difference in the open-ended questions in the pretest, $F(1, 118) = .312$, $p = .578$. The two groups therefore did not differ significantly in their pretest scores.

To further analyze the differences in the posttest scores of the two groups (Table 1), we conducted two one-way analyses of covariance (ANCOVA) with the total pretest scores as the covariate to control for prior science knowledge differences. The dependent variables[4] were (a) scores for the multiple-choice items in the posttest and (b) scores for the open-ended items in the posttest. For both analyses, investigation of the homogeneity of slopes assumption indicated that there was no statistically significant interaction between the groups and the covariate on the dependent variables. Additionally, homogeneity of variance was satisfied for both analyses, $F(1, 118) = .005$, $p = .943$ (for the multiple-choice items) and, $F(1, 118) = .942$, $p = .334$ (for the open-ended items).

[4]Pre- and posttests from students who declined to have their data used in the study are not used in the analysis.

The ANCOVA for the multiple-choice items was not significant, $F(1, 117) = 2.44$, $p = .12$ ($MSE = 8.914$, $ES = .02$). There were no significant differences in the adjusted multiple-choice posttest scores between the classes taught by the two teachers. We found that there was a significant difference between the two groups in the adjusted posttest scores for the open-ended items, $F(1, 117) = 11.29$, $p = .001$ ($MSE = 23.11$, $ES = 0.09$).

As mentioned before, two concept-mapping tests were conducted, one halfway through the unit (midterm) and the other at the end of the unit (final). According to Novak and Gowin (1984), concept maps are intended to represent meaningful relations between concepts in the form of propositions. Research has shown that that concept mapping is a powerful and psychometrically sound method for assessing conceptual change (Markham, Mintzes, & Jones, 1994; Ruiz-Primo & Shavelson, 1995; Trowbridge & Wandersee, 1994). Studying successive concept maps provides insights into how knowledge is restructured in the course of acquisition (Cary, 1986).

We used the midterm ratios as the covariate to adjust for students' prior differences in the concept-mapping test (see Table 2). A one-way ANCOVA was conducted with the midterm richness ratio as the covariate and the final richness ratio as the dependent variable. Assumptions of homogeneity of regression and homogeneity of covariance were verified prior to interpreting the ANCOVA results. We found that the difference between the two groups was significant, with Group 1 (Jane's classes) students significantly outperforming Group 2 (Linda's classes) students, $F(1, 124) = 4.71$, $p = .032$ ($MSE = .34$, $ES = .037$). The same was noted with the depth ratio, $F(1, 124) = 7.03$, $p = .009$ ($MSE = 0.13$, $ES = .054$).

To summarize, our analysis of the scores on the physics pre- and posttest show several interesting trends. The single-samples *t*-test shows that students in both the groups had significantly higher learning gains in the multiple-choice items. Students in both groups performed significantly better in the multiple-choice part of the posttest, as compared to their pretest scores. However, although students in Linda's classes did not do significantly better in the open-ended items in the posttest as compared to the pretest, students in Jane's classes did. The ANCOVA

TABLE 2
Summary of Final Concept Map-Test Scores

Group	*M*	*SD*	*n*
Richness ratio			
1	1.964	.6638	71
2	1.529	.6105	54
Total	1.776	.6743	125
Depth ratio			
1	1.266	.4490	71
2	1.092	.1738	54
Total	1.191	.3663	125

shows that there was a significant difference in the open-ended part of the posttest, in favor of students in Jane's classes, but not on the multiple-choice items. Similarly, students in Jane's classes also performed significantly better than students in Linda's classes on the concept-mapping test, as indicated by the ANCOVA. It is interesting to note that out of the three measures of physics knowledge, as far as knowledge of factual information of the topic was concerned, both the groups showed learning gains at the end of the unit, and they did not differ significantly from each other. However, scores on open-ended items and the concept-mapping test show that students in Jane's classes performed better, indicating that they had a better understanding of the connections between science concepts and principles.

We turn to the qualitative data to understand the ways in which Jane and Linda enacted the curriculum that may have led to differences in learning outcomes.

PART II: UNDERSTANDING CLASSROOM ENACTMENTS

To understand whether an implementation has been successful, and if so, why and how it has been successful, it is important to understand the factors in the local setting that might have contributed to its success (Brown & Campione, 1996; Design-Based Research Collective [DBRC], 2003). We used classroom videos to understand the differences in the enactments by the two teachers.

QUALITATIVE DATA

Our qualitative data were in the form of classroom videos and field notes of observations. Although videos and observations were collected from only one randomly selected class per teacher, a researcher was present in all classes to observe in the classes that were not targeted for video recording. The presence of a member of the project team in all of the classes enabled us to validate that the videos from the target class were indeed representative of the activities that were undertaken in all of the classes. Day planners collected from both the teachers also helped us put the videos in context and helped verify that the activities in classes by the two teachers were comparable, and the activities in different classes taught by the same teacher were parallel.

Classroom interactions for all the machines were videotaped resulting in 22 hr of video. For each machine, classroom interactions—consisting of an initial brainstorming session, generation of questions to explore, small group interactions during investigations, the use of CoMPASS, and the final whole class discussion—were videotaped. In addition, videos of small group interactions included group discussions during students' use of CoMPASS, for which two groups were randomly chosen from each class, and group interactions between the students and teachers were recorded. All videos were viewed and transcribed by two members of the project team, resulting in 80 pages of transcripts. One researcher also collected observations in the form of field notes. The field notes consisted of a narrative of classroom events in the order that they happened. The observations were triangulated across researchers (Patton, 1990), in that a second researcher observed two classes per week, per teacher. The observations were then compared to control for bias and subjectivity.

Selection of Videos for Analysis: The Pulley Challenge

The simple machines unit comprised of six machines, each of which consisted of an investigation so that students could incrementally build knowledge to be able to design their can-lifts. We selected classroom interactions for one investigation, the pulley challenge, for a comparative analysis of enactment of the intervention across the two teachers. To check that the 2-week pulley challenge was indeed representative of the kind of facilitation that Jane and Linda engaged in throughout the unit, we referred to the classroom observations.

Our classroom observations show that the activities in the unit were parallel in classes taught by both teachers. Both the teachers started the unit with the can-lift challenge. Thereafter students conducted investigations for each of the machines: lever, wheel-and-axle, pulley, inclined plane, and wedge–screw, in that order. Students visited their can-lift designs halfway through the unit, after the pulley challenge, and at the end of the unit. This order was the same in classes taught by Jane and Linda. The activities that students carried out in all of the classes, including the use of CoMPASS, were the same in all of the classes.

As described in Table 3, there were three main phases for each investigation. Phase 1 consisted of brainstorming and question generation. In this phase students engaged in a whole class discussion in which they discussed what they knew about a topic and what they needed to know. The teacher also introduced the investigation during this time. Depending on the length of the investigation, one or two class periods were typically allocated for this phase. Phase 2 consisted of carrying out the investigation. This involved spending some time familiarizing with the materials, planning and setting up the investigation, using CoMPASS, carrying out the investigation, and collecting data. Because all the classes had access to one wireless laptop per group, students were able to go back and forth between their hands-on investigations and using CoMPASS to learn more about a particular topic. Phase 3 consisted of students reporting their data and reflecting on their investigation in a whole class discussion facilitated by the teacher. The consistency of investigations and classroom activities enabled us to zoom in on the pulley challenge with confidence that it was representative of both the activities that students engaged in for each of the simple machines, and the classroom culture that was prevalent throughout the unit in Jane and Linda's classes.

TABLE 3
Activities Within the Investigation for Each Simple Machine

Phase of Investigation	*Type of Discussion*	*Time Spent*
Phase 1		
Brainstorming	Whole class discussion	One class period for smaller investigations (e.g., wheel-and-axle)
Question generation		Two to three class periods for longer investigations (e.g., pulley)
Phase 2		
Work on hands-on investigation ↕	Small group work with the teacher interacting with groups of students	One class period for smaller investigations (e.g., wheel-and-axle) Three class periods for longer investigations (e.g., pulley)
Use CoMPASS to find information Record relevant information from CoMPASS Collect data Record data and observations	Students could go back and forth between working on their investigations (hands-on) and finding information in CoMPASS that they could apply	
Phase 3		
Reporting data and observations	Whole class discussion Complete KWL charts	One class period
Reflection and writing about the investigation	Group report Individual students' reports	One class period

We chose to use the classroom interactions during the pulley challenge for several reasons. First, the pulley challenge took place approximately halfway through the unit when both the students as well as the teachers had some experience with the unit. Second, the teachers were very invested in the design of the pulley activity, more so than the other machines, because it was adapted from a version that the two teachers had designed themselves. The activity was revised during the summer workshop to allow for open-ended exploration in CoMPASS. Third, our decision was also based on practical aspects of implementation. During the pulley challenge, there were no breaks, field trips, and no weather related problems such as "snow days," so that there was continuity in the unit. Fourth, both teachers spent 2 weeks on the pulley challenge, engaging in activities such as brainstorming, investigations with pulleys, use of CoMPASS, and whole class discussions.

In the pulley challenge, students were required to work with simple or compound pulleys so that a bottle of water that weighed 600 grams could be lifted with the least effort. They worked with a range of pulleys that were made available by the teachers. Students were required to put the best system together using either fixed or movable pulleys or both. There was a reward for the group that designed a system that reduced the most effort. The challenge began with a brainstorming session to get students thinking about what they already knew about the machine. They then explored the different type of pulleys (fixed, movable, and compound) and measured the effort and distance, raised questions, and used CoMPASS to find information that would help them with their challenge. Teacher-facilitated small group discussions took place during their investigations, when they set up their pulley systems for the challenge, and during the use of CoMPASS. Whole class discussions that took place throughout the topic helped students to discuss ideas and questions as a class.

For the analysis described in this article, we used all the whole class discussions that ran parallel in the classes taught by both the teachers during the 2-week pulley unit, consisting of 3.5 hr of videotape, out of the 22 hr of videotape collected. We used classroom interactions in which students (a) engaged in brainstorming, (b) generated questions to explore in CoMPASS, and (c) reported their findings in a whole class discussion. In addition, videos of small group interactions included group discussions during students' use of CoMPASS, for which two groups were randomly chosen from each class, and group interactions between the students and teachers were recorded.

Coding Transcripts

Coding process. All of the classroom interactions (i.e., brainstorming, generating questions, and whole class discussions) were videotaped, resulting in a total of 3.5 hr of video. Analysis of the videos was done in three stages. First, the videos were watched and transcribed by two researchers, one of whom had no prior knowledge of the project. The transcription resulted in 18 pages of student and teacher interactions. Second, coding categories were generated. Third, three researchers coded the transcripts.

Our first step involved watching the videos and transcribing the interactions. For the sake of consistency, two researchers watched and transcribed all the videos. One of the two researchers was new to the project and had not been in the classes when the videos were recorded. After the transcription, a random selection of 10% of the transcripts was read and corroborated with the videos by a third researcher to check for accuracy. The next step was the generation of coding categories. A total of 15 categories were generated as described in Table 4. Once the categories were established, our final step was to code the transcripts. Each "turn" that the teacher took in leading the discussion was counted as one unit. Appendix C shows an example of the discussions along with the coding categories. After initial coding of all the transcripts by one researcher, two other researchers coded a randomly selected subset of 25% of the transcripts. Interrater reliability for coding of the transcripts was 92.6%.

Coding categories. The coding categories were driven partly by research on cognitive studies in science learning in an inquiry environment and partly by a process of inductive analysis (Patton, 1990).

The first two categories, *relating topics* and everyday *examples,* refer to the way in which the teacher helped students refer back to what they already knew about the topic being introduced. Expert teachers use learners' prior understanding as a foundation and help bridge their new experiences to prior understanding (e.g., Bransford, Brown, & Cocking, 1999). The first category, relating topics, refers to the ways in which students were encouraged to think back about the topics that they had already learned, and connect that learning to the new topic that was being introduced; for example, how a fixed pulley is a first class lever. The second category, examples, is helping relate the science that they were learning to everyday examples of simple machines (staplers, hammers, fishing rods, etc.). Relating topics therefore refers to relating knowledge acquired in previous science classes to the current topic, and examples refers to knowledge of science that students had from the real world.

The next two categories, *relating activities* and *focus on goals,* focus on how teachers helped connect the different activities in the unit (Kolodner et al., 2003; Schauble et al., 1995; Schneider et al., 2005; Singer, Marx, Kracik, & Clay Chambers, 2000). Relating activities refers to helping students relate aspects of their investigation (e.g., finding information) to their hands-on design activities. Focus on goals refers to helping students keep the overall goal of the challenge in mind while they are engaged in other activities, such as generating questions or finding information.

The next four categories again reiterate the importance of enabling deeper understanding of science by making connections (e.g., Glynn et al., 1991; Newton &

TABLE 4
Coding Categories With Examples

Category	*Example*
Relating topics	OK we thought that it [pulley] might be a first class lever. Did we determine why?
Everyday examples	Is the reel of a fishing rod a pulley?
Relating activities	So what I'd like to do is that I would like us to get on to CoMPASS and … let's think about some good questions from the back of your sheet that might help you … . So I should see everyone look at the back of their paper, reading the questions and thinking about which questions would be the most appropriate questions to answer in reference to meeting the challenge and reducing your effort the most.
	Maybe you can do a little bit more research to see if it's the ropes, if it's just the rope itself. Think back to our experiment. Do you think If you had a longer rope, then the pulley … the mechanical advantage … .
Focus on goals	Think about what the purpose is here, what is our challenge?
Relating concepts	You are increasing distance and when you increase distance you reduce your?
Relating concrete application with abstract concepts (abstract–concrete)	So you guys actually had to use a longer string. And what would that tell you right away, if you need more string, what would that tell you right away?
Reiterating big ideas	If you increase the distance you decrease the effort.
Encouraging deep reasoning questions (questions–reasoning)	How is a fixed pulley a first class lever?
Restating	Patrick just said that the fixed and movable pulley together, combined use the least effort in order to lift the load.
Giving explanations	When I put Kevin in the wheelbarrow we talked about him being closer to the wheel and that would make it easier for me to lift the load, if he is closer to the fulcrum it is easier for me to lift the load because, on the wheelbarrow, if he is right on top of the wheel where does his weight go?
Addressing misconceptions	So you can't just have a whole lot of pulleys and try to put them together. You need to try to think of a system or a strategy to put them together properly, right? … .
Giving instructions	Go to the back of the page where you wrote the questions and … .
Providing encouragement	That's a good question. I think that's a perfect question for the back of your paper because on the back of your paper it asks you what ideas related to pulleys and pulley systems did we need to know more about.
Task completion	I want you to look at your sheet and answer all the questions.
Clarifying questions	OK, so you might want to know what some of your options are as far as pulley systems are concerned, what are some of the setups, what a pulley actually is. Good.

Newton, 2000). The first of the four categories is *relating concepts*—that is, helping students to make connections between the concepts. The second category, *relating concrete experiences with abstract concepts,* refers to helping understand how the phenomena they were experiencing, such as “increasing the length of the string,” is related to the science concepts such as distance. The third category, *reiterating big ideas,* relates to how teachers helped students focus on the core principles in the unit by bringing them up in class discussions for each of the machines, and enabling students to see the connections between the machines. The fourth category, *encouraging deep reasoning questions,* comprised teachers’ efforts to help students ask deep reasoning questions—questions that would help students to reason about science phenomena and justify their claims.

The next three categories are largely derived from the video data. These are (a) *restating*—restating student comments in scientific language, (b) giving *explanations*—providing explanations about science phenomena where necessary, and (c) *addressing misconceptions*. In addition to these three categories, we had other categories such as *giving instructions, providing encouragement, discussing task completion,* and *clarifying students’ questions*. Table 4 illustrates examples for each of the categories.

RESULTS: DIFFERENCES IN ENACTMENT

In this section we discuss the sequencing of the activities in classes taught by Jane and Linda, gathered from classroom observations. We also discuss our qualitative analysis of classroom discussions.

Activities Within the Pulley Unit

Our observations indicate that the sequencing of the activities within the 2-week period was very different in the classes taught by the two teachers. Table 5 describes the sequence of events in Jane’s classes during the pulley challenge.

As described in Table 5, Jane started with a brainstorming session to enable students to think about what they know about pulleys and then asked each group to write down their questions. She then had them experiment with pulleys, and she encouraged them to think about their challenge as they did so. After this, she asked them go back to the questions that they had written to figure out whether any of their questions needed to be clarified. After revisiting their questions, the students shared the questions in a whole class discussion and chose the best questions to help them with their challenge. Students then used CoMPASS and as they were working, Jane guided them to think about how the information that they were finding would help them with the challenge and not to simply write down “answers” to their questions. Students used CoMPASS as they were working on their challenge

TABLE 5
Sequencing of Activities in Jane's Class During the Pulley Challenge

Day	*Description*
Day 1	Brainstorming about pulleys (prior knowledge, examples) in a whole class discussion. Jane introduced the pulley challenge: Design a can-lift device using pulleys to lift a bottle that weighs 600 grams using the least amount of effort. She then demonstrated materials that could be used to build the pulley device.
Day 2	Students collaborated in groups to generate questions about pulleys to address the challenge. Jane helped groups come up with questions.
Day 3	Students used the materials to "experiment" with pulleys and examine the differences between fixed and movable pulleys and refined their questions
Day 4	Students shared their questions in a whole class discussion, and selected questions that will help them with their challenge.
Days 5, 6, and 7	Students used CoMPASS to find information related to the challenge. Students used, built, and tested their pulley device. There was a lot of interplay between the building activities and their exploration on CoMPASS.
Day 8	Whole class discussion: Groups were asked to justify their reasoning for the setting of their pulley device, report the amount of effort force required to lift the load, and what they learned from the pulley challenge.
Day 9	Reflection: Students were asked to write about their pulley design and what they learned from it.

and went back and forth between the two activities of finding information and applying it to their designs. Having laptops on their desks enabled students to switch between the two activities. After each of these steps, whole class discussions were facilitated by Jane who helped students make connections between the investigation and the questions that they came up with. She also helped them relate their questions to the goal of lifting a load with least effort (their overall challenge).

Table 6 shows the activities in the 2-week unit in Linda's class. Students in Linda's classes also started with a brainstorming session and then generated questions about pulleys and pulley systems. They brainstormed as a whole class and then answered questions on CoMPASS. Following this, Linda gave them a set of eight questions (and added one more from the questions that students had generated) and asked them to find answers to the questions on CoMPASS. Students were asked to write down the answers to all the questions. After they had answered all of the assigned questions, students completed the pulley challenge and shared their experience in a whole class discussion. On the last day of the challenge, students were given a quiz on what they had learned about pulleys and pulley systems.

Although students in both teachers' classes carried out all the activities in the unit, the sequencing was very different. Jane had her students raise questions in their groups and had them "play" with the materials before they generated questions. She also had them go back and forth between their hands-on investigation and exploring

TABLE 6
Sequencing of Activities in Linda's Class During the Pulley Challenge

Day	*Description*
Day 1	Brainstorming and question generation in a whole class discussion.
Day 2	Linda introduced the pulley challenge: Design a can-lift device using pulleys to lift a bottle that weighs 600 grams using the least amount of effort. Demonstration of materials that could be used to build the pulley device.
Days 3 and 4	Students used CoMPASS to answer questions that Linda had generated in a handout.
Days 5 and 6	Groups used materials to build and test their pulley device.
Day 7	Whole class discussion: Student were asked to report the amount of effort force required to lift the load and what they learned from the pulley challenge.
Day 8	Complete the assignment of writing up their answers.
Day 9	Quiz on pulleys.

the information on CoMPASS. In Linda's class, students did not have any experience with the materials (pulleys) before they started working with CoMPASS. They used CoMPASS to find answers to questions and when they found answers, they completed the pulley challenge and tested their devices. On the whole, the sequencing of the unit in Linda's class was very linear in that each activity was completed as a "task," and there was little overlap between any two activities.

Chronological Representation of the Class Discussions

To understand how the two teachers facilitated classroom interactions leading up to the use of CoMPASS, during students' exploration on CoMPASS and what happened after, we used a chronological representation of the discussions as described by Luckin (2003) and Hmelo-Silver (2003) in their use of the CORDFU (Chronologically Ordered Dialogue and Features Used) and CORDTRA (Chronologically-ordered Representation for Tool-Related Activity) methodologies respectively. These methodologies enable a graphical representation of the chronology of discourse, allowing an understanding of how it changes over time. Figures 4 and 5 describe the discussions as they occurred over the different activities—before the use of CoMPASS, during the use of CoMPASS, and the whole class discussion after students explored and completed their pulley challenge. Each line in the figures depicts a single category (described on the right side of the figures) with the incidence of teacher comments in that category along the horizontal axis.

Figure 4 illustrates the strategies that Jane used in her facilitation of classroom discussions during the early brainstorming and question generation phase (1–122), small group facilitation while students used CoMPASS (123–158), and the whole class discussion after students completed their challenge (159–251). Statements 1–122 occurred during whole class discussions before students started using CoM-

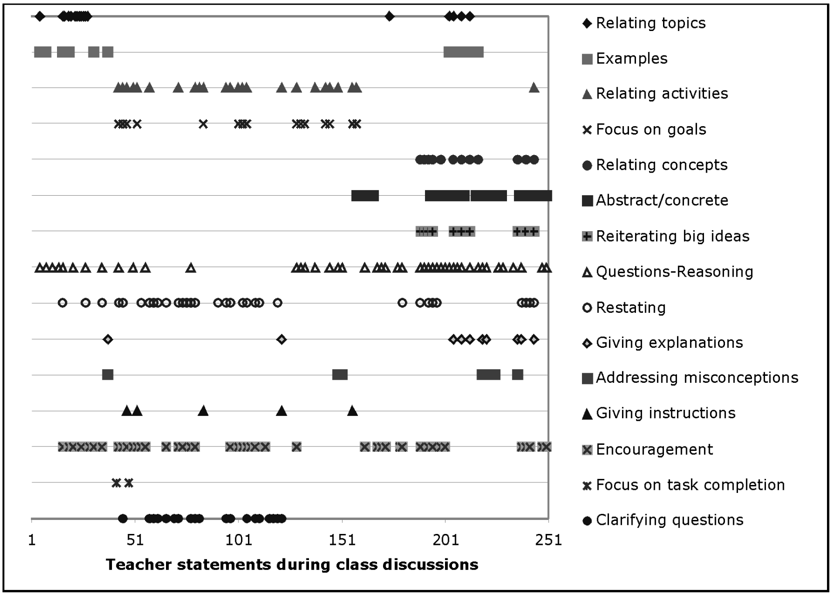

FIGURE 4 Representation of discourse in Jane's classes.

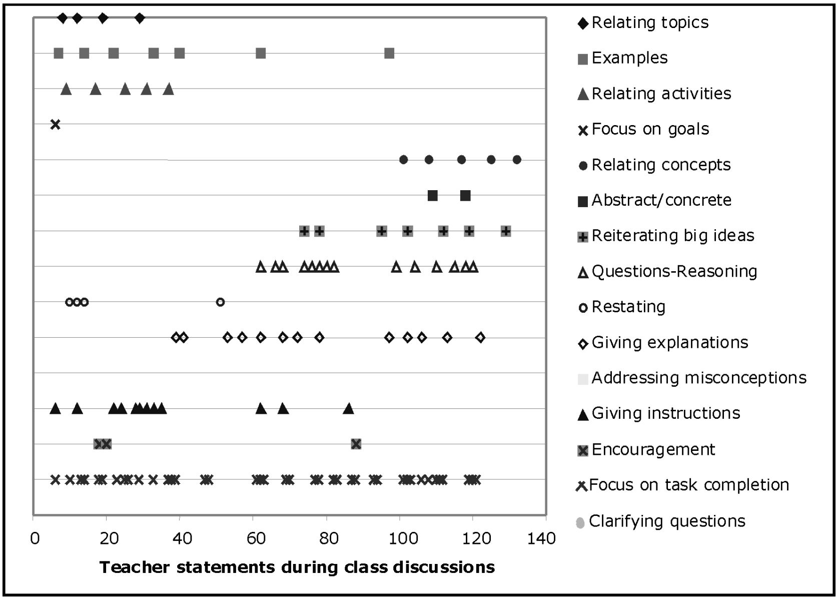

FIGURE 5 Representation of discourse in Linda's classes.

PASS in Jane's class. The figure indicates that there were three predominant themes in Jane's facilitation during this time. First, her discussion was indicative of helping students "situate" the current activity; that is, solving the pulley challenge, in the context of the simple machines unit as a whole (relating topics), as well as everyday knowledge of pulleys (examples). She specifically asked students to think about what they had learned before, both from everyday examples as well as from other topics already covered in class. Second, the other category that we see is "relating activities" in which she was helping students understand the purpose of their question generation. Restating students' comments and questions was the third category noticed in her discussions during the early part of the unit. Third, we see several instances of helping students raise questions that were deep as opposed to "fact" questions and providing students with encouragement.

Statements 123–159 illustrate the talk during students' use of the CoMPASS system. As the figure indicates, during this time Jane focused on (a) helping students think about the goal for their exploration on CoMPASS, (b) encouraging them to see the relation between looking for information related to their questions on CoMPASS, and (c) asking them questions so that they could reason about what they were finding. Another theme that was seen during this time was helping students relate the abstract knowledge to their hands-on activities (abstract–concrete).

Statements 159–251 in Figure 4 illustrate that the predominant categories in Jane's facilitation of the whole class discussion were as follows: reiterating big ideas, such as the trade-off between force and distance; helping students make connections between their hands-on experience and the abstract science concepts, such as how more string means more distance (abstract–concrete); helping them make connections between concepts (relate concepts); and asking them questions so that they justified their claims scientifically.

Figure 5 shows parallel interactions from Linda's class. The figure shows classroom interactions prior to the use of CoMPASS (1–34), small group facilitation when students were using CoMPASS (35–90), and the whole class discussion after students had completed the pulley challenge (91–140). During the brainstorming and question generation phase, the figure indicates that Linda gave students many instructions. There was some evidence of referring back to what they had learned before in the early part of the pulley challenge, and helping students relate pulleys to other machines that they had learned about. There are also some instances of helping connect with everyday examples and providing explanations.

Statements 35–90 in Figure 5 show Linda's facilitation of small groups during their exploration in CoMPASS. As the figure indicates, Linda provided explanations during this time and also asked students questions about the science content. During the whole class discussion at the end of the unit (91–140), the discussion had some instances of relating concepts, reiterating big ideas, asking questions, and providing explanations. Throughout the three phases, the two most frequent categories were focusing on task completion and providing instruction.

Two main differences can be seen from the representation of the discussions. First, the volume of talk in Linda's class was lesser than in Jane's class. Second, Jane's strategies were different for the different phases of the unit. In the early part of the unit, she focused on situating the topic and helping students to connect the current topic to what they already knew. Her facilitation in this phase showed more instances of helping students think about what they knew about pulleys, relating the activities of generating questions to the overall purpose of the challenge, and helping students focus on their goals. She also provided clarifications for students' questions as well as restating their comments in the early part of the unit. In the later part of the unit, when students had gained some knowledge on the topic, she asked them questions to elicit reasoning and justifications for their pulley designs, helping students relate concepts, relate their hands-on learning to abstract science concepts, providing explanations, and addressing misconceptions. Throughout her facilitation, there were numerous instances of providing encouragement. Linda's class discussions on the other hand, focused largely on task completion throughout the unit. There were some instances of other categories such as relating concepts, activities, and reiterating big ideas, but there seemed to have been no pattern in that these were spread throughout the unit. Furthermore, there were no instances of responses in two of the categories, addressing misconceptions and clarifying questions, in Linda's class discussions.

In the next few sections, we discuss with examples the classroom interactions in the classes taught by the two teachers. We start with episodes of brainstorming and generating questions, teacher facilitation during small group work, and whole class discussions at the end of the pulley challenge.

Brainstorming and Generating Questions to Explore in CoMPASS: Jane's Class

During this phase, discussion about what students already knew about pulleys and pulley systems, and generating questions for their investigations were the focus of Jane's facilitation. This excerpt was part of the brainstorming session:

Jane: OK we thought that it [fixed pulley] might be a first class lever. Did we determine why?

Class: Yeah, yeah … I think so (*many students answer at the same time*) [*Jane has drawn a pulley on the board.*]

Bob: Would that be the fulcrum and that be the effort? [*Bob refers to the drawing*]

Jane: What's that and that? Come on up.

Bob: I think this is the load, this is the fulcrum, and this is the effort. [*He labels the diagram*]

Jane: OK who agrees with Bob that this might be the way, the reason that a pulley is a first class lever? Who agrees? We've got four people, five people, six, seven, eight people in agreement, nine … . [*There is a discussion about how a fixed pulley is a first class lever*].

In the previous example Jane asked students to reason about why a pulley (fixed) is similar to a first class lever. She had one of the students label the figure of a pulley that she had drawn on the board to clarify to the class how a fixed pulley could be classified as a lever. Students had already worked with levers and were familiar with the different classes of levers. This episode illustrates that the teacher used the prior knowledge from previous parts of the simple machines unit to help them relate the two topics: levers and pulleys.

The brainstorming session was followed by students generating questions in their groups and subsequently sharing them in a whole class discussion. The following episode is part of the whole class discussion where the groups shared their questions with the rest of the class:

Jane: What are some questions that will help you for your challenge?
Pat: How do pulleys gain mechanical advantage?
Jane: Mechanical advantage … OK, we will find out
Tim: Guess what Mrs. G. We can like write it like a hypothesis.
Jane: OK, let's hear.
Tim: I think that the more pulleys you have the easier it will get to like pull something
Jane: OK, good excellent. If we have more pulleys then …
Tim: (*Tim restates the hypothesis again*) If we have more pulleys then it will be easier to lift the load.
Jane: Excellent, great!
Katie: How do we know how much effort …
Jane: That's a good question … While you're thinking about your challenge you should probably be thinking about some questions that you need to know more about so that you can actually do this challenge really well. Katie asked how do we know if we reduced the effort, OK? And that's a really good question. How are you gonna measure what your effort is? What are some other questions we could ask?

As this vignette illustrates, an important aspect of Jane's facilitation in the early part of the unit is to help students understand that the questions that they are raising are for a purpose (focus on goal). She also encouraged them to see the relation between asking questions and finding information (relate activities). Jane restated students' questions and statements so that they could explain them in more appropriate scientific terms. Her facilitation is aimed at enabling students to understand why they are generating the questions and how the information they will acquire for each of the questions will help in their challenge.

A little later in this session, Jane summed up what students should do with the questions that they generated, as in this excerpt:

Jane: … But we had a whole list of questions on the back that we talked about together as a class (*She goes on to list some of the questions that she has written on the board*). These are all good questions that we had to try to help us complete our challenge. So what I'd like to do is that I would like us to get on to CoMPASS and … let's think about some good questions from the back of your sheet that might help you … … So I should see everyone look at the back of their paper, reading the questions and thinking about which questions would be the most appropriate questions in reference to meeting the challenge and reducing your effort the most.

After all the questions were on the whiteboard, Jane asked students to think about which ones were most relevant to their challenge, and find information on CoMPASS related to those questions.

Brainstorming and Generating Questions to Explore in CoMPASS: Linda's Class

The subsequent episode is from the brainstorming session from Linda's class. Students in Linda's class also started with thinking about what they knew about pulleys:

Linda: Before we begin this unit, on the section of unit on pulley, I want to take a minute to talk about what we know about pulley. What are the some of things we already know about pulley? Arnold?
Arnold: They consist of the wheels.
Linda: Did you say of some wheels?
Arnold: Of wheels. Yeah.
Katie: Do you want us to write this?
Linda: No. Katie
Jenny: They have, they pull off heavy stuff up. They don't involve a lot of effort.
Linda: I like you say that they don't involve a lot of effort. Clive, do you have your hand up over there?
Clive: Oh, yeah. The more pulleys you have, the less effort you will need.
Linda: OK. Jenny.
Jenny: umm, they are simple machines.
Students: Really cool.

Linda: Pete.
Pete: They always have to have wheels?
Linda: What do you mean by that?
Pete: It's just like …
Linda: Yeah. Tom.
Terry: All pulleys must involve something to it. They must have …
Terry: The Greek invented the pulley.
Students: Yeah. That's true. It's true.
Linda: I believe you. I am not arguing you.

As seen in this example, there was some discussion about the parts of the pulley and students came up with a few examples of pulleys. However, there was not much discussion on how the pulley is related to other machines. After the brainstorming, Linda started by writing a question on the board: How do you make a pulley setup? She then asked students to come up with their own questions:

Linda: Any other questions? We probably have some more questions. Remember we are trying to seek to reduce the amount of effort we need to apply to lift an object. What would be another question Gary?
Gary: In detail how does a pulley work?
Linda: OK, in detail how does a pulley system work? *(She is writing on the board without talking)*. More questions. Dan …
Dan: Hmm … oh do pulleys work better when they are closer or further apart?
Linda: (*The teacher writes on the board without talking*)
Dan: How do you judge how much effort …
Linda: (*Linda continues to write the previous question and then she opens a drawer and gets spring scales out).* All right, more questions. What's your question?
Ron: How does the pulley reduce effort?
Linda: Excellent question
Ron: Are we writing these down?
Linda: Yeah, these are some questions that we are going to need to answer today, tomorrow in lab. *(She writes on the board).* This question is excellent. How does a pulley reduce effort? Because essentially that is what we are seeking to answer. That answer is what will tell you how to create your design to make it easier to lift the load.

The brainstorming activity in Linda's class showed some evidence of having students focus on the overall goal of the challenge. Students raised some interesting questions related to their pulley challenge, such as how a pulley can help reduce effort. But they did not use the questions that they had raised in the class for their exploration on CoMPASS. When students had raised questions, Linda gave them the following instructions to use CoMPASS for their exploration:

> Linda: I have, beyond what we've brainstormed here I've typed some questions I'd like you to answer in CoMPASS today. I will explain why I've given you questions. Because from what I've seen through all of my classes I'm not confident that everybody, that all of you are reading what you need to be reading. Some of you are but some of you aren't … When you log on today, this is very important, when log on today, you are going to go to Internet Explorer … (*she goes on to explain what to do to log on*) … In CoMPASS today you are going to work and energy like you always do. You are going to go to pulley section. Before … I want you to start at the right hand side I really want you to read this whole section, the whole thing. Guys, I have typed up eight questions that are specific to the pulley that I want you to answer through the links today. The first probably five you can answer just from that first link, the first page. For the others you need to maneuver through the next three.

Linda gave students handouts with questions that she had written prior to class. Linda was concerned that if students were not asked to find information based on the specific questions that she had written, they would not learn the necessary science principles. She wanted students to have a purpose and not just "click on the links" (as sixth graders can often do); she gave her students purpose by giving them a list of questions and told them where to find the answers. At the end of this discussion, she handed out a sheet of paper on which she had typed eight questions. As indicated in the previous excerpt, Linda asked students to add another question to the ones that she had already written. Students used CoMPASS to find answers to the questions that they were given. The questions on the sheet were as follows:

1. What is the purpose of a pulley?
2. What are the three types of pulleys?
3. How does each type of pulley make work easier?
4. Each type of pulley can also be classified as a lever. What class of lever is each pulley associated with?
5. Why is a crane a good example of a compound pulley?
6. In simplest terms, how would one define force?
7. Define input and output force. Why is it important to understand these two terms?
8. Define power. Why is power important?

Our classroom observations indicate that Linda had written the questions beforehand—before the class started. The questions were typed on sheets of paper that she handed out to students. Thus, the questions that students raised in class were not used to guide their exploration on CoMPASS. In her instructions, she also told students that they would find answers to the first five questions on the first page in CoMPASS, and that they might need to explore a little to find answers to other questions.

To summarize, in Jane's class, the brainstorming session focused on grounding the current investigation in what students already knew, both in terms of knowledge acquired in school as well as the real-world knowledge of pulleys that they had. The activity of generating questions was connected to the research in CoMPASS and to the overall goal of designing the best pulley system. It is interesting to note that after students raised questions in the class, Jane asked students to select questions to best help complete the challenge and also asked them to think about the purpose for finding information on CoMPASS, rather than answering all the questions. In Linda's class, students were given a set of questions to find answers to. The questions were not the ones that students had generated, and were therefore not connected to students' own ideas about what they wanted to find out, but were written by Linda prior to class. The questions were not connected to the overall goal, the pulley challenge, because they were mostly about finding facts or defining terms.

Discussion During Students' Exploration in CoMPASS: Jane's Class

After students had generated questions and Jane had asked them to think about their goals, students worked on CoMPASS in their small groups and also experimented with pulleys and pulley systems to understand how they could set up pulleys and what worked best for their challenge. As students worked in their groups, Jane went around the classroom to help students. The following episode is an example of how Jane facilitated a small group discussion when students were using CoMPASS:

Jane: How are you guys doing?
Amit: Uh, well we have the same thing as them. Like, uh. The mechanical advantage of the pulley is equal to the amount of supporting ropes …
Jane: And what does that mean to you in terms of setting up your experiment?
Ron: Uh, that we want more rope so we can get more mechanical advantage.
Jane: And how are you going to make more rope? And why does more rope give you more mechanical advantage? Are you just going to make the rope longer? Do you think that's going to do it?

Amit: Maybe.
Jane: Maybe? *(Amit looks very thoughtful).*
Jane: Maybe you can do a little bit more research to see if it's the ropes, if it's just the rope itself. Think back to our challenge. Do you think if you had a longer rope, then the pulley … will have more the mechanical advantage? You should do a little bit more research.

This conversation illustrates the way in which Jane encouraged students to think about and find out more information by themselves instead of giving them answers. In this particular episode, she wanted the students to think about why more rope might result in more mechanical advantage. By asking questions that encouraged her students to think about how the information applies to their challenge, she got the students to explore pulley systems and the relation between more rope and mechanical advantage. By asking them why more rope meant more mechanical advantage, once again she was helping students to find out more about relations between the phenomena that they were learning, instead of focusing on a basic fact such as "more rope equals more mechanical advantage."

In another conversation with a different group, Jane helped students reason about why they were answering the questions:

Jane: How are you ladies doing?
Ann: Good. We are on first, second, third, fourth question.
Jane: So you are going through the whole list hoping that you are going to find something? *(Ann and Rose nod their heads).*
Jane: But I mean for helping you with your challenge. Have you found anything to help you with your challenge yet?
Ann: (*She shakes her head to indicate "no")*. Hmm … how to set up a pulley?
Rose: Hmm … the size of the pulley, the size matters.
Jane: The size of the pulley … Does it matter? Why does it matter? How will it help you with your challenge?

Students in this group were merely focusing on the list of questions that they had written down. In her conversation with this group, Jane focused on two things. First, she asked them to think about how their questions were related to their goal and why. Second, she reminded them of the pulley challenge and also had them think about the fact that they were just going over the list of questions and not thinking about why they needed to answer the questions. She also asked them to reason about the size of the pulley and whether it mattered in reducing the effort while lifting a load.

Discussion During Students' Exploration in CoMPASS: Linda's Class

Students in Linda's class also worked on CoMPASS to find answers to the questions that they were given. Linda walked around the class and talked with groups of students as they were working on CoMPASS:

Dan: In this one (*refers to one of the question on the handout).* For the last question I understand how … but I don't understand how exactly it makes work easier.

Linda: Alright. *(Linda is looking at the text in CoMPASS)* Why do you think movable pulleys make lifting easier? *(She starts reading aloud a paragraph in CoMPASS).* More sections of rope are supporting the weight. It's like having someone help you carry something heavy. The more help you have the lighter the load becomes.

Dan: So it says more pulleys, but how can you have more than one combination of pulleys? So if it is like that (*He points on the picture of the fixed pulley arrangement in CoMPASS)*

Linda: Oh, you know what you can do? You can sometimes wrap the rope through two pulleys and have the distance far enough apart. There are a couple of different ways. A pulley is designed especially to do that. Let me show you *(She grabs some pulleys from the drawer that are different kinds of pulley; i.e., a double and a triple pulley, and demonstrates them to Dan)*. Pulleys will sometimes set up to do that. And here it is an interesting thing because I want you to look at these two pulleys and what do you notice about these two pulleys?

Dan: One is smaller.

Linda: Why would I show them to you?

Stacy: *(Special Education student, Dan's partner while using CoMPASS).* Because he is smart.

Linda: No it has nothing to do with smartness. It's a question that he asked earlier.

Dan: They are really close together.

Linda: One is …

Dan: One isn't.

Linda: What question did you ask?

Dan: Does it make a difference if the pulleys are close together?

Linda: Does it make a difference if the pulleys are close together?

Dan: I was talking about this *(the student holds the two pulleys close together to express that his question referred to the distance between the two pulleys rather than the wheels within each pulley (as in a double, triple pulley).*

The question that was raised by Dan indicated that he was confused about what it meant if the distance between pulleys is increased or decreased, in a situation where there are multiple pulleys. This was a complex issue, and not something that students could find a ready answer to on CoMPASS. The excerpt indicates that at the end of this interaction, Dan still had the question that he started with. This example again presents a situation in which students had to make connections between what they were reading and what they were doing in their hands-on activities—an important part of learning that needs guidance. In another group, the discussion was about "finding" an answer to a question that students were given, as a task in itself, unrelated to the other activities in the unit:

Linda: Defining power, question number 8 on your sheets. What is power? Katie?

Katie: Power tells you how fast work gets done

Linda: Yeah … Power tells you how fast work is being done. Why would that be important? [*Looks around for a few seconds and nobody raises their hand*] Why would you want to know how fast work is being done? Why would that be important? Stacy?

Jack: It's … in a car like the gasoline's levels should be high, like really really high cause then …

Linda: It relates to efficiency. Sure, absolutely! OK, a lot of connections there. Any other questions? Ben, I have a question for you. At this point in your research how does a pulley reduce the amount of effort?

Ben: I said it changes … I don't know if it's right 'cause I haven't found that answer … I said it changes the direction of the force.

Linda: OK? Maybe it changes the direction of the force and this is my charge to you tomorrow morning. I want you to find that answer tomorrow.

In this example, Linda's discussion with the students revolved around the questions that she had given them; for example, define power. Students in Linda's class continued to find answers to the questions. It is interesting to note that Linda asked one of the students how a pulley reduces effort, but the student was not sure of his answer because he had not found the information in CoMPASS at that time. Changing the direction of the force is only one way of reducing effort in a pulley; students needed to understand that a fixed pulley only changes the direction of the force, whereas in a movable pulley one can also reduce the amount of effort by increasing the distance. Classroom observations indicated that students were mostly writing down the information verbatim. By the end of the class period students had written down answers to most of the questions.

In summary, Linda's students were finding answers to her questions—not ones that they had generated and understood the significance of. Linda also provided answers during small group interactions, whereas Jane focused on having students find the information and asked them more questions. It is interesting to note that whereas Linda asked students to write answers to her questions, when a group of students were concentrating on finding answers (example discussed previously), Jane specifically asked them to think about how the question and the information was related to their goal. In Jane's class, there was more emphasis on guiding students to ask deeper questions in ways that encouraged them to reason about science principles and justify their designs.

Whole Class Discussion at the End of the Pulley Challenge: Jane's Class

After students had found information on CoMPASS and completed their pulley challenge, Jane had each group describe how they set up their pulley systems and what they had learned in their pulley challenge. This was the closing discussion in which students had to explain their designs in scientific terms. Each group was asked to explain why they had decided to set up their pulley system the way they did, the effort force required to lift the load in their system, and what they had learned from the pulley challenge. Each group had to explain how much effort they had reduced and why. The following episode represents a part of the whole class discussion that took place at the end of pulleys:

Jane: You are increasing distance and when you increase distance you reduce your?

Class: Effort

Jane: Effort. They needed more string to go through their pulley system. What would you make for a prediction about how much effort they reduced? What would you make for a prediction? What would you make for a prediction Ed? If they needed a lot more string for their pulley system?

Ed: It would make it easier.

Jane: It would make it easier. How many grams of effort did it take?

Ed: 50 grams

Jane: 50 grams of effort for them to lift the resistance force. So what happened … somebody tell me why this has reduced the effort so much. Somebody tell me why this has reduced the effort so much. I got my three, OK I have four hands up, five hands, six hands. Why, Dan?

Dan: I think it was because hmm … we used a longer rope and hmm … we had a lot of pulleys.

Jane: So what happens to the weight of the resistance force? I mean the resistance force is still 600 grams, how come it feels like 50? What happens to the weight?

Jane: Yeah, what are you thinking? Does anybody know? Do you want to take a guess?

Rose: Well, when you put all the pulleys together and the string, the string, the support ropes in the pulley, hmm … take off the effort.

Jane: It supports the weight, right? All the weight of this is distributed over all these different pulleys, just by a little bit on each of these pulleys, where it's resting. So if you have more pulleys and string for the weight to kind of rest on, because the ceiling is also holding everything, right? You have those pulleys and strings for it to rest on, the weight is distributed and there is less weight for you to lift, it's like having extra hands. So what did we learn from this. I should see lots of hands. Kathy?

Kathy: I learned that the more pulleys and the more ropes that we have, MA, mechanical advantage is increased, distance is longer, and the effort is less.

Jane: You increase your distance and reduce the effort. Beautiful, excellent! That was a very nice way to kind of put it in a succinct explanation. I am really glad that you learned that. Pat?

In this episode, Jane questioned the students on what it meant to have more string. She encouraged students to connect their experiences with physical objects and the conceptual knowledge represented in CoMPASS by having them reason about what they had accomplished in their challenge and what that meant in terms of the science that they were learning. One of the most important principles that students needed to learn in the simple machines unit was the trade-off between distance and effort. This was not an easy concept to grasp and students needed several experiences with materials as well as several reiterations of this principle in discussions, before they understood this relation. Jane focused on helping students see the relation between distance and effort, by questioning students each time they encountered this aspect of the machine. She asked students to explain how and why the effort was reduced and provide reasoning for their pulley designs and results.

Whole Class Discussion at the End of the Pulley Challenge: Linda's Class

In Linda's class, all of the students groups succeeded in reducing effort; however, they were not asked to explain how they did so, or why some of the groups were more successful than others:

Linda: … Now Bill and Kyle, in your group, you had, you took, you went a different avenue, hmm … and don't be upset because I think you had a really good idea. OK, what was the premise of using those types of pulleys? What was the basis of your decision choosing to use those types of pulleys?

Bill: Hmm … I don't know.

Kyle: More pulleys.

Linda: More pulleys and you had the rope supported by the pulleys. I think you were thinking about that. What did you discover though through this task? Did it reduce effort? Were you successful in reducing effort?

Group: Yeah

Linda: Yeah. Did you reduce it the most?

Group: No

Linda: No, it has to do with the way pulleys are set up. But you reduced effort so you accomplished your goal. I think you did a nice job working on it. You guys here did you reduce effort?

Group: Yeah.

Linda: Absolutely. I would like to compliment this group for their creativity in planning and thinking how to design this. Because they have quite an elaborate the pulley system going on. *(Students start clapping)*

Linda: I see fixed pulleys, I see movable pulleys, I see a design work on the table to get that pulley to be actually a fixed pulley in that direction. You reduced effort, you were successful. You didn't reduce the effort the most but that's OK. What did we learn through this activity? What are some things we learned in this group?

Kim: The more pulleys …

Tom: Teamwork.

Linda: OK, the more pulleys, doesn't always necessarily reduce the effort the most, it might depend on the setup of the pulleys. Tom, you brought something up—teamwork. When I came over to this group they said ah … we already lost because some other group already has 90 grams in their pulley system. But I said to them, no, you've been very successful because we have four people here. Every person was doing a job, every person is helping out in working together, and that to me that is success … Now Bill, Robin and Steve—your group—have we tested it yet?

Group: Yeah

Linda: What did we get for effort?

Linda: What was it Claudia? Is it still the same?

Bill: 140.

Linda: That's OK. Did you reduce effort? Did you reduce effort?

Group: Yeah

Linda: Yes you did, the starting effort weight of this setup is 600 grams. So you reduced it by well over half, OK? By over half. That is successful … that's OK.

A challenge in open-ended curricula such as design-based approaches to science is that it is possible for students to optimize their designs by trial and error without really paying any attention to and reasoning about the science (Kolodner et al., 2003).

For students to focus on the science they need to be scaffolded during all of the activities and especially during small group and whole class discussions. In Linda's class, students' presentations focused on the fact that they had reduced effort and the actual amount by which they had reduced the effort force to lift the object. Much of the discussion in Linda's class focused on sharing with the class, whether the task had been completed satisfactorily (i.e., whether effort was reduced). But the facilitation did not include many instances of reasoning how effort was reduced.

A major difference in the whole class discussions in classes taught by the two teachers is that Linda's students did not explain their reasoning, but mainly reported how much effort they reduced. Linda asked her students how much effort they had reduced, but she did not ask them to explain why effort was reduced and how their designs helped reduce effort. But Jane's students justified their designs based on the science they were learning. She asked students questions that encouraged them to justify why their designs reduced effort and also helped students connect concepts. In the class discussion after the completion of the pulley challenge, she also provided explanations and reiterated one of the major principles of the unit: the trade-off between force and distance.

DISCUSSION: COMPARISON OF ENACTMENTS

As the excerpts illustrate, Jane and Linda have very different teaching styles. What seemed to be significantly different in the two enactments was the culture of inquiry that was fostered in the classes. There were two major differences in the two enactments. First, all the different phases of the pulley challenge were carried out as an interconnected set of events in Jane's classes, whereas in Linda's class each activity seemed to be an end in itself. Although Linda had all the parts of inquiry, the deep structure that connected all the phases was lacking. Students in Linda's class were on task and completed all of the investigations in the curriculum. Jane seemed to have encouraged her students to think about the purpose of every activity and how it was connected to the others in the unit. Second, Jane's strategies during facilitation of whole class discussions were different for the various phases of the unit. In the early part of the unit, Jane focused more on enabling students to ground the current topic in what they already knew about simple machines, whereas in the later discussions she asked questions that encouraged students to reason about the science that they were learning, and she helped make connections between abstract science principles and their concrete hands-on experiences and connections between concepts.

Earlier in this article, we noted that two aspects of science learning were important for richer understanding: connections that students make between activities in a unit and understanding the interrelatedness of science knowledge. We now compare Jane and Linda's enactments along these two issues.

Helping Students Make Connections Between Activities

One of the main differences in the two enactments is that all the different phases of the pulley challenge were seamlessly integrated and tied to the overall goal in Jane's class. However, in Linda's class each activity seemed to have been completed as an assigned "task." This difference was seen throughout the unit, starting from early brainstorming to the end of the unit.

Connecting prior learning to the current topic. In the brainstorming sessions, the focus of Jane's facilitation was on helping connect prior knowledge and experiences to the topics being learned. The brainstorming sessions in Jane's class emphasized the importance of helping students elicit what they knew about simple machines and relate it to their current topic, and also to the real-world examples of pulleys that they were familiar with. By encouraging students to share what they knew about pulleys and relating this knowledge to other machines that they had already learned about, Jane helped provide opportunities for what Tabak and Reiser (1997) described as making students' individual knowledge "public," providing a shared knowledge base for all the students. In a classroom where groups of students with varying levels of prior knowledge are learning together, it is important to provide a common forum for students to share what they already know. This was achieved in Jane's class in the early discussions in the unit.

Students in Linda's class also started with a brainstorming session in which they talked about everyday examples of pulleys. They came up with some interesting examples of pulleys, such as blinds and the reel in a fishing rod. Although students shared what they knew about everyday examples of pulleys in the whole class discussion, there was no discussion about how pulleys were related to other simple machines, especially levers.

Generating goal-related questions. There are also differences in the ways in which Jane and Linda used student generated questions. Although both teachers had whole class discussions to help students raise questions, the purpose of the activity was very different for each of them. For each question that students raised, Jane asked students to write down the questions that were most relevant to their investigation—the pulley challenge. Although Jane encouraged her students to select questions that were relevant to their goal, Linda assigned questions that she had already prepared. At the same time, she also gave students instructions about where to find the information for each of the questions, so her students concentrated mainly on finding answers to the questions provided by her. Our study suggests that teacher facilitation can play an important role in helping students generate questions that are relevant to their projects. Jane fostered this throughout her interactions with students, but more particularly in the early part of the unit when students were generating questions that they could explore on CoMPASS.

In their small group activities of using CoMPASS, the facilitation provided by Jane and Linda was quite different. An important aspect of scientific inquiry is for students to be able to use informational text successfully (National Research Council, 1996), with a critical stance (Goldman & Wiley, 2002) and understand scientific principles that are often abstract. When students use resources, there is "a mindset, that transcends technology" in that students expect to find answers on specific page (Soloway & Wallace, 1997). Soloway and Wallace pointed out that students often follow the "path of least resistance" and write answers to questions instead of engaging in critical skills, such as evaluating the relevance of the information to their current goal and synthesizing the different bits of information that they find in the resources provided. In Linda's class, students did not have the opportunity to critically examine the information that they were finding and think about how it would help them in their investigation, because (a) they did not use the questions that they generated and (b) the questions that they were given were not related to the overall goal of the challenge. Students merely focused on finding answers to the questions. In Jane's class, students were encouraged to select questions that would help them find information related to their goal; hence their use of CoMPASS was more meaningful to the overall goal of their investigations.

Connecting concrete experiences with abstract science knowledge. Davis and Petish (2001) argued that if teachers cannot make connections between the science principles that they read in books or other electronic resources and real-world applications of those principles, they are less likely to promote those connections in their teaching. In Jane's class, both her facilitation and the sequencing in the unit helped students make connections between connecting concrete experiences with the science knowledge that they were finding on CoMPASS.

Several of the ways in which Jane facilitated classroom discussions were aimed at helping students make the connection between abstract and concrete representations of the science phenomena that they were learning. First, in the early part of the unit, she helped students keep the overall goal of the pulley challenge in mind, so that their questions and information seeking activities were related to the overall challenge. Second, in the latter part of the unit when students were explaining their results, she asked pointed questions such as "what does it mean to have more rope?" Third, she often reiterated the connections several times for students to be able to grasp them. It is important to note that in whole class discussion at the end of the pulley challenge, rather than giving answers to students, Jane followed up students' questions with more questions, forcing them to think.

Integration of activities within the unit. The ways in which Jane and Linda sequenced the activities might have impacted the connections that students could make between the activities. The sequencing of design activities and use of CoMPASS in Jane's class also might have helped integrate the two activities. In Jane's class, students experimented with pulleys and pulley systems after the first brainstorming session, raised more questions in groups based on their experiences, and then used CoMPASS. This seems to have provided students with a better grounding for their questions because they had thought about everyday examples of pulleys and also how the topic of the pulleys was related to other topics that they had already learned in the simple machines unit (e.g., levers). The hands-on experience with pulleys also helped them refine their questions. In Linda's class, students used CoMPASS after they had raised questions. But because they had no experience with using pulleys, they had several questions about the information on CoMPASS; for example, questions that Dan asked about the distance between pulleys. The questions that they answered in CoMPASS were the ones that Linda had typed up on handouts before the class. Because students did not have any first-hand experience with pulleys and pulley systems, their second-hand experience (Palincsar & Magnussen, 2001) of using CoMPASS may not have been very fruitful. By ordering the activities in such a way that students could use the hands-on experiences to raise questions, and having them think for themselves instead of giving them the information, Jane helped them see for themselves how the physical aspects of their investigations were related to science principles, because of her "deliberate structuring" (Lampert, 2001) of the activities in the unit. This integration was almost lacking in Linda's class. There were very few instances of having students see the different activities were connected to each other and to the overall goal of the unit.

Helping Students Make Connections Between Concepts

As indicated before, an important aspect of learning science is that students need to understand the interrelationships between concepts and principles and not study them as isolated facts. "Knowledge-centered" (Bransford et al., 1999) environments are believed to be those in which students learn in a way that enables them to develop an integrated understanding of the important concepts. CoMPASS showed relations between concepts and principles. However, merely providing a representation of the relations is not sufficient for deep understanding. Classroom activities and interactions need to support the affordances of a resource. Jane's facilitation focused on helping students see these connections. When students discussed single concepts, she helped them understand what other concepts or principles (or both) might be related and provided clarifications and explanations. This was a critical part of the whole-class discussions in that it helped students to see how concepts such as "force" and "distance" affect work.

By providing students with many opportunities to connect their past and current learning, Jane ensured that students had a firm understanding of the "big ideas" that they were learning in the simple machines unit and that these were always revisited when new topics were learned. Lampert (2001) argued that teaching in domains such as mathematics requires that teachers help students see the big ideas that are common and applicable across topics. By encouraging students to see how concepts such as mechanical advantage or the idea of trade-off between effort and distance applied in the different machines, Jane enabled students to understand the scientific principles in different contexts.

IMPLICATIONS AND NEXT STEPS

In the last decade and a half, there has been much discussion about the divide between educational research and practice and a need to understand learning in complex real-world contexts (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Collins, 1992; DBRC, 2003). This is in an effort to develop usable knowledge (Lagemann, 2002) that will be helpful to practitioners, alongside developing theories of teaching and learning in context. Design-based research methods in which researchers try to understand the ways in which learning occurred in a particular setting are increasingly being used to understand teaching and learning in classroom settings. Unlike traditional experiments that involve controlling variables, the thrust in design-based research is to characterize the environment in which the intervention is used by developing an understanding of the actors (e.g., teachers, students) and the social structures in a particular setting to develop rich representations of teaching and learning. An important aspect of design-based research is to understand student learning as well as the learning environment (Cobb, Confrey, et al., 2003). To understand the learning environment, it is essential to examine the many variables that might affect student learning, particularly when the same intervention is being implemented in multiple contexts. Very often, this means a systematic analysis of enactments in a setting, in an effort to understand the factors in a local context that may or may not have led to the success of an intervention. One of the main aspects of such an analysis is studying classroom interactions to develop an understanding of the factors that might have contributed to student learning. The study described in this article represents an attempt to begin examining some of the classroom issues in an effort to understand the factors that might have affected student learning.

We presented a comparison of enactments of an inquiry-based science unit. Two teachers used a technology-enhanced simple machines curriculum. We first examined student learning outcomes that showed that students in classes taught by two teachers significantly differed in their learning as measured in a pre- and posttest and a concept-mapping test. We then analyzed classroom discussions to understand how teacher facilitation enables the intertwining of different activities in a unit that is carried out over several weeks, and how classroom interactions impact the making of connections between science principles and concepts so that students attain a richer understanding of the knowledge. Our quantitative results show that students in Jane's classes performed better on the open-ended questions in the posttest and on the concept-mapping test, as compared to Linda's students. We conducted a retrospective analysis (Cobb, McCain, & Gravemeijer, 2003) of classroom interactions to understand how scientific reasoning evolved as the instruction progressed in the classes taught by both teachers. We examined the role that classroom discussions, especially teacher facilitation played in the development of scientific reasoning. Our results point to important aspects of the ways in which the two teachers conducted classroom discussions. Our results suggest that Jane's facilitation might have been more conducive to the formation of rich knowledge representations as measured by the concept-mapping and open-ended items.

A retrospective analysis of classroom videos does not allow us to make any causal claims about the differences in learning outcomes of students in the classes taught by Jane and Linda. However, in future studies our aim would be to specifically examine enactments of the CoMPASS intervention across naturally occurring variations in classrooms taught by teachers using different teaching styles. A study is currently underway to examine how teachers in four different schools (two teachers in each school with each teacher teaching either three or four sixth-grade classes) implement the CoMPASS intervention. The schools are in different states in varied areas (e.g., inner city, rural, and suburban areas). Each site is different in student population, teacher experience and preparation, and teaching styles and practices. Teachers from all the schools participate in summer workshops each year. Our plan is to systematically study the enactment of the intervention across the different contexts by examining the variations in teacher preparation and practices, by qualitative analyses, and comparison of the implementation (classroom videotape and audiotape) across the different contexts. Starting with the strategies identified in the study described in this article, we will find evidence for these or derive new successful strategies that teachers may have used, and study their relation with learning outcomes. For this purpose, multilevel contextual models will be used to include derived variables from the qualitative synthesis of the enactments that may help to explain differential outcomes (if any) across conditions. Teachers in all the schools will implement the CoMPASS materials over a period of 3 to 5 years, enabling us to examine trends and growth in teacher practices over time.

It is interesting to note that in our study, there was no difference between students' scores on the multiple-choice questions in the posttest. However, students in Jane's classes performed significantly better on the open-ended questions and in the concept-mapping test—both of which were measures that tapped students' deeper understanding of science phenomena. Our study suggests that the support provided by teachers—helping students draw connections between the science phenomena that they are learning, enabling them to focus on the big ideas and core principles, and helping them see the connections between abstract science principles and their concrete real-world instantiations—might have had an effect on their learning as captured in the open-ended items and concept-mapping tests. This is an important finding, given the concern raised by researchers in educational reform and assessment on the appropriateness of multiple-choice tests as a basis for measuring student learning, and a push toward performance assessments (Baxter, Elder, & Glaser, 1995), as well as alternative forms of assessment (Herman, 1997). Our results support the need to have measures that can assess deeper conceptual understanding, rather than just surface level knowledge as measured by traditional forms of multiple-choice questions to fully understand the benefits of an intervention and inform educational reform.

We are also using the lessons learned from Jane's facilitation in our professional development activities, especially reiterating the strategies that she used. These are, namely, helping students raise questions that are related to the overall goal of the challenge, helping students see how abstract ideas are related to their experience with physical objects, enabling an understanding of how each activity in the unit is connected to the rest of the unit, and reinforcing the connections between concepts that they are learning and enabling students to understand core principles by reiterating big ideas. However, as research in helping teachers implement innovative curricula has suggested, ongoing professional development and reiteration of successful strategies in various forms, such as instructional materials, online support, in addition to professional development workshops, is required to bring about changes in pedagogy. In particular, we plan to use curriculum materials for teachers to promote successful strategies (Davis & Krajcik, 2005). As Brown and Campione (1996) noted, "philosophies are hard to script. Learning principles need to be understood and internalized if flexible use and creative adaptation is the goal" (p. 292). Our aim therefore is to reinforce successful strategies in professional development workshops as well as in instructional materials.

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APPENDIX A
EXAMPLE TEST ITEMS

Example of Multiple-Choice Items

An example of a second-class lever is a:

o (a) Seesaw
o (b) Bottle opener

o (c) Shovel
o (d) Fishing pole

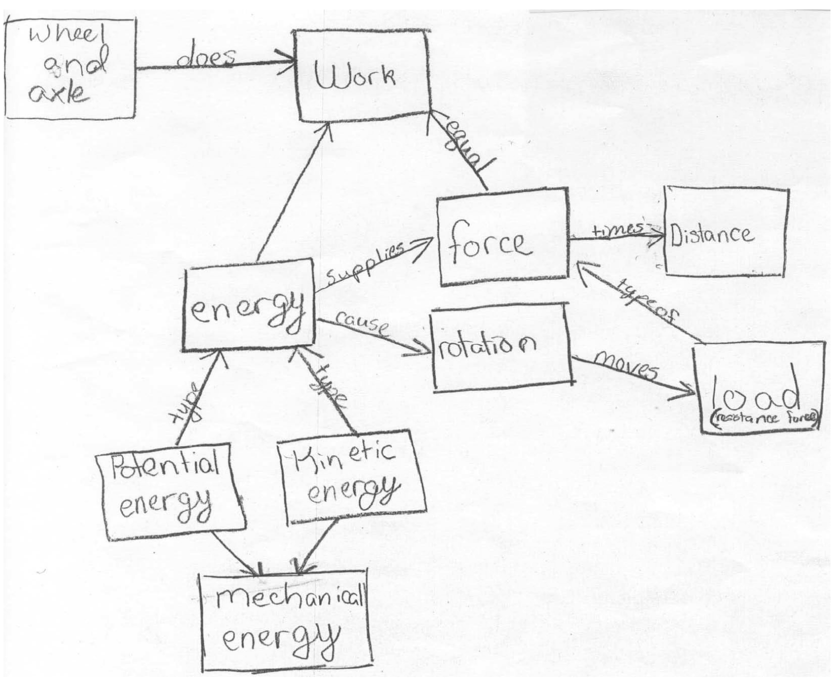
1. When you bend your arm at the elbow, the bones and muscles in your arm are acting as a system. What simple machine does this system represent?:

o (a) Inclined plane
o (b) Pulley
o (c) Wedge
o (d) Lever

Example of an Open-Ended Question

What type of simple machine is the blade of a knife? Explain how it works.

APPENDIX B
EXAMPLE CONCEPT MAP



APPENDIX C
Example of Coding

Examples of Teacher Statements	*Coding Categories*														
	RT	*EX*	*RC*	*CA*	*RA*	*FG*	*ER*	*RS*	*BI*	*EXP*	*AM*	*CQ*	*IN*	*EN*	*TC*
Teacher: You are increasing distance and when you increase distance you reduce your?			RC				ER		BI						
Students: Effort															
Teacher: Effort. They needed more string to go through their pulley system. What would you make for a prediction about how much effort they reduced? What would you make for a prediction? What would you make for a prediction Ed? If they needed a lot more string for their pulley system?							ER	RS							
Ed: It would make it easier.															
Teacher: It would make it easier. How many grams of effort did it take?								RS							
Student: 50															
Teacher: 50 grams of effort for them to lift the resistance force. So what happened … somebody tell me why this has reduced the effort so much. Somebody tell me why this has reduced the effort so much. I got my three, ok I have four hands up, five hands, six hands. Why Dan?							ER							EN	
Dan: I think it was because hmm … we used a longer rope and hmm … we had a lot of pulleys.															
Teacher: So what happens to the weight of the resistance force? I mean the resistance force is still 600 grams, how come it feels like 50? What happens to the weight? This is a tricky part. This is actually why a pulley can help you with mechanical advantage.							ER								

(*continued*)

APPENDIX C (Continued)

	Coding Categories														
Examples of Teacher Statements	*RT*	*EX*	*RC*	*CA*	*RA*	*FG*	*ER*	*RS*	*BI*	*EXP*	*AM*	*CQ*	*IN*	*EN*	*TC*
Rose: Well, when you put all the pulleys together and the string, the string, the support ropes in the pulley, hmm … take off the effort.															
Teacher: It supports the weight, right? All the weight of this is distributed over all these different pulleys, just by a little bit on each of these pulleys, where it's resting. So if you have more pulleys and string for the weight to kind of rest on, because the ceiling is also holding everything, right? You have those pulleys and strings for it to rest on, the weight is distributed and there is less weight for you to lift, it's like having extra hands. So what did we learn from this. I should see a lot of hands. Kathy?		EX					ER								
Kathy: I learned that the more pulleys and the more ropes that we have, MA, mechanical advantage is increased, distance is shorter and the effort is less.															
Teacher: You increase your distance. Beautiful, excellent. That was a very nice way to kind of out it in a succinct explanation. I am really glad that you learned that. Pat?								RS						EN	

Note. Coding categories: RT = relating topics; EX = everyday examples; RC = relating concepts; CA = relating concrete experiences with abstract concepts; RA = relating activities; FG = focusing on goals; ER = encouraging deep reasoning questions; RS = restating; BI = reiterating big ideas; EXP = giving explanations; AM = addressing misconceptions; CQ = clarifying questions; IN = giving instructions; EN = providing encouragement; TC = task completion.