THE JOURNAL OF THE LEARNING SCIENCES, *8*(3&4), 451–493

Developing Scientific Communities in Classrooms: A Sociocognitive Approach

Leslie Rupert Herrenkohl
Educational Psychology
University of Washington

Annemarie Sullivan Palincsar
Educational Studies
University of Michigan

Lezlie Salvatore DeWater and Keiko Kawasaki
Seattle Public Schools and the University of Washington

The focus of this research is the role and value of scaffolding student discussions in advancing students' ability to co-construct theories and models from data they have collected while investigating floating and sinking. Three principles, derived from a sociocognitive perspective on science teaching and learning, undergird this instruction: (a) engaging students in reasoning practices in science, (b) offering explicit guidance on the roles students can assume to monitor their own and their peers' thinking, and (c) fostering a sophisticated epistemology of science by having students experience science as a process of revision. The participants were members of a Grade 3/4 split-level gifted class and a Grade 5 class in an urban district. Instruction occurred over a 10-week period, in which students worked in small-group and whole-class contexts to develop and refine explanations for floating and sinking. Pre- and postassessment data revealed changes in children's conceptual understanding, as well as changes in their beliefs about the nature of scientific problem solving. The primary data were transcripts of whole-class discussions that were analyzed to reveal how children's notions of theorizing evolved over the course of the program of study through a process of negotiation that was significantly guided by the teachers, supported by the roles that students assumed, and assisted with the use of an array of tools, such as theory and question charts, as well as the investigative activity itself.

Correspondence and requests for reprints should be sent to Leslie Rupert Herrenkohl, University of Washington, Educational Psychology, P.O. Box 353600, Seattle, WA 98195. E-mail: leslieh@u.washington.edu

The purpose of this study was to design and implement a classroom intervention to foster the development of an intellectual community in the context of science instruction. Our work is based on the assumption that young children can think about and discuss science in sophisticated ways in classroom contexts that support student interaction and engagement. Specifically, our focus was on the role and value of scaffolding student discussions in the interest of advancing their ability to co-construct theories and models from the data they have collected in the course of inquiry regarding floating and sinking. This study joins an emergent literature regarding the use of scientific discourse to promote learning in classroom communities (Herrenkohl & Guerra, 1998; Herrenkohl & Wertsch, 1999; Hogan & Pressley, 1997; Palincsar, Anderson, & David, 1993; Van Zee & Minstrell, 1997; Wells, 1996). Three principles figure prominently in our approach: (a) having students focus on important reasoning practices in science, such as building explanations by differentiating and coordinating theories and evidence, and using models to offer further support for their explanations; (b) offering students explicit guidance on the roles that they can take in classroom discussions to help them monitor their own and others' thinking; and (c) creating opportunities for students to develop a sophisticated epistemology of science by participating in science as a process of revision.

SCIENTIFIC THINKING PRACTICES

Inquiry is a complex form of human thought that has developed over thousands of years. It is a cultural legacy that prior generations have given to us to employ and change. In a Vygotskian sense, it is a "cultural tool" (Wertsch, 1985) of a psychological nature, an approach to reasoning that others before us have found useful. As a result of this position, we strongly believe that children should not be expected to come to some understanding of the nature of scientific thinking simply by being exposed to interesting materials and problems. As Driver, Asoko, Leach, Mortimer, and Scott (1994) note,

> [The] ontological entities, organizing concepts, and associated epistemology and practices of science are unlikely to be discovered by individuals through their own observations of the natural world. Scientific knowledge as public knowledge is constructed and communicated through the cultural and social institutions of science. (p. 6)

From this perspective, learning science is a social process of enculturation regarding the activities, conventions, and values of the scientific community. Enculturation in science involves the development of understandings that reflect both the substantive and syntactic knowledge of the discipline (Schwab,1978). *Substantive knowledge* refers to the prevailing concepts, theories, and principles of the discipline, whereas *syntactic knowledge* refers to the forms of evidence, methods of inquiry, and approaches to analyses that have been embraced by those practicing the discipline. Although these processes are central to understanding science as a discipline (Carey & Smith, 1993; Driver et al., 1994; Songer & Linn, 1991), they are not self-evident, and students need considerable support as they develop and master a repertoire of scientific reasoning skills.

Our approach explicitly focuses students' attention on two important scientific inquiry strategies. The first involves the important idea that theories and evidence must be coordinated. Kuhn's (1992) work has demonstrated that both children and adults have a difficult time developing sound arguments in which their choice of evidence is effective in supporting their claims, even in domains that are familiar to them. Furthermore, research by Schauble and colleagues (Schauble, 1990; Schauble, Klopfer, & Raghavan, 1991) with upper elementary students elucidates the range of challenges that students encounter in the inquiry process, including the systematic generation and interpretation of evidence. The students in these studies tended to seek confirmation of their theories, and in the process made invalid judgments about disconfirming evidence and supported interpretations with the use of invalid evidence. This raises an important issue for teachers and researchers who view science as a form of argument where data are used to bolster theoretical positions (Driver et al., 1994; Kuhn, 1993). If children and adults are not able to coordinate theory and evidence in familiar domains, it is appropriate to conclude that they would not be able to do this in domains that are unfamiliar to them. If we make the further assumption that many students have not had extensive opportunities to become acquainted with the physical or life sciences, it is logical to believe that students come to class without an understanding of how to generate convincing arguments and explanations.

With this as a starting point, we have developed a set of intellectual tools that we discussed with the students as our "three strategic steps in science." These tools include (a) predicting and theorizing, (b) summarizing results, and (c) relating predictions and theories to results. These three steps are not designed to mimic the "scientific method," nor are they designed to be used as a rote set of procedures. We have conceptualized them as a set of thinking practices that can explicitly guide students to construct powerful and convincing scientific arguments. We view this set of steps as one of many sets of strategies that may be used to help students generate and organize their explanations in science.

The interrelations between substantive and syntactic knowledge demand that we also attend to how students make sense of the data gathered in the inquiry process as well as examine the significance of the data with regard to existing theoretical and conceptual understandings. To support this goal, we have chosen a second inquiry strategy—modeling. Modeling is yet another process that is central to scientists' work, especially the development of theories (Hestenes, 1992). Several researchers have carefully investigated and examined the use of modeling with students of science (Grosslight, Unger, Jay, & Smith, 1991; Penner, Giles, Lehrer, & Schauble, 1997; Smith, Snir, & Grosslight, 1992). It is evident from this work that modeling is not a straightforward process for students. It is another way to organize thinking that needs a good deal of support to become a part of students' repertoire of scientific reasoning strategies. In an effort to support students to construct models that could be used to explain their perspectives, software designed to facilitate model building (Smith et al., 1994) was included in a set of activities for small-group exploration. In addition, there were several whole-class benchmark activities that were designed to get students to actively relate concepts with metaphors and graphic representations.

STUDENT ROLES

Another important aspect of our program, in addition to addressing and supporting the development of complex thinking processes in science, is the explicit discussion of roles that students can take in an effort to monitor and further their own and others' understanding. Given that much of schooling involves teacher-directed activities and discussions (Cazden, 1988; Lemke, 1990), it is not surprising that we have observed that students do not spontaneously ask questions of each other when given opportunities to do so (Herrenkohl & Guerra, 1998; Herrenkohl & Wertsch, 1999). Expecting students to do this is analogous to assuming that they will eventually discover strategies for scientific understanding if given collections of interesting materials. As we can see with the thinking strategies, just providing materials and opportunities for physical manipulation is not enough to get students to develop complex thinking practices. It is necessary to provide explicit guidance. This is just as true for taking on roles that embody good "habits of mind" (Rutherford & Ahlgren, 1990) in science. If we want students to be supporting each other's thinking then we need to help them find the voices to do so.

There are a number of possibilities for giving guidance to students regarding roles that they can assume. In our case, we have chosen to begin by creating two sets of roles that students take on, one procedural set that they use when working in small groups to complete their investigations and another sociocognitive set to use when acting as audience members during the time that small groups report about their investigations to the whole class. The set of procedural roles is similar to many cooperative learning programs and are designed to help the students distribute tasks in an effort to efficiently complete an investigation with the participation of all group members. The second set of roles, what we have come to call *audience roles,* is designed to get students involved in questioning and commenting on each other's thinking in science. We believe that—in addition to helping students come to take on the roles of questioner, commentator, and critic—we also have to give them guidance about what they might want to be questioning or commenting on. In an effort to give both social and cognitive/disciplinary direction, students in the audience are assigned roles that correspond to three steps in science. Thus some audience members are responsible for checking predictions and theories, others are focused on the summary of results, and the remaining students are assessing the relation between predictions, theories, and results. Both sets of roles rotate so that students have a chance to take on all roles several times.

DEVELOPING STUDENT EPISTEMOLOGIES: A "RE-VISIONARY" NOTION OF SCIENCE

The third feature of our approach attempts to address the need to help students see science as a process of revising thinking over time. Too often science is conceptualized as a passive process of receiving facts from textbooks and teachers or simply observing and recording information accurately (Songer & Linn, 1991). It is not viewed by students as an active and flexible set of conceptions that can and do change over time (Carey & Smith, 1993). In our view, this perspective is a problem for at least two reasons. The first is that science is not an objective set of facts nor can it be found "out there" in the natural world. It is a body of representations about the world that is both developed and constantly scrutinized within scientific communities (Driver et al., 1994). It is contentious and debatable and changing so quickly that many of us cannot keep up with the pace. If we as a society are going to be able to continue this fast-paced exploration of the world, we need students who see science as alive and as something that they may have a hand in furthering and transforming.

The second reason that students' epistemologies of science are problematic is that they continue to perpetuate the "mistake stigma" in schools, a myth that runs deeply through the fabric of school life. Despite the widespread emphasis on constructivist approaches to learning, the object of schooling often seems to be to "get the right answer." Many school practices such as recitation, worksheets, and in some cases lectures present or request the right answer. Attending these practices is the myth that mistakes are "bad," they are embarrassing, and the students (and teachers) who make them demonstrate a lack of competence. In contrast, mistakes have been crucial to the development of scientific knowledge, as important insights are often developed as a result of what might be viewed as "chance" or "error" (Taton, 1957)—hence our interest in the design of learning environments in which mistakes are appreciated for their value in advancing learning and development.

We have attempted to redress students' narrow views of science and their negative view of mistakes through the use of the intellectual roles mentioned previously and the use of public documents that allow students to chart and see the change in their collective thinking over time. These public documents are derived from whole-class discussions and modified over the course of a unit of study. For example, we created a *theory chart* that was displayed every day during science. Students were responsible for articulating and adding theories that were developed throughout the unit. Frequently, students who reported for their group on a given day would be asked to make contributions to this chart. It was also common to find students in the audience who were interested in knowing if the theory that a group was using was different than the theory they used on prior days. In addition, one entire class session during the middle of the unit was devoted to reviewing the theory chart and deleting theories that were no longer deemed plausible. This theory chart (and public documents generally) supported students to make connections among perspectives, ask questions of one another, and observe their revisions over time. The public documentation coupled with the intellectual roles supported knowledge building rather than direct assimilation of knowledge (Chan, Burtis, Bereiter, 1997). Practices such as these are extremely important, as they provide occasions for students to revise or literally "see again" what they had said and thought on prior days. They also focused students' attention on important metalevel understanding about the nature of scientific knowledge. As Carey & Smith (1993) note, "metaconceptual knowledge is important in its own right, and it can be gained only by *actively constructing scientific understanding and reflecting on this process*" (emphasis is ours, p. 245). We believe that building reflection into the process of science will help students adjust their thinking about mistakes generally and build an epistemology that is more commensurate with the work of science.

RESEARCH DESIGN

Setting and Participants

Two classroom teachers acted as instructors and collaborators throughout this project. One teacher had over 20 years of classroom experience, whereas the other teacher had 4 years of classroom experience at the time of data collection. Both teachers are interested in science and had participated previously in teacher training institutes that focused on constructivist teaching in science. The teachers contributed to all aspects of the research design. Many hours were devoted to planning and applying our program in the classrooms. One teacher taught in a third/fourth-grade split-level gifted program with 27 students, and the other teacher was the instructor of 24 fifth-graders. The classrooms were located in two different schools, approximately 1 mile apart, in a large urban city in the Northwest. The classrooms were quite different from one another in terms of the population of students. Profiles of the classrooms are provided in the following:

Third/Fourth-grade split-level gifted classroom	*Fifth-grade classroom*
Teacher's second year with most fourth-graders	Teacher's second year with most students
18 boys	11 boys
9 girls	13 girls
13 third-graders	24 fifth-graders
14 fourth-graders	
17 European American	6 European American
5 African American	12 African American (1 immigrant)
5 Japanese American (1 immigrant)	2 Vietnamese American (immigrants)
	2 Filipino American (1 immigrant)
	1 Laotian American (immigrant)
	1 Latino (immigrant)
1 ESL	6 ESL
0 Eligible for special services as learning disabled	4 Eligible for special services as learning disabled
2 free or reduced lunch	13 free or reduced lunch

Materials

To incorporate both teachers' interests in sinking and floating investigations, a program of study focusing on this topic was developed. We worked together to generate the topic and then designed the small-group investigations as well as the overall plan for the unit. We began by gathering resources that addressed children's understanding of sinking and floating, buoyancy, and density. The work of Smith et al. (1992; Smith et al., 1994) was influential in helping us design the program of study. Specifically, we have adopted their "crowdedness model" as a way to help students explain density at a macroscopic level that does not require an understanding of the particulate theory of matter.

Each part of the unit had a set of activities associated with it.[1] In an effort to help provide further context for our approach, we describe the baseline activity and the first set of activities. This description will be important for readers to understand some of the results we present later. The baseline activity asked students to predict if 16 everyday items such as a plastic spoon, a piece of graphite, and an apple would sink or float and then give a reason to support their prediction. Students were asked to test their predictions and record the results. The students then prepared a report to share with the class. This activity was designed to elicit a baseline discussion from the students as a whole class before giving them instruction in the intellectual tools (i.e., three steps in science) and roles that they could apply when working on their investigations and reporting to one another in a whole-class setting.

[1]Before beginning the program of study, students reviewed the ideas of mass and volume through activities and discussions in class.

The investigations after the baseline were organized differently. There were three sets of three activities that students rotated through as groups. Two groups of four to five students each worked on the same investigation on any given day. The roles and the public documentation were introduced during the first set of activities and carried throughout the rest of the investigations. The first set of activities asked students to order a set of objects[2] according to weight (Investigation 1), volume (Investigation 2), and a characteristic of their choice (Investigation 3). After ordering the objects, students were asked to make predictions, test them, record the results, and prepare a report for the class. Students were prompted to use the three steps in science during small-group work time. Also, students were assigned intellectual audience roles (which corresponded to the three steps in science) for the first time after they completed their second investigation in this first set.

Another set of materials consisted of public documents that were developed with the students during the course of the unit. The first was a *questions chart* that helped the students generate possible questions to ask reporters when taking on their audience roles. This chart was created by the teacher and students when the audience roles were introduced for the first time. The chart was then displayed on every subsequent day to help support students in taking on their audience roles. The other form of public documentation was the theory chart. This chart kept a running record of all the theories that were generated by the small groups as they worked on their investigations.

Classroom Contexts

Our science program involved four primary participant structures (Phillips, 1972), including (a) whole-class time, (b) reporting or presentations of small-group results, (c) small-group investigations, and (d) writing activities designed to instruct students in the use of different written genres in science (see Appendix A for further details on these participant structures).

Approximately 90 min of instructional time per session for a total of 19 sessions were devoted to these lessons, which took place over the course of a 10-week period. Students were instructed to use their intellectual tools to guide them while they completed their small-group problems. Again, these tools included (a) predicting and theorizing, (b) summarizing results, and (c) comparing predictions and theories to results. These tools were used as the basis for roles that were assigned to student audience members during reporting time such that some students were responsible for checking the predictions and theories in the reports of other groups,

[2]The objects were large and small cylinders, large and small cubes, and a set of spheres made of wood, lucite, recycled plastic, and aluminum. A different subset of these items was used for each investigation.

some were responsible for the summary of results, and the remaining audience members were responsible for examining the relation between predictions, theories, and findings. In addition to intellectual roles, procedural roles such as reporter (presented small-group investigation to class) and scribe (prepared poster for reporter's use during reporting time) were also used during small-group investigations (see Appendix B for a complete description of roles).

Data

Classes were videorecorded and audiorecorded during all whole-class time and all reporting sessions. One small group from each class was recorded during small-group investigation time. In addition, field notes were taken by a researcher. Both teachers made journal entries throughout the duration of the project at well. Transcripts of whole-class reporting sessions are the focus of discussion in this article.

Pretest and posttest data were collected in the form of written protocols. These pretests and posttests involved a series of questions designed to determine students' level of conceptual understanding, students' beliefs about the nature of scientific knowledge and the activity of scientific problem solving, and students' general approach to learning in science. These questions were administered in two 45-min sessions (on a pretest and posttest basis) with reading assistance offered by the teacher.

FINDINGS

Our Science Communities

Our main research question was: How did the intellectual communities develop over time? Do the children's scientific explanations and understanding of tools for scientific thinking, including predicting and theorizing, summarizing results, and relating predictions and theories to results, change over the course of the study? In this discussion of our findings, we specifically focus on the evolution of the notion of theory in both classes. This was a pivotal concept for the students to understand and something that was clearly not familiar to them before we began. Because students were asked to assume intellectual audience roles where they were responsible for asking other groups' questions about their predictions, theories, results, and relations between these constructs, it was imperative that they establish some collective understanding right from the start. In the following pages we describe how each class negotiated the meaning of "theory" as a conceptual tool that they would then use to gain an understanding of why some things float whereas others sink.

Before we explore the actual unfolding of discussion in each class, we present results from the pretesting and posttesting to highlight the changes we observed in student understanding. These changes provide a backdrop for exploring the actual discussions in each classroom.

Students' Explanations of Sinking and Floating

Students' understanding of sinking and floating was assessed by asking them the following question after they had just seen a demonstration:

> Write your best explanation and model of why the plastic piece sank in the fresh water but floated in the salt water.

Coding of this question involved two focal areas. The first focused on the written explanation, and the second focused on the model. The written explanation was simply coded for a reference to density. Terms such as *density, crowded, compact, packed tightly,* and *heavy for its size* were all taken as evidence of a density explanation. The second level of coding focused on the model. If a model was given, it was coded to determine if it was a "dots and boxes" type (i.e., that it clearly depicted the mass, volume, and density units within the model itself).

Table 1 presents the third/fourth-grade students' pretest and posttest responses to this question. As the table indicates, third/fourth-graders improved on the posttest both in their written explanations (62.96% appealed to a density explanation vs. 3.70% on the pretest) and their models (96.30% included a model on the posttest with 30.77% of those models being a dots and boxes type compared to 59.25% offering models on the pretest with 0% being of the dots and boxes variety).

Table 2 presents the pretest and posttest responses for the fifth-grade class. The patterns here are the same as the third/fourth-grade class. Students demonstrated improvement in both their written explanations and their models. Posttest explana-

TABLE 1
Third/Fourth-Grade Split-Level Gifted Class

	Pretest	*Posttest*
Explanation appeals to density	3.70% used a density explanation	62.96% used a density explanation
Model	59.25% included a model	96.30% included a model
Type of model	0% of models were "dots and boxes" types	30.77% of models were "dots and boxes" types

Note. There were no missing pretest or posttest data in the third/fourth-grade class.

TABLE 2
Fifth-Grade Class

	Pretest	*Posttest*
Explanation appeals to density	0% used a density explanation	47.83 % used a density explanation
Model	4.16% included a model	91.30% used a model
Type of model	0% of models were "dots and boxes" types	52.38% of models were "dots and boxes" types

Note. There was one missing posttest in the fifth-grade class.

tions involved density 47.83% of the time, whereas it was not used at all on the pretest. Models were provided on the posttest 91.30% of the time with 52.38% of the models being dots and boxes types. Only 4.16% of the students offered a model on the pretest with none of the models being of the dots and boxes variety.

These findings from both classes indicate that the students progressed as a group in their conceptual understanding of sinking and floating.

Students' Understanding and Use of Scientific Thinking Strategies

Students' understanding and use of scientific thinking strategies was assessed by asking them several questions, including,

> What is a prediction?
> What is a theory?
> What does it mean to solve a problem in a scientific way?
> How do people decide which are the best scientific ideas?

The first question about predictions was coded by noting those definitions that were at least at the level of guess or educated guess. It could also include those responses that explicitly defined predictions as theory-driven. Either response was taken as evidence that the concept of predicting was understood at an elementary level. The second question about theory was coded by noting those definitions that discussed why or how something happens. Such responses were taken as evidence that students had an elementary understanding of theories as conceptual objects. The question about solving problems in scientific ways was examined to determine if it included a reference to using scientific tools or strategies such as using predictions, theories, or results, making models, or some general reference to using evidence to support ideas. General references to experimenting, using your mind, or being skeptical were not coded as meeting this criteria. Finally, the question about how people decide which are the best scientific ideas was coded to determine if there was some reference to the importance of having evidence to justify claims. Generic references to discussing and deciding, voting, what works best, and so forth were not accepted as meeting these criteria.

Table 3 presents the third/fourth-grade students' pretest and posttest responses to these questions. The evidence presented demonstrates that students improved on all questions. Students defined prediction at least at the level of guess 92.59% at the time of the posttest whereas 88.89% did so at the time of the pretest. The students defined theory at the level of answering why or how 77.78% on the posttest, whereas none of the students defined theory at that level on the pretest. The students said that solving problems scientifically involves a set of tools or strategies 44.44% on the posttest, whereas none of the students responded this way on the pretest. Finally, on the posttest, 22.22% of the students discussed the importance of evaluating scientific ideas by examining if evidence is used to justify claims, but none of the students offered such a response on the pretest.

Table 4 presents the pretest and posttest responses for the fifth-grade class. The patterns here are the same as the third/fourth-grade class. Students demonstrated improvement in their responses to every question. The students defined prediction at least at the level of a guess 77.24% on the posttest, whereas only 58.33% defined it this way on the pretest. The students defined theory as addressing the questions why or how 50% on the posttest, whereas only 4.35% defined it in this manner on the pretest. Furthermore, 60.87% of the students explicitly wrote that they did not know what theory meant on the pretest, whereas only 4.55% responded in that way on the posttest. The students reported that solving problems scientifically involves a set of tools and strategies 50% of the time on the posttest, whereas only 12.5% responded this way on the pretest. Finally, 50% of the students on the posttest sug-

TABLE 3
Third/Fourth-Grade Split-Level Gifted Program

	Pretest	*Posttest*
Defines prediction at least at the level of "a guess"	88.89% define prediction as a guess	92.59% define prediction as a guess
Defines theory at least at the level of "why or how something happens"	0% define theory at level of "why or how" 11.11% state "I don't know"	77.78% define theory at level of "why or how" 0% state "I don't know"
Solving problems scientifically involves using a set of tools	0% discuss scientific problem solving as involving a set of tools	44.44% discuss scientific problem solving as involving a set of tools
Choosing the best scientific ideas	0% discuss the importance of ideas relating to the evidence	22.22% discuss the importance of ideas relating to the evidence

Note. There were no missing data in the third/fourth-grade class.

TABLE 4
Fifth-Grade Class

	Pretest	*Posttest*
Defines prediction at least at the level of "a guess"	58.33% define prediction as a guess	77.24% define prediction as a guess
Defines theory at least at the level of "why or how something happens"	4.35% define theory at level of "why or how" 60.87% state "I don't know"	50.00% define theory at level of "why or how" 4.55% state "I don't know"
Solving problems scientifically involves using a set of tools	12.50% discuss scientific problem solving as involving a set of tools	50.00% discuss scientific problem solving as involving a set of tools
Choosing the best scientific ideas	4.17% discuss the importance of ideas relating to the evidence	50.00% discuss the importance of ideas relating to the evidence

Note. There were two missing posttests in the fifth-grade class.

gested that scientific ideas can be evaluated by determining if evidence is offered to justify claims, but only 4.17% of the students responded in this manner on the pretest.

Pretest and Posttest Coding and Reliability

Coding schemes were developed with respect to each question as described previously. After the coding schemes had been used to code the pretest and posttest measures, an assessment of reliability was conducted. A second rater used the schemes to code 30% of the pretests and 30% of the posttests from each class. These tests were chosen randomly. Intercoder agreements of 91% to 100% were achieved for each question.

EXPLORING CLASSROOM DISCUSSIONS

Similarities Across Classrooms

Before examining the specific nature of how the notion of theory evolved in each classroom, a general description of the similarities across the classes is warranted. Four major issues emerged during the early weeks of the unit when the students in both classes were working hard to define and appropriate *theory* as a tool. The ordering of the items reflects the order in which they were addressed in the classes. However, negotiation of one issue was not necessarily completely resolved before another one surfaced. Many of these issues were being addressed in an overlapping and recursive manner:

1. A theory tells *why*. This distinguishes it from a *prediction,* which relates *what* you think will happen.
2. Theories are provisional. Theories can be changed.
3. Theories need to have an evidence base.
4. Theories are used to make predictions. Therefore, new theories are formulated to account for results that do not support predictions. Theories are testable.

Some of these components were of greater concern to one class than they were to the other. Also, all issues did not surface in the context of the same conversations in each class. There were some basic differences between the classes that are important to acknowledge before exploring how these issues were treated in each context. First, the teachers did not consider themselves equally familiar and comfortable with the notion of theory. The third/fourth-grade teacher felt that she was not as clear about how she might help the students understand and employ the notion of theory, whereas the fifth-grade teacher felt very comfortable with this approach. Second, each teacher conducted the first lessons with a different orientation toward the students and their participation in establishing definitions of key intellectual tools such as theory. The third/fourth-grade teacher engaged the students as partners in establishing these definitions, whereas the fifth-grade teacher offered definitions to her students. Third, each class ended the unit at a different point. The third/fourth-graders stopped as they were beginning to understand the importance of evidence in confirming or disconfirming predictions that in turn provided information about the feasibility of theories. The fifth-graders also arrived at this point and extended beyond it as they began to talk explicitly about the role of arguing in science.

Giving Meaning to "Theory": Perspectives From the Third/Fourth-Grade Class

We begin to examine how the third/fourth-grade class gave meaning to theory by noting how predicting and theorizing were introduced by the teacher. The teacher did not define the terms for the students but rather asked them to offer their own perspectives. In examining the responses, it is evident that these students drew heavily on their notions of predicting within the context of their language arts classes. Terms like "educated guess" and "foretelling" exemplify this early conversation.

Teacher: So what does it mean when you are predicting and theorizing? That's the first step but what does it mean? What does it mean when you are predicting and theorizing? What does that mean, Christina?

Christina:	Well, you're guessing, not exactly guessing, it's an educational guess kind of.
Teacher:	Good, ok, it's an educated guess, educational guess. [writes] All right, what else does predicting and theorizing mean? Akira.
Akira:	Foretelling what will happen next.
Teacher:	[writes] Good, foretelling. Terrific.

From this first discussion, the students are engaged in mobilizing knowledge about predictions from their language arts context in an attempt to apply this idea to science. What is clearly missing, however, is a discussion of theory. In these early conversations, the teacher did not ask the students to explicitly differentiate predictions and theories, in part because of her lack of comfort in making these distinctions herself. Therefore, when the student perspectives were exhausted, the teacher and the students moved on to define the two other steps. After they completed these definitions, the teacher asked if anyone has questions or comments. The researcher raised her hand and, with the teacher's permission, offered a comment followed by a question.

Researcher:	I have a comment. I think that maybe in step number one, there might be something missing. Do any of the children think that there's something missing?

The teacher takes this question and turns to the students and asks them what they think. The following conversation ensues.

Teacher:	Hmm. Katie, what do you think might be missing?
Katie:	What kind of theory and what you think will happen, you know, it will do it every time or just once or twice?
Teacher:	And how is that different [interrupts herself], what do you think? You were saying something, right before you said that you said, I think this goes with
Katie:	Theorizing
Teacher:	[Researcher mouths "why" to the teacher] I think what Leslie was getting at was the why. Was the why. What's going to happen but what you think, what you think will happen every time and why. I'm not sure, should I write that down? [question directed toward researcher as teacher begins to write] And why you think that. So that gets at something we've talked about before, to give your reasons. This is what you think will happen but then why? Why do you think that? *What have you seen, what have*

	you observed, what are you thinking about that leads you into this thought?

In this exchange giving meaning to *theory* involved negotiation between the teacher, researcher, and students. As the teacher reflected on this segment of the unit, she noted that at the beginning she felt less sure of her understanding of theory and therefore was less confident in her ability to guide the students. She and the researcher agreed that they would work together while "online" with the students. However, the exchange between the researcher and teacher may have served to confuse the students. The researcher attempted to provide a brief reminder of prior planning discussions (i.e., theories explain and answer the question 'why?'), but this is not something that worked seamlessly to convey meaning to the teacher. The teacher's last line, "What have you seen, what have you observed, what are you thinking about that leads you into this thought?" is meant to help define the kinds of things that might address the "why." This is not the scientific understanding of "why" that the teacher and researcher originally intended to help the students develop. As we will see later, the students begin using past observations to account for why an object sinks or floats. Although this is not what the teacher and researcher planned in advance, working through the debates that occur around whether past experience counts as a reason why were some of the most exciting conversations that took place within the classroom. Just as the teacher struggled to understand the difference between a scientific and everyday notion of "why," so did the students. So the teacher started at a point that was intuitive to the students. These conversations did not arise immediately. They only took place once students began taking on the intellectual audience roles. There were two days that came before this time that gave the researcher and teacher a false sense that everyone was beginning to share the same definition of prediction and theory.

The following transcript excerpt, which took place on the next day, Day 4, exemplifies the kind of discussion that took place during reporting on this day. The audience roles had not been introduced yet, so the teacher was still taking on a good bit of the responsibility for questioning the reporters. In the following example, she asked the students to provide theories before moving on to their results. These students responded like many groups did on this day. First they claimed that the teacher had not warned them in advance that they would have to do this. Then with a reminder that they could consult their lab notebooks, they were able to tell her their group's theory.

Teacher:	Before you go on, are those your results?
Chris:	Yeah, these are the results.
Teacher:	Share some of your theories about what you thought, why you thought what you thought.
Chris:	We didn't have enough time to make up a theory.

Isaac:	Yeah, she [meaning the teacher] didn't even warn any of these other groups, did she?
Teacher:	I didn't? That wasn't part of one of the steps?
Isaac:	No.
Teacher:	It was, why you thought [interrupts herself] Sure, he knew about it in advance, go ahead. Tell me if you had any ideas about why you got what you did. Did you write them down?
Chris:	Our notebooks are over there, Isaac.
Teacher:	Okay, go ahead.
Isaac:	We thought the aluminum cubes would sink, because it is heavy, and it's not like they're just aluminum, they're fairly light, it's all compact, there's a lot of metal put together.

Other reports proceeded in a similar fashion on this day. In all but one case, the students did not mention theories spontaneously. When the teacher asked them to elaborate, many claimed that they were unprepared to do so. Upon consulting their lab notebooks, they discovered that they had come up with a theory during their small-group time. Only one group was unable to provide a theory even after consulting the reporters' lab notebooks. In every report except one, the theories offered addressed a scientific notion of "why" without appealing to previous experience or observation. This led the teacher and researcher to believe that, although the students had not spontaneously incorporated discussion of theories into their reports, they were indeed talking about them and recording them (as had been observed) during their small-group work time. As the students became more comfortable and familiar with the terms, it was expected that they would include these ideas without prompting from the teacher. On the next day, however, when students were asked to develop questions for the questions chart, it became apparent that they were still struggling to focus on the notion of theory as a conceptual tool.

As the students were developing questions for each of the three audience roles, it was obvious once again that the notion of theory was something that was not well understood. Students offered many questions that addressed predictions (e.g., What were some of your predictions? What did your group think was going to happen?); however, they needed significant prompting from the teacher to focus on theories. One such example follows.

Teacher:	Leo.
Leo:	Like say something like, I don't know, like something out of this world and then you say what do you mean by whatever that the person said.

Teacher: If they say something, give me an example of what they might have said.
Leo: Uh [pause]
Teacher: Remember, your job specifically is to get them to say their predictions and theories. How are you going to draw that out of them with your question?
Leo: Well, if they say like a really weird prediction
Teacher: But isn't that okay?
Leo: Well, if you don't know what it is.
Teacher: OK. If someone gives an odd prediction, you want them to back it up with what?
Leo: With,
Teacher: You can't just predict anything. I'm asking you to give predictions that have what to back them up?
Leo: That have the answer? I don't know.
Teacher: Okay, Molly.
Molly: That explains.
Teacher: Yeah. Or what, what's the other word for that? That you've been using, I want your prediction to have a
Leo: Theory.
Teacher: So if they give a strange prediction you might ask, to give me your what, to back it up.
Leo: Give me your theory.
Teacher: Yeah.

So, with significant guidance from the teacher, the students added a question to the chart that asked them to support their prediction with a theory. Another example of a question addressing theory came a bit later, after several more prediction questions were suggested. The teacher again tried to focus the students on the fact that they have provided many questions that address predictions but not many that ask about theories.

Teacher: Again, most of these get at predictions but theory has a really different feel to it. [questions two boys about sitting appropriately] Okay, Laurel.
Laurel: Why do you think that?
Teacher: And let's fill it out a little bit. Why do you think what? Why do you think what, Laurel?
Laurel: Why do you think that would happen?
Teacher: Okay. [writes] That would happen. [Again talks with two boys about how they are sitting] Why do you think that would happen, but again I'm standing here now and I

thought it before, so you might want to think about it, Anthony, as in why did you think, why did you think that would happen?

These were the two principle questions that appeared on the questions chart that supported students to ask about theories without asking simply for more or different theories that were not discussed during small-group work time. It was not until the students began employing the questions in their roles as audience members on Day 6 that there was evidence of a deeper understanding of theory as a conceptual tool. It was when students actually attempted to use the idea of theory to question others that they began to establish individual understanding and shared meaning. This change in perspective on the part of the students seems crucial to the learning process.

On Day 6, after the first set of reporters (Katie and Shawn) finished giving their report, the teacher opened the floor for questions from students who had the audience role of checking predictions and theories. Because this was the first time the students were adopting the roles, the teacher supported those students who attempted to ask questions of the reporters. The "theory" that Katie and Shawn presented during their report was that they knew some things would float because they had seen them float before. Alan was in the role of checking predictions and theories and noticed that what Katie offered as a prediction and a theory did not satisfy his understanding of these conceptual tools. He pursued a line of questioning about "why" objects sink or float, which put Katie on the defensive. This was something that happened during the early stages of audience role-taking within this classroom. These students did not have as much difficulty questioning others as they had coping with being questioned themselves.[3]

Teacher:	Your role is to check predictions and theories, if you have heard the predictions and theories or if you have a question for the reporters? Alan B.
Alan:	They really didn't explain why they [teacher interrupts—Alan is looking at her]
Teacher:	No, ask them.
Alan:	You really didn't explain why you thought the aluminum cube would sink. Or like the plastic cube.
Katie:	Well, it's not our fault. We weren't the people that wrote it [scribes prepare the reporting materials with the reporters] They [the scribes] told us to say it.
Teacher:	Okay, but Katie, you are reporting for your group. And one of the things that I sent you back with was to make

[3]See Herrenkohl (1998) for further discussion of the conflict that came up in this classroom as a result of taking on audience roles.

	sure that you discuss all the theories that were in your group. Alan, they may not have a theory for that, right? So is there a way you can ask that question?
Alan:	Maybe next time you could include some.
Teacher:	Well is there any way you can ask that question to find out if they do?
Alan:	Do you have any reasons why the clear cube floated?
Katie:	Well [long pause—turns to her partner] Shawn. What was the question?
Alan:	The aluminum which you know would sink. Do you have any theories on why stuff floated? That you know the wood you know would sink, but that you know would float?
Katie:	I don't understand your question. Why do we think [Alan interrupts]
Alan:	No, why did you think [Katie interrupts]
Katie:	The wood would float?
Alan:	No, why do you think the clear cube floated, or why do you think the weird thing [Katie interrupts]
Katie:	Because it was the second experiment, that's why.
Alan:	Yeah, but why do you think that happened?
Katie:	Well, I
Shawn:	Cuz plastic floats.
Katie:	Well, if I knew what it was I could answer that question, but I don't. It was just a lucky educated guess.
Alan:	Now do you have the theories why?
Katie:	No!

Katie and Shawn address Alan's question by stating that they do not know why things sink and float and if they knew why they could answer the question. They restate that what they have offered is a "lucky educated guess" based on the fact that they know plastic floats. Katie implies that part of the reason they know that plastic floats is that they had seen it before saying, "it was the second experiment." Alan, still not satisfied, probes further, asking, "Now do you have the theories why?" To this Katie responds with an exasperated "No!" The teacher allowed Liz to pursue a similar line of questioning until it was apparent that the students were not making any real progress.

Liz:	Do you have a theory that you didn't get to write down?
Children:	Do you have a theory for the experiment?
Teacher:	You may have to think of a way to rephrase the question. I think she's heard the question.

Katie:	I heard the question plenty of times, I know what she's been saying, but I don't get it. It's like do you have a theory why you did the experiment or something?
Teacher:	You let Liz, Isaac, your chance will come up later [Isaac is assigned a different role]. Liz, can you think of a way to phrase the question? [pause] A theory about what? What specifically are you getting at? [pause]
Liz:	Um [long pause]
Teacher:	Is there someone else whose job it was to check predictions and theories, could help Liz out? Want to give it a try now?
Alan:	Do you have any [interrupts himself] why do you think that some stuff floated and some stuff sunk, because their volume was greater, because it was heavier, because it had air in them, were lighter than water?
Katie:	I don't know that, because I don't have five lines and everybody in my group, I don't have a line of people, lines of people in our group. Not everybody wrote their own theory, so it's not my problem.
Alan:	Well, what about Shawn?
Teacher:	I'm going to move us to summarizing results.

In this exchange, the students are not making any progress in understanding theory. Katie continues to be defensive and suggests that it is not her fault that the scribes did not write down a theory from every person in her group. Alan offers even more support this time than before, giving Katie examples of theories that might have been discussed in her group. Even this prompt does not seem to help Katie focus on theory-building in the immediate reporting environment; she is more concerned with providing reasons why her group did not record their theories on their poster. The teacher senses this stall and moves the conversation on to checking summaries of results. The students do confront theories again, however, as they begin to tackle the third and most difficult aspect of role-taking, checking the relation between predictions, theories, and results.

Teacher:	What about your theories? All right, I'm jumping in because—what about your theories, how did your theories relate to what happened, the theories that are there or the theories that you have?
Katie:	I don't understand that.
Teacher:	Well, the reasons why things happen, how did that relate to what actually happened? So for example, give me somebody's theory up there.

Katie:	I knew it would float because I've seen sticks float in the water.
Teacher:	Is that your theory?
Katie:	Is that like a theory?
Teacher:	When you're giving experience [turns to researcher] Can you do it? Go ahead.

At this point it is evident that the early confusion between scientific and everyday notions of theory are working at odds again. The teacher's statement, "*What have you seen, what have you observed, what are you thinking about that leads you into this thought?*" could have influenced the students to believe that previous observations were a sufficient basis for a scientific theory. When students introduced past experience in reporting sessions prior to this day, they were unchallenged by the teacher and other students. This did not happen often, however; with all of the other things that were being addressed, no one ever followed up on it when it was mentioned. So, this is the first day that the issue of previous experience as a "theory" was confronted directly. The teacher looks to the researcher for support at this point and asks her to try and talk the students through this sticking point. In the excerpt that follows, the researcher focuses the students on why something sinks or floats and whether past observations provide an answer to this "why" question. In this excerpt, multiple attempts are made to help students disentangle the scientific and everyday notions of the "reason why." The researcher asks the student to differentiate what prompts them to think something might sink or float from an attempt to *explain* the basis for the observed phenomenon. From students' perspectives it is perfectly legitimate to offer past experience as a "reason why" they think something will sink or float, but it fails to meet the criteria of an explanation in a scientific sense. The researcher is trying to help them come to see this important distinction.

Researcher:	Could I have everybody's attention for a second? Zeke, could you look at me? I'm curious about whether or not you guys think that experience counts as a theory? Just seeing something before, is that a reason why something would sink or float? Paul.
Paul:	I think it is.
Researcher:	You think it is?
Paul:	Because if you've seen it before, then it's a theory.
Researcher:	Okay, so you've had experience with it and that's one way of predicting whether or not something's [interrupts herself] but I think I heard Alan saying something before where he was trying to get at reasons why, and is just

	knowing that it happened before, does that give you any idea of what reasons there could be for why something would sink or float, just because you've seen it before? Does that give you any reasons why?
Paul:	No.
Researcher:	No, it just tells you that it does sink or float.
Paul:	Yeah.
Researcher:	Christina, do you have something to say?
Christina:	Well, a theory's kind of different from a prediction because a theory is, you know why it happened, you're not guessing.
Researcher:	Okay, talk a little bit more about that. What do you mean by the difference between guessing and knowing why something happened?
Christina:	Well
Researcher:	Can you give us an example, maybe?
Christina:	Like we had to guess what *made* Mickey go up and down when you turn it on? But most people didn't have a theory of why.
Researcher:	Okay. So there's something different about just guessing whether something goes up or down versus knowing why.
Researcher:	Alan, did you have your hand up before? Did you want to say something about this? Okay.
Alan:	I know what a theory is. You predict that a [toy] submarine goes up and down before air comes into it and the air escapes, but the theory why is that, the theory that everything has to be that way. A theory that all wood floats, that means all wood has to float in your theory, otherwise your theory's wrong.
Researcher:	Okay, but you're saying all wood floats is [Alan interrupts]
Alan:	That's a theory.
Researcher:	That's a theory?
Alan:	That has been proven right.
Researcher:	Does that tell me why wood floats though?
Alan:	Uh, no.
Researcher:	Okay, so can you give me an example—let's take wood. From our experience some of us know that wood floats. So why? Why does wood float? Can you give us a theory?
Alan:	My theory is that you can trap air underneath and that's my theory.

Researcher:	Okay, so that is a reason why. Does everybody understand that? Are people clear on the difference between a prediction and a theory now?
Children:	Yeah.

At the end of this excerpt, Alan suggests something that could qualify as a scientific explanation. It is fascinating that both Christina and Alan discuss another dimension of theory that is salient to them, namely "knowing why with certainty." These comments clarify why a more scientific notion of theory may be challenging for them to understand and employ. The students do not know why something sinks or floats with the level of certainty that they think is required. This is clearly what Katie had been arguing earlier as well. She said if she knew why she could answer the question, but she does not know why things sink or float. So, although she understands the question, she cannot answer with certainty, so it is not possible for her to respond at all. She would be guessing and that does not seem to fit her definition of theory. It is quite interesting that the students did not think of theories as changeable entities at this point, they were more equated with the "right answers" expected within the context of schooling. This posed a challenge for the teacher and researcher, who could understand what was happening but needed the right moment to try and begin to introduce the idea that theories can be changed. This happens in the next segment, which followed right after the children claimed that they now knew the difference between prediction and theory. Katie offers (again) past observations as a theory when the teacher and researcher try to help her compare her predictions, theories, and results.

Teacher:	How did your theories compare to what actually happened. So how did your reasons *why* compare to what actually happened? And then I think we got off, well then we realized that maybe some of the theories that were created were actually predictions. And not theories. So do you think you have a theory up there, a reason why something might happen from your group?
Katie:	No, because we didn't have time, some people just didn't do it, cuz they forgot.
Researcher:	So Katie, when you say you didn't have enough time, does that mean when you're doing the activity you didn't have enough time?
Katie:	No, when we were making this [the poster].
Researcher:	Okay, so even if it's not up there, let's not pay attention to that right now. Does anybody have a theory about, say, the wood, why does wood float? Why did you predict that wood would float?

Katie: Because I've seen it float.

Researcher: Okay, but I think we just talked about and decided that our experience is a good way of helping us make predictions, but doesn't explain to us why, why something happens. I think this stuff is hard but maybe it's something that we need to keep [working on] because it's hard to do what you're saying, Ms. Kawasaki, if we don't have a theory we can't talk about how it relates to anything.

Teacher: That's right.

Researcher: So maybe it's just something we all need to remember and work on, because it seems to me that not all of us are clear about what a theory is.

Teacher: So if you don't have a theory, you can't relate it to your results, can you. No, but you do have a reason why you think something will happen, you can compare it to your results and what actually happened.

Researcher: Because sometimes if you make a mistake, if you predict something and something that you didn't expect to happen actually happens, you may have to change your theory. That's what it's supposed to help you do.

Teacher: Let's give the Blue Noodlers reporters a big round of applause for being good sports. [student applause] That was very hard, I know, because you're really in the hot spot. We're getting used to this whole procedure and we had to experiment on you. Thank you very much, Katie and Shawn.

The report ends here with the teacher and researcher working together to try and introduce the idea that theories can be changed. This idea is still something that many if not most of the students are not grasping. Answering "why?" does not require a definitive, certain answer but a tentative one that can be changed based on the evidence that can be gathered from investigations. This process of revising theories was extremely difficult for the students to understand. However, as they continued to adopt the intellectual audience roles, the conversation continued and the need for certainty diminished.

In the next excerpt, which takes place on the next day, Day 7, there was still much discussion about how sure one must be in constructing a theory. Lisa opened this discussion with a statement expressing the immutability of theory.

Lisa: Well, a theory really isn't what you thought, it's what kind of happened and what always happens. And why. (p. 5)

Lisa is taking the position that theories are things that always happen, that one must know "for sure" and not just "think" about. In responding to this, Isaac and Ernie suggested that what Lisa has described is what they consider to be "results." The conversation continued as Sarah struggled to voice her perspective.

Sarah	… Because a theory is like, a theory is [sigh] what you know happens, what you think happens. I mean, it is what you think happens, but, you know what I mean?
Isaac:	What would obviously happen, like obvious …
Sheila:	Well, I think a theory is more like why it happened, not what you think, because what you think is more like a prediction. Like I think there's air bubbles in the milky white cube
Sarah:	Yeah, that's like your prediction. You're taking your predictions as theories. Because you said that the milky white one would float, but you never said why, why does it float? You said why you *think* it floats, but not *why* it floats. (p. 6)

Sarah and Sheila again argue for a level of certainty when articulating a theory. When Sarah said "You're taking your predictions as theories," she was expressing her concern about presuming to know why something happened. She was taking issue with people saying that they know *why* and suggesting that everything that a person does not know for sure needs to be called a prediction. Both girls are suggesting that we classify predictions as things that we Think, and theories as things that we Know, or Are Known. This is similar to Lisa's perspective in that they all seem to hold Theory as somehow irrefutable.

Zeke takes issue with the definition of theory that is being offered by the girls. He succinctly states his objection in the following excerpt.

Teacher:	Say it, Zeke.
Zeke:	That's a theory, theories aren't always right.
Sarah:	Right, but [Zeke interrupts]
Zeke:	Like people had theories that … there were little green men on Mars. But were they right? (p. 6)

This pronouncement encouraged further discussion by the class because Zeke suggested an alternative that had not been advocated by anyone else. Several students noted that what Zeke said was actually a prediction in their minds and not a theory; however, he did challenge other students to think about whether theories had to be right or certain. As other students took speaking turns, they also introduced examples from outside of sinking and floating to try to give examples that would help define the notion of theory for their class.

Isaac:	Okay, this is like a theory. I think Ernie will buy another pair of those shoes.
Sheila:	That's a prediction.
Zeke:	You could say that I think that Ernie will buy new shoes because his old ones are worn out, and that would be a theory. (p. 7)

As the students continued to struggle with these ideas, there was a shift in the class definition of theory. Theories became things that were not absolute and certain but tentative and changeable. Furthermore, as the students began working with this new definition, they began to explore the idea that evidence from investigations could be used to confirm or disconfirm a given theory. In the next excerpt, Molly picks up on this idea in trying to clarify what she thinks Laurel was suggesting to one of the groups. She uses an example from a report where a group predicted that a clear plastic cube would float because it had air bubbles in it. The results were that the cube sank. Molly argues that it is important for this group to go back and change their theory to accommodate their results.

Molly:	This might not be what she's trying to say, but this is what I think she's trying to say. Like even though it might not be a theory, I don't what to start another thing [debate over theory-ness], but I mean if that "clear plastic" there was a theory and let's say that you thought it would float because there were air bubbles in it, in your prediction, and then it sunk, then you could say, but well, "I think I was wrong because I don't really think air bubbles were in it actually, I think probably this [a new theory] was why it sank." You didn't really compare it like
Laurel:	Yeah, you didn't.
Teacher:	Laurel, go ahead and say what you said a minute ago when Molly was talking.
Laurel:	You didn't change it. I mean if one of the ones you said would float, it had sunk, you changed your [Molly interrupts]
Molly:	You're supposed to take your theory and say like if you're wrong. (p. 11)

This is the first evidence of the students understanding and advocating for the relation between predictions, theories, and evidence. It is also the first clear articulation of how the dynamic nature of theories could be applied to the sinking and floating investigations that they were completing. In the days that followed this one, the students continued to build on this budding knowledge and apply theory in a much more flexible manner, changing their theories and talking openly about how they use evidence from their experiments to help them evaluate their perspectives.

Giving Meaning to "Theory": Perspectives From the Fifth-Grade Class

We will begin our discussion, as we did in the third/fourth-grade class, by examining the teacher's introduction of the term *theory.* She introduces it by telling the students the meaning of the words *theory* and *theorizing.*

> Teacher: When we ask you to explain to us *why,* perhaps, you think the object will sink or float ... that's *theorizing.*

The teacher also noted that the science investigations that would ensue would incorporate theories as an integral part and that the students would always need to include a *why* for their predictions. This served as a preliminary introduction to the students. However, it would take many more conversations for them to develop a workable understanding of *theory.* At first the students grappled with the difference between what and why. What follows outlines how they coped with this aspect of defining *theory* and differentiating it from *prediction.*

After introducing what she thought was a straightforward definition of prediction and theory, the teacher assumed that the students would be ready to employ these conceptual tools in the context of their investigations. As a matter of habit, the teacher would check back with the students occasionally to make sure they understood the meanings of *prediction* and *theory.* Such was the case on the third day of the project after the teacher reviewed the intellectual tools associated with science (predicting and theorizing, summarizing results, and relating predictions and theories to results), which were intended to guide the students' thinking throughout the activity and reporting sessions.

> Teacher: Who can help me decide what we're going to mean by *predicting* and *theorizing*?
>
> Sung: Guessing if it will sink or float, and then telling why you think that.

Because Sung's response was unchallenged, and most students did not appear to have difficulty distinguishing prediction from theory in the early reporting sessions, the teacher assumed that the students held a common conceptual understanding of these terms. The fact that, a few minutes after this, a student who had missed a session offered the group's *theory* when asked for their *predictions*, did not alert the teacher to any problems the students might be having understanding and using these terms. After all, the student had missed a session and with guidance was able to recognize her statement as the theory. She was also able to move quickly to reporting the predictions and results for her group, labeling them appropriately.

Five days into the unit, however, it became apparent that it was not just one student, but *several* students who could not clearly articulate a distinction between *prediction* and *theory.* As the teacher attempted to have students note a connection between *prediction* and *theory,* she quickly discovered that they needed more time to think about and employ the terms individually.

Teacher:	What are we looking for in a theory anyway?
Karyn:	It's like part of a prediction. It's what you think is going to happen.
Teacher:	Is it just what you think is going to happen?
Jean Paul:	It is more like a guess.
Teacher:	The theory part is more like a guess?
Jean Paul:	The prediction.
Teacher:	The prediction part is more like a guess. What's the theory part of it?
Jean Paul:	What happened, I guess.
Teacher:	So a theory is like the result?
Jean Paul:	Uh, no. What you think is going to happen.
Teacher:	Well, you just told me that's what the prediction is, what you think is going to happen. So we need to clarify this a little bit more.
Curt:	Well, a theory is, um, say an object floats, I mean sinks, something like that, what was your theory and why do you think it does that.
Sung:	What I was going to say is like theorizing is like backing up why you think that's going to happen.

The simple act of repeating or paraphrasing what the teacher said earlier obviously does not constitute a deep understanding of prediction and theory. As the students began to try and use these conceptual tools to guide their thinking in small groups and reporting time, it became a real dilemma for them. To share important aspects of their investigations and ask questions of one another, they had to agree on what they meant when they used terms such as *theory.* It was in this context that they began to collectively define the conceptual tools that would guide their subsequent discussions. A crucial aspect of this defining process came as the students adopted audience roles. It was the active use of these intellectual tools to ask questions of others that ultimately allowed students to negotiate a shared meaning of *theory*.

At the beginning of this process of adopting audience roles, students were asked to generate questions to compose the questions chart. This chart helped the students think about questions they could ask others in each of the three audience roles (checking predictions and theories, checking summaries of results, and checking the relation between predictions, theories, and results). In this example, Veena offered a question to address the role of checking predictions and theories. Her question was the first to focus on the "why." All the questions suggested prior to this point related to predictions.

Veena: Why do you think it will sink or float?
Dennis: That's a theory.

Dennis immediately recognized that the "why" indicated that Veena was asking a question about theory. He was anxious to share his recognition out loud and reaffirm for himself and his classmates that this was, in fact, what Veena was addressing. It is opportunities such as these to actively create questions and use them as intellectual tools that began this process of recognition and negotiation.

As these questions were taken into the classroom and used during the course of reporting, students began to spontaneously note when there was a discrepancy between the definitions agreed upon by the class and the use of the terms by a particular group. In this example, which occurred on Day 6, Curt promptly remarked that what had been offered as a theory was actually a prediction.

Karyn: Larisha's theory was I think that some will float and some will sink.
Curt: Your theory that some will float and some will sink, that's not really a theory, it's more like a prediction.

From this point on, the reporting sessions indicated very little confusion with the use of prediction and theory. And on Day 9, right before the theory chart review (the session devoted to evaluating the viability of all theories that had been proposed thus far), Sung included the word *explanation* to further characterize *theory*. With this reference, students were introduced to another dimension of the illusive "why." The *theory* explains the behavior. At this point, *theory* was no longer a teacher-defined concept; ownership had shifted to the students.

Sung: … a theory is like—I have an explanation of why this does this or does that. That's what a theory is to me.

On that same day, as the students were determining the fate of each "theory" listed on the theory chart, the "why" became a useful tool in this determination. The theory up for review was "All wood floats, sinking and floating depends on material."

Teacher:	Does this explain why things sink or why things float?
Curt:	No.
Teacher:	Why not?
Curt:	It just says wood floats, it didn't say why.

With these preliminary definitions of *prediction* and *theory* in place, the students were ready to tackle a more difficult dilemma, the *why* for the "why."

On one of the first days of the project, Sung had disclosed a wariness about the idea that theories address "why" something happens. It was the first intimation that the students would not be comfortable with *just* a why.

Sung:	Well, how do you know, um, well, um, an object sinks, how do you know a reason for that?

This idea of how you come to an idea for a theory was brought to the forefront again on Day 5 when Kathy made a suggestion for the questions chart on *predictions* and *theories*.

Kathy:	What cause does your theory have?
Teacher:	What cause? Could you explain that? I am not sure I know what you mean by that.
Kathy:	Well, it is kinda hard to explain.
Teacher:	Could you say in another way what you mean?
Kathy:	Why did you think that?

When the teacher asked in summary if what Kathy had intended with her first question with the use of the word *cause* was "what caused you to think that," Kathy responded in the affirmative. It appeared that from the beginning, this group of children intuitively knew that there had to be more substance to a *theory* than simply producing one from thin air. *Something* had to make you think that. Just what that something was would not become apparent for several sessions. Students were still adjusting to their new way of doing science. There were too many things to attend to, too many things to consider. And so when they first began to question each other about the origins of their theories, they simply read the questions off the questions chart without carefully considering the reporters' responses and following up with more detailed probing.

Leah:	What did you base your theory on?
Sung:	Now, that would be material, right? That we based it on materials.
Karita:	What caused you to think that? What caused you to think that theory?
Sung:	Well, because wood floats and metal doesn't, because, I don't know, well, well, I don't know.

Sung was uncomfortable with her response, but neither Leah nor Karita cared to pursue it further. The students were still practicing their roles, trying them on for size so to speak, so the content remained subordinate to the process at this point. However, the tone of the reporting changed dramatically on the 8th day of the project. The students were finally feeling comfortable enough with the idea of theory that they began to move from depending on the listed questions on the questions chart for a source of their queries to developing their own questions related to theory. As the process settled into routine, more attention was being paid to the content of both the questions and the answers. It was in this environment that Stuart emerged to champion the *cause* of the theory. After a group had reported that their theory was based on "density that showed how packed it is inside the object, and the material," Stuart began a relentless pursuit of the origin of that theory.

Stuart:	What do you mean by the density of the material? I mean you said that was the answer, that's what you based it on. What do you mean by that?
Sung:	How packed it is inside the material.
Stuart:	How do you know how compact it is inside?
Sung:	No, I mean [Stuart interrupts]
Stuart:	Like, how can you tell ? You said your theory is based on that. How can you tell?
Sung:	Well, like the large aluminum cylinder? It's metal, right? Well, uh [pause]

It is as if Stuart was battling this in his own head, because when Sung failed to give an adequate response he replies to his own question.

Stuart:	So it's basically an educated guess that metal is compact inside, basically.
Sung:	Yeah.
Stuart:	And wood isn't and then plastic isn't. How do you know that, though?
Sung:	The way it [pause]

Stuart:	When we were doing our test before, we found that something that floated was actually heavier than something that sunk.

With this Sung turned to her reporting partner, Shamone, for some help. Finding that no one could respond to his last statement, Stuart rephrased the question once again. He had recognized that there was some significance to the fact that a heavier object floated whereas the lighter object sank and seemed to want to use this public forum to clarify and make sense of his own mental struggle with a theory, so he was not yet willing to relinquish his quest.

Stuart:	What do you mean by [interrupts himself] , not what do you mean by density, like how did you base your theory on how dense it was.
Sung:	That's a good question.
Shamone:	That's a good question.
Sung:	Actually, I don't think I know.
Shamone:	We just went from smallest to biggest [meaning they ordered the objects in this way before completing the experiment]
Stuart:	But that doesn't answer my question.

This group finalized their report, admitting that they were more confused now about their theory than they had been when they began their report. Stuart had not given up, however, and began a similar line of questioning with the next group of reporters who had stated that their theory was based on the weight for the size of the object.

Stuart:	What do you mean by your theory?
Dennis:	What?
Stuart:	What do you think your theory means, I mean how did you get it?
Dennis:	How did we get that theory?
Stuart:	The weight for the size of the object.
Dennis:	The weight, like the last group? Like if it's well, well [Stuart interrupts]
Stuart:	Do you mean it's big for its weight?
Dennis:	And has, yeah. Or it can be small and heavy and still sink, like that small thing?
Stuart:	Doesn't really matter?

Dennis: Nope, size doesn't really matter. Because we had a small clear cube that sank, and we thought that would float because it was so small, and the other one, I think it was a cube I think, I really don't know. And that one sank with it, and I was wondering why, so size has nothing to do with it.

Stuart did not continue. Dennis's citing of the observations his group had made during their activity, to rule out size alone as a factor in whether something sinks or floats, had somehow appeased him. It was similar to what he had offered the first group of reporters about his experience when the weight of the object did not seem to matter. So reference had been made to *evidence* from an experiment that seemed to suggest that weight alone did not matter, as well as evidence from another experiment that suggested size alone did not matter. They had not managed to explicitly articulate the need for a clear link between evidence and theories yet, but Stuart had managed to show that it might be important to consider outcomes of investigations when answering questions about theories.

The relevance of the observations made during activities to the evolution of their theories frequently escaped the students during the first several days of the science program. Stuart was the first to bring this to their attention, and his efforts were not unnoticed by them. On the theory chart review day, evidence from the activities was used to support the dismissal of certain theories from the chart. The dialogue that follows is typical of how the students utilized the results of the activities to inform their decisions about theories.

Teacher: Let's talk about the next one [she is referring to the next theory on the chart]. If the object is heavy, it will sink; if the object is light, it will float. What do we think about that one?

Denita: Take it off.

Lynn: Well, you see, when we, our team weighed things, there was an object that was heavy, made out of aluminum, that was lighter than the object made out of plastic and the little aluminum object sank, the plastic one floated. So that doesn't work.

Dennis: That doesn't work. Now I don't think that one works because for one thing you know the one that we just did? The small one? The small plastic cube? It was so small and it was so light, we thought it would float, but it sank. So I don't think if the object is heavy it will sink and if the object is light it will float. So you can *cross it out!* [motions broadly with arms]

Similar arguments were used to reject theories that had implied that size or shape had something to do with whether an object would sink or float. As mentioned previously regarding the theory chart review, the students had been able to recognize if the theory included a why, and they had also been able to reference evidence from experiments that ruled out particular variables, at least these variables by themselves. These were powerful tools the students now had in their employ. This became a turning point for the project. The empowered students could, and did, take greater responsibility for the reporting discussions. They become more critical of theories that were subsequently proposed. They questioned with the intent of trying to understand novel and more abstract ideas. They wanted to know *why* some things floated and others things sank, and they believed they were capable of figuring this out.

Just how far this inner-city class was able to advance was probably best demonstrated on the final day of the unit as the last group came to the front to report. The students tried to tie together all that had transpired from the pretest demonstrations at the very beginning to the scientific modeling process that took place near the end. They compared their theories and created hypothetical situations to test them further. They debated the merits of several theories and found themselves embroiled in a heated argument. At this point their focus shifted from the content of the arguments and proposed experiments to the merits of arguing in science. Their discussion took on a distinctly philosophical and epistemological tone.

Sung:	I say that arguing is a part of science, kind of, I know I'm wrong, but I mean because if you don't argue that, you can't find answers to stuff.
Students:	[clapping]
Dennis:	OK, OK, can I saying somethin' Lynn? [Lynn is the reporter leading the discussion] Well, if you argue where will it get you? You won't get nowhere.
Sung:	Okay, Dennis, your argument is where would we get? We'd get to the truth.
Students:	[shouting]
Karita:	I agree.
Toneisha:	Anyway, Sung, you say that the object is you [inaudible word] by arguin'? You guys don't have to be so loud. I'm not saying that you guys can't argue, I'm just saying you guys don't have to be that loud.
Sung:	What's the point of arguing if you can't scream and yell?
Karita:	I know, thank you.
Dennis:	I have something to say in response to that.
Karita:	Yeah, I agree.

Dennis: All right, if you're arguing, right? One person says something, you have another person say something, you have another person say something, how can you get to the truth when everybody's saying something? You can't even hear yourself think.

These fifth-grade students ended their science unit by raising questions about the merits of arguing for advancing scientific understanding. Clearly their definition of argument (i.e., disagreeing with yelling and screaming) significantly differs from the one most scientists would espouse. However, Sung's point about the role of argument in finding what is truth is something that concerns philosophers of science. Also, Dennis's suggestion that it is hard to "get to the truth" when everyone keeps saying something different is also quite profound. It appears that these young students, by virtue of their own practices and discussion, have come to a place where they are able to see both the value and challenge of the scientific enterprise.

It is unfortunate, in many ways, that we had to conclude at this point. There were still so many questions unanswered, and so many experiments the students wished to perform in an attempt to answer them. They developed a new way of thinking about science and created a common set of tools with an accompanying language to talk about their thinking. The students and the teacher had crafted a lively intellectual community where real issues were debated and discussed and tough questions were always on the table.

DISCUSSION

Consensus is emerging that essential to the enhancement of conceptual understanding in science is the attainment of knowledge regarding the purposes, methods, and values associated with scientific inquiry (Brewer & Samarapungavan, 1991; Schauble & Glaser, 1991). These ideals are also advocated in the National Science Education Standards (1996). The ability to engage in reflection on theory has been identified as a cornerstone in the development of this syntactic knowledge. Specifically, it has been posited that students need to acquire an explicit understanding of the relation between theory and evidence (Chinn & Brewer, 1993); an understanding of the need for consistency among theoretical ideas and between theoretical ideas and data (Reif & Larkin, 1991; Strike & Posner, 1985); an active fair-mindedness in theory evaluation (Nickerson, 1991); and an understanding that science is a continuing process of debate about evolving theories rather than a static body of knowledge (Easley, 1990; Munby, 1982).

Chinn and Brewer (1993), among others, have argued that these epistemological understandings are best learned in the context of evaluating evidence and theory, debating alternative theories, and discussing responses to anomalous data in a context in which students are apprenticed in the craft of scientific reasoning. This is a tall order, especially when considering the complexities of most classroom contexts in which students may well be experiencing these aspects of the scientific enterprise for the first time.

In this research, we observed that third-, fourth-, and fifth-grade students were able to achieve a number of these understandings in a context in which they were supported by the use of intellectual tools and roles designed to explicitly focus their attention on the relation between evidence and theory. As the transcripts reveal, this process was not linear; clarification and consistency occurred through an iterative process in which students tried out a range of explanations and negotiated the unique features of a theory (in contrast to a prediction, description, or results).

Clearly, this form of instruction poses significant challenges to the teacher who is identifying the threads in the classroom discussions, engaging the students in evaluating their own and their peers' thinking, mirroring the ideas that are in play, and generally shaping the discourse. This role requires clarity on the teacher's part regarding the characteristics of a theory, the topic-specific features of a working theory, and the role that social negotiation can play in advancing these understandings. In these classrooms, the teachers consistently refrained from directing the conversation and instead used the thinking strategies and theory chart to scaffold the classroom discourse. However, they also assumed the critical role of sustaining the groups' work, monitoring for coherence and direction, and interceding when the discussion faltered.

The tools, roles, and theory and questions charts that the teachers employed were valuable but also had limitations. The tools of predicting and theorizing, summarizing results, and relating predictions, theories, and results worked well for the students in the section of the unit devoted to investigations focused on identifying potential factors that affect sinking and floating. As the students moved on to the idea of modeling and representing their theories, this set of heuristics was not as useful. A new set of tools was needed for this part of the unit.

The roles also provided affordances and constraints. Early in the unit, as the students were beginning to experiment with questioning others, the roles were crucial in guiding them and helping them focus on one set of issues at a time. As the unit progressed and the students became more proficient questioners, this assignment of specific audience role responsibilities during reporting often limited the students who could ask questions of reporters at any given time. Toward the middle and end of the unit it was not uncommon to hear students preface a question by saying, "this wasn't my job but ..." Using these roles flexibly and allowing students more freedom as the unit progressed was crucial, ensuring that important questions were always able to surface. Shifting and changing these roles as modeling became the focus of the inquiry was also important.

Finally, the questions and theory charts were helpful public documents that were used throughout the unit as flexible "running records" of what was happening in the classroom. The questions chart was a major source of support to students as they began taking on their audience roles. This chart, which was constructed by the entire class together, then served individual students as they assumed their audience roles. Early on in the unit, especially in the fifth-grade class, students relied heavily on this chart, in some cases simply reading questions from the chart without listening to the reporter's response. However, this early practice shifted over time as students became more comfortable with the nature of conversation during reporting. Students even began critiquing what they had originally included on the chart, remarking that certain questions "did not make any sense." As a tool for supporting students to take on a new set of roles within the classroom, this chart seemed to work well.

The theory chart was also a useful way to document developing theories over time. Students used this chart as a point of reference as they questioned reporters about their theories. Thus the chart was not something that was augmented daily and forgotten. Students actively sought to understand how theories presented on one day connected with those offered on the next. The chart served this purpose until the day when the theory chart review took place. This day was very powerful for students. They were able to actively review the chart and make modifications to what they had said and thought on earlier days. Revising the chart was a culminating activity that allowed students to use their new knowledge to recreate a document that would accurately represent their thinking process as well as their final product.

This discussion would be incomplete without mention of the unique nature of the collaboration between the researcher and teachers. How many elementary teachers have an opportunity to plan extensive units together, have the luxury of another adult in the classroom, and have the resources to have hours and hours of classroom videotapes transcribed so that they can analyze them? The opportunity for extensive collaborative planning and decision making was unusual. Furthermore, the involvement of another adult in the classroom monitoring the activity and reflecting with the teacher was another special feature of this work. This is indeed a luxury, but it is also befitting the complexity of the kind of teaching that was being enacted. By no means are we suggesting this as the only model. Nor are we saying that it was without inherent difficulties and problems (at times our active approach to working together may have served to confuse the students in the third/fourth-grade class). These factors are both limitations of the study as well as strengths.

CONCLUSION

In this article we presented findings from a project that was designed to engage students in meaningful discussions about their ideas in science. Although the purpose of this work is in some ways similar to other research in the area of elementary science, it can be set apart based on the explicit focus that is placed on discussion. To accomplish the goal of helping students engage in sophisticated conversation, we harnessed research findings from both the cognitive and social realms to establish intellectual strategies that are important within the discipline of science. These strategies guide young novices and focus their attention on building explanations in science rather than memorizing facts or simply experimenting with interesting materials without knowing the significance of the experiments or the outcomes. Second, these strategies are made to correspond with a set of social roles that motivate collaboration and discussion of ideas, provide a level of accountability among classroom members, and promote important dispositions toward learning (Herrenkohl & Wertsch, 1999). Finally, public documentation of progress through the unit (i.e., the theory chart) was used to focus the students on the need to modify their thinking as they gathered more evidence.

The findings from our work suggest that this approach is a fruitful one. We provided evidence from pretests and posttests as well as classroom discussions that took place throughout the first half of the intervention in both a third/fourth-grade gifted class and a fifth-grade regular education class. Pretest and posttest data demonstrated that students improved in their conceptual understanding as well as their understanding of the use of scientific tools and thinking strategies. This finding was then explored further through an analysis of the classroom discussions that provided a foundation for learning and thinking. In both classes, as the strategies, roles, and public documentation were introduced, discussion became more elaborate and productive. The students in both classes struggled to collectively define and employ the concept of theory within the context of their sinking and floating investigations. However, each class achieved a much deeper level of understanding through these conversations. The approach described in this article is not the only or perhaps even the most efficient way to support student thinking in science. However, it points to the need to make scientific thinking strategies and sociocognitive roles explicit to students so that they can engage in significant cognitive work together. Further research is needed to identify other avenues that can be used to support the development of learning communities that emphasize the role of discussion in science. Also, understanding the ways in which students become thinkers and speakers in one domain will help us generate ideas about how to accomplish this goal across the curriculum. Our hope is to continue to create elementary classroom environments that involve students in the exciting and complex process of learning.

ACKNOWLEDGMENTS

The authors wish to thank the James S. McDonnell Foundation for the postdoctoral grant to Leslie Rupert Herrenkohl that made the collaboration described in this article possible.

The views expressed are the sole responsibility of the authors.
An earlier version of this article was presented at the 1998 annual meeting of the American Educational Research Association, San Diego, CA.

REFERENCES

Airasian, P. W., & Walsh, M. E. (1997). Constructivist cautions. *Phi Delta Kappan, February*, 444–449.

Brewer, W. F., & Samarapungavan, A. (1991). Children's theories vs. scientific theories: Differences in reasoning or differences in knowledge? In R. R. Hoffman & D. S. Palermo (Eds.), *Cognition and the symbolic processes* (pp. 209–232). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist, 28*, 235–251.

Cazden, C. (1988). *Classroom discourse: The language of teaching and learning.* Portsmouth, NH: Heinemann.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*, 1–40.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implication for science instruction. *Review of Educational Research, 63*, 1–49.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*, 5–12.

Easley, J. (1990). Stressing dialogic skill. In E. Duckworth, J. Easley, D. Hawkins, & A. Henriques (Eds.), *Science education: A minds-on approach for the elementary years* (pp. 61–95). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Grosslight, L., Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*, 799–822.

Herrenkohl (1998). *Scientific explanation, self-understanding and the role of "others": A case of establishing intersubjectivity in an elementary classroom.* Paper presented at the Fourth Congress of the International Society for Cultural Research and Activity Theory, Aarhus, Denmark.

Herrenkohl, L. R., & Guerra, M. R. (1998). Participant structures, scientific discourse, and student engagement in fourth grade. *Cognition and Instruction, 16*, 433–475.

Herrenkohl, L. R., & Wertsch, J. V. (1999). The use of cultural tools: Mastery and appropriation. In I. Sigel (Ed.), *Development of mental representation: Theories and applications* (pp. 415–435). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Hestenes, D. (1992). Modeling games in the Newtonian world. *American Journal of Physics, 60*, 440–454.

Hogan, K., & Presley, M. (1997). Scaffolding scientific competencies within classroom communities of inquiry. In K. Hogan & M. Pressley (Eds.), *Scaffolding student learning: Instructional approaches and issues.* Cambridge, MA: Brookline Books.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*, 155–178.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*, 319–337.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex.

Lotman, Y. (1988). Text within a text. *Soviet Psychology, 26*, 32–51.

MacWhinney, B., & Snow, C. (1990). The child language data exchange system: An update. *Journal of Child Language, 17*, 457–472.

Munby, H. (1982). *What is scientific thinking?* Toronto: Guidance Centre, University of Toronto.

National Science Education Standards. (1996). Washington, DC: National Academy Press.

Nickerson, R. S. (1991). Modes and models of informal reasoning: A commentary. In J. F. Voss, D. N. Perkins, & J. W. Segal (Eds.), *Informal reasoning and education* (pp. 291–309). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Palincsar, A. S., Anderson, C. W., & David, Y. (1993). Pursuing scientific literacy in the middle grades through collaborative problem solving. *Elementary School Journal,* 543–658.

Penner, D. E., Giles, N. D., Lehrer, R., & Schauble, L. (1997). Building functional models: Designing an elbow. *Journal of Research in Science Teaching, 34,* 125–143.

Phillips, S. (1972). Participant structures and communicative competence: Warm Springs children in community and classroom. In C. B. Cazden, V. P. John, & D. Hymes (Eds.), *Functions of language in the classroom* (pp. 370–394). New York: Teachers College Press.

Reddy, M., Jacobs, P., McCrohon, C., & Herrenkohl, L. R. (in press). *Creating scientific communities in the elementary school.* Portsmouth, NH: Heinemann.

Reif, F., & Larkin, J. H. (1991). Cognition in scientific and everyday domains: Comparison and learning implications. *Journal of Research in Science Teaching, 28,* 733–760.

Rutherford, J., & Ahlgren, A. (1990). *Science for all Americans.* New York: Oxford University Press.

Schauble, L. (1990). Belief revision in children: The role of prior knowledge and strategies for generation evidence. *Journal of Experimental Child Psychology, 49,* 31–57.

Schauble, L., & Glaser, R. (1991). Scientific thinking in children and adults. In D. Kuhn (Ed.), Developmental perspectives in teaching and learning thinking skills. *Contributions to Human Development, 21,* 9–26.

Schauble, L., Klopfer, L. E., & Raghavan, K. (1991). Students' transition from an engineering model to a science model of experimentation. *Journal of Research in Science Teaching, 28,* 859–882.

Schwab, J. (1978). *Science, curriculum, and liberal education.* Chicago: University of Chicago Press.

Smith, C., Snir, J., & Grosslight, L. (1992). Using conceptual models to facilitate conceptual change: The case of weight–density differentiation. *Cognition and Instruction, 9,* 221–283.

Smith, C. L., Grosslight, L., Davis, H., Maclin, D., Unger, C., & Snir, J. (1994). Archimedes and beyond: Helping middle school students to construct and understanding of density and matter. Cambridge, MA: Weight and Density Research Group, Harvard University.

Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching, 28,* 761–784.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. T. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 211–231). Orlando, FL: Academic.

Taton, R. (1957). *Reason and chance in scientific discovery* (A. J. Pomerans, Trans.). London: Hutchinson & Co.

Van Zee, E. H., & Minstrell, J. (1997). Reflective discourse: Developing shared understandings in a physics classroom. *International Journal of Science Education, 19,* 209–228.

Wells, G. (1996). From guessing to predicting: Progressive discourse in the learning and teaching of science. In C. Coll & D. Edwards (Eds.), *Ensen~anza, Aprendizaje y Discurso en el Aula.* Madrid, Spain: Fundacion Infancia y Aprendizaje.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind.* Cambridge, MA: Harvard University Press.

APPENDIX A
Description of Participant Structures

1 Whole Class Time—teacher moderated
   - a Introductions to small group investigations—teachers introduced or reviewed the cognitive tools, roles, and public documentation that the students were using, introduced the problems to be completed, addressed general concerns or questions.
   - b Whole class discussion, reflection, and review—teachers and students took time to reflect on, review, and revise what they had accomplished (for example, "theory chart review," which took place at the end of the first part of the unit.
   - c Benchmark lessons—teachers would introduce new ideas, materials, etc., and allow time for whole class activities and discussions.

2 Whole Class Time—teacher and student moderated
   - a Reporting—student reporters share their group's perspective while student audience members take on roles to help reporters present and discuss their predictions, theories, findings, and the relation among the three.

3 Small Group Investigation Time—students worked in small groups to investigate a specific problem. Students adopted procedural and intellectual roles during this time.

4 Individual reflection and writing time—students were given time to reflect and write in their laboratory notebooks.

APPENDIX B

Student Roles—Small Group Procedural Roles	
Reporter 1	Distribution of lab notebooks
	Monitoring each member's record of the experiment
Reporter 2	Distribution of "scribe materials"
	Monitoring scribes' work on presentation materials
	Gather and bring supporting materials needed for reporting
Scribe 1	Get and maintain group materials
	Monitor appropriate use of materials
	Participate in designing and completing materials for reporters to use during reporting time
Scribe 2	Reads problem card
	Coordinates clean up
	Participate in designing and completing materials for reporters to use during reporting time
Scribe 3	Timekeeper and noise monitor* [Scribe 1]
	Return materials* [Scribe 2]
	Participate in designing and completing materials for reporters to use during reporting time

Note. In cases where there are only four groups members, Scribes 1 and 2 share the jobs usually assigned to Scribe 3.

Student Roles—Audience Roles	
Predicting and Theorizing	Checking group's predictions and theories
Summarizing results	Checking group's summary of results
Relating predictions and theories	Checking group's discussion to results of the relationships among predictions, theories, and results