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A Window into Thinking: Using Student Writing to Understand Knowledge Restructuring and Conceptual Change

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Nancy Jane Fellows

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A WINDOW INTO THINKING: USING STUDENT WRITING TO UNDERSTAND KNOWLEDGE RESTRUCTURING AND CONCEPTUAL CHANGE

VOLUME I

By

Nancy Jane Fellows

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ABSTRACT

A WINDOW INTO THINKING: USING STUDENT WRITING TO UNDERSTAND KNOWLEDGE RESTRUCTURING AND CONCEPTUAL CHANGE

By

Nancy Jane Fellows

Research shows that students have difficulty changing their conceptions of science as a function of instruction. Given the difficulty of conceptual change, it is important to understand the process of learning science concepts by way of instruction.

First, the researcher investigated the usefulness of students' writing to show students' understanding and changes of science concepts over the course of a learning unit. Second, the researcher observed classroom events that occurred in conjunction with students' knowledge changes to discover mechanisms that might have influenced students' conceptual change.

The researcher collected students' writings, conducted clinical interviews about content and writing from six target students, recorded videotapes of classroom lessons and two target small group interactions, conducted teacher interviews, and studied text materials. The researcher investigated the writing of twenty-seven students using semantic node-link networks to trace students' changes in schema during a twelve-week instructional unit. Findings about students' knowledge restructuring, goal conception attainment, and learning strategies were used to analyze two lesson clusters for the mechanisms within classroom events that could be associated with knowledge restructuring.

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Students' writing served as a "window" for observing their thinking as they learned. All students showed some form of knowledge restructuring. Students who demonstrated weaker restructuring were more likely to have had prior experience in the domain or have had difficulty learning the content. Students who demonstrated radical restructuring had added concepts and changed the organization of their schema, but they did not always attain all of the scientific goal conceptions.

Instruction that provided concrete activities, writing tasks, and opportunities for language interactions directly related to students' initial conceptions and the lesson goal conceptions seemed associated with students' more successful conceptual change.

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Stephen Tchudi for sparking it; and for providing the inspiration that lead to my interest in the possibilities for writing and language in the classroom.

Marilyn Wilson for cultivating it; and providing a role model for using writing and language in the classroom.

Michael Burbank for sustaining it; and providing the significant emotional support necessary to complete such a work.

Donna Skolnick for activating it; and providing the stimulus to begin thinking about the possibilities writing has for learning.

John Fershee for financially supporting it; and contributing to the necessary practical considerations for undertaking the learning involved in this work.

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Esther Frederickson, my mother, for modeling how to do it; and showing that I could do anything I set out to do.

and my children, Ann Elizabeth Fershee, John Paul Fershee, and Adrienne Elise Fershee, who believed in me.

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Chapter 1

INTRODUCTION

The Context: Teaching and Learning in Science

Over the last ten to fifteen years, science educators have observed the learning their students accomplish, or do not accomplish, and concluded that many science concepts require difficult thinking changes for students, and even special instructional techniques to assist and guide students in their learning (Anderson & Roth, 1988; Anderson & Smith, 1983; Carey, 1986; Glaser, 1982; Posner, Strike, Hewson, & Gertzog, 1982). Indeed, the thinking changes students need to accomplish in any subject of study may prove difficult and time-consuming for new learners with little prior knowledge. The subject of this study is those difficult knowledge changes that science students must make to learn new science concepts. In this study, I attempted to find out more about learners' initial knowledge states when they encounter new scientific information in the nature of matter and physical change. I attempted to follow learners' transition processes from beginner to more expert thinking in this domain, shed more light on the difficult knowledge restructuring changes students undergo, and identify the instructional techniques that seem most helpful for supporting and guiding students in their learning. To assess students' thinking, the researcher collected students' written work from their lessons. More teachers in science are asking students to write to help students clarify and think about their ideas. Teachers are then using students' writing as a means of understanding students' thinking (Ammon & Ammon, 1987). In this study I observed the relationship between students' writing and their thinking

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their thinking to better understand how students' writing might help teachers "see" students' thinking, and how students' writing might contribute to their knowledge restructuring.

The Problem: Understanding Knowledge Restructuring and the Mechanisms

Much of learning is either the incorporation of new knowledge within prior knowledge, or the modification of prior knowledge to fit with new information (Bransford, 1979; Rumelhart & Norman, 1981). Knowledge is often seen as a structure or schema that individuals build and rebuild, a metaphor for understanding cognitive processes. As individuals learn, they may need to change their existing schema to reinterpret their prior knowledge and account for new information. Carey (1985a), Glaser (1984), and Vosniadou and Brewer (1987) conceptualized ***domain-specific restructuring*** as the developmental changes that occur in knowledge structure when individuals learn new concepts in a subject area. Within a domain, novices and experts differ in their basic knowledge structures and logical thinking. Experts possess a broad repertoire of strategies and schema for recognizing patterns in the domain as a result of their rich background experience with problems (Chi, Glaser, and Rees, 1982; Clement, 1983; Larkin, McDermott, Simon, & Simon, 1981). As individuals shift from novice to expert in some domains, they may need to change their theories, just as changes have been observed in the history of science theories (Kuhn, 1970).

Understanding should be at the core of the science curriculum (Carey, 1985a; Novak, 1981; Posner, et al., 1982; Roth, 1985), and the focus of our research needs to be placed on understanding and assisting students to make the changes to more expert thinking (Glaser, 1982). Learning science requires

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students to read texts, listen to their teachers, perform experiments, and gain understanding by relating this information to what they already know about science. Chi, Glaser and Rees (1982) described the novice to expert shift in science like this: Novices often have alternative conceptions about the elements of the domain, and different organization and relationships between the concepts than do experts. Students in science courses also possess similar alternative conceptions, based on their real-world knowledge, and inadequate strategies for making sense of new science concepts. Much of the literature on the novice-expert shift in science learning documents the difficulty of imparting the understanding necessary for expert-like thinking to students in science (Carey, 1986; Driver & Easley, 1978; Roth, 1989; Smith & Lott, 1983). Recent work observing the novice-expert shift in physics suggested that a process known as knowledge restructuring occurs as individuals learn a new science domain (Larkin, 1983). If science students are novices to the extent that they possess different conceptual frameworks than what is being taught, and lack a consistent conceptual system for understanding the intricate relationships among science concepts, then students must undergo some changes in their knowledge. Thinking and learning in science deserves a closer look to insure that the necessary cognitive changes occur as students attempt to learn.

As learners restructure their knowledge in a domain, they may need to change and add to their conceptual structures because of their insufficient knowledge base or inexperience in the domain. Educators find that some of the restructuring that learners must do is difficult, and that learners often do not make the restructuring changes necessary to learn the concepts they are taught, especially in science (Carey, 1986; Driver & Easley, 1978; Roth, Smith,

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& Anderson, 1983; Smith & Lott, 1983). Novice learners come to science with alternative schema for understanding science, and they resist the difficult knowledge restructuring changes required to learn and understand new information. Sixth grade students in science provide a good example of this phenomenon: When learning about the nature of matter and physical change, sixth grade students show common real-world or alternative conceptions in understanding both at the macroscopic and at the microscopic level (Lee, Eichinger, Anderson, Berkheimer and Blakeslee, 1990). For instance, before learning about the nature of matter and physical change, when students were asked to explain what happens to the air inside a cool bottle when the bottle is heated with warm hands, they said that the "hot air rises" or that the air when warmed moves to the top or the bottom of the bottle. When asked about the molecules in this instance, they will attribute the properties of the air substance to the molecules, such as "molecules expand", or the "molecules get hot and rise to the top".

Even when instruction takes students' alternative schema into account, and improves methods to help students confront their real-world or alternative conceptions and restructure their knowledge, students often retain many original alternative conceptions. Lee, Eichinger, Anderson, Berkheimer and Blakeslee (1990) revised their unit on Matter and Molecules based on students' beginning alternative conceptions to make instruction speak more to students' real-world ideas, and help students revise and use their knowledge to accommodate new more scientific ideas. Students were provided with instruction, experiments, and discussion that helped them explain and discuss that air expands evenly in all directions, and that molecules, when heated, move faster and spread farther apart in all directions, but the molecules

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themselves do not get hot or cold, only their behavior changes. When later students were asked to explain why a balloon placed on a cold bottle inflates when the bottle is warmed, many used some of the new conceptions about "air expanded", or "molecules moved farther apart", but retained their real-world or alternative notions that the "molecules expanded", and "moved to the top" as a result of heating the bottle. Lee and her colleagues were able to improve students' ability to use molecular language in their explanations, but students still seemed to retain about half of their original naive or alterative conceptions about the nature of matter and physical change.

The difficulty with studying knowledge restructuring is our inability to view and describe learners' thinking processes directly. Researchers have attempted to infer descriptions of knowledge structures in science by documenting students' misconceptions (McDermott, 1984; Viennot, 1979), analyzing student's perceived similarities among elements (Chi, Glaser, & Rees, 1982), analyzing students' problem-solving processing (Larkin, McDermott, Simon & Simon, 1980), and analyzing students knowledge using "concept mapping", representing student concepts in graphic form (Carey, 1986; Chi, Glaser, & Rees, 1982). These studies carefully ***described*** knowledge restructuring, but they did not illuminate the possible ***mechanisms*** by which the restructuring occurs.

Although many researchers described knowledge restructuring changes, few attempted to characterize the processes in detail, and explain the ***mechanisms*** that are associated with the changes as knowledge develops. The ***mechanisms*** for knowledge restructuring are the ***events*** individuals experience that ***catalyze*** or ***mediate*** their attempts to understand new information. In other words, for the purposes of this study, ***mechanisms*** that affect studen

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affect students' knowledge restructuring likely occur as a result of some experience that the individual has with the environment that in turn triggers individual thinking change or rearrangement of knowledge structures and ways of thinking about a phenomenon. One example of an experience that could trigger changes in knowledge structure is argument about a concept that demonstrates a new way of looking at a phenomenon, and causes the individual to add this new insight to her understanding. Vosniadou and Brewer (1987), in their review of the recent research on knowledge restructuring, suggested that researchers need more accounts and descriptions of knowledge acquisition processes in a number of specific domains, so teachers and researchers can more fully understand the ***changes*** that occur as knowledge develops, and the ***mechanisms*** that are associated with those changes. Once teachers and researchers are aware of the possible mechanisms that influence knowledge restructuring changes, they can begin building restructuring opportunities into their lessons, and testing the relationship of these events to student learning in more systematic ways.

A Solution: Describing Restructuring Changes and Uncovering the Mechanisms through Student Writing

Given that students have difficulty restructuring their knowledge in some domains, some teachers have their students put their thoughts into writing when they are attempting to learn new subject matter (Lee, Eichinger, Anderson, Berkheimer, and Blakeslee, 1989; Staton, 1982; Staton and Kreeft, 1988). As students write about their science thinking, they record their ideas about new concepts. After recording, students can reflect and explore how the concepts fit with their real-world understandings. Teachers often have students write answers to questions in an attempt to explain science phenomena.

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phenomena. Students often write whatever comes to mind to answer the questions in an expressive form of writing. Expressive writing differs from the writing done most often in science classrooms. Expressive writing is writing for one's self or for a limited audience for the purpose of exploring ideas (Britton, Burgess, Martin, Mcleod, and Rosen, 1975). In typical science classrooms, the writing students do is often in the form of formal essays about their hypotheses, observations, experiments and outcomes (Langer & Applebee, 1987). Expressive writing is more personal and informal than the knowledge-telling writing of essays (Barnes, Britton, & Rosen, 1969). Britton (1970) proposed that when students write expressively as they think, they may engage in the kind of activity that encourages exploration and discovery. Several researchers have reported that writing about thinking improves learning as measured by achievement levels (Ammon & Ammon, 1987; Barnes et al., 1969; Emig, 1977; Langer & Applebee, 1987; Rosaen, 1987).

Asking students to write about and explain their ideas might help teachers "see" students' thinking, and establish whether students are making the conceptual changes we hope they will make as a result of instruction. Staton, Shuy, Kreeft and Reed (1988) showed that student writing provided a vehicle for teachers to follow students' changes in thinking as they moved from topic to topic, and expressed their understanding of concepts. Through their writings about their reasonings, students provided teachers with a window into their thinking processes. One of the purposes of this study was to observe students' writing as they wrote about and explained their new ideas about the science content to see if this kind of writing can provide a window into students' thinking, and show how student writing might help teachers get in touch with how students are making sense of the instruction. Another purpose of the study wa

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The Overview: Knowledge Restructuring in 6th Grade Science

Learners apparently restructure their knowledge when learning new concepts in a domain. These changes can take the form of weak or radical restructuring, depending on the differences between the learner's schema and theories about the domain, and how different they are from the new information they will learn. Few studies of knowledge restructuring have done more than describe changes in thinking. Though my study also attempted to describe such changes, another purpose was to identify possible ***mechanisms*** that might be associated with knowledge structure changes, and that might be visible to teachers and researchers under the constraint of classroom curriculum and activities. On the basis of the above propositions, I undertook this study to investigate the thinking that students exhibit when they write about their science understandings in response to instructional activities. I attempted to answer the following questions:

(a) Do students show in their writing that they are restructuring their science knowledge, and how much restructuring seems to occur for students during a typical lesson unit?

(b) What mechanisms from classroom events seem to be associated with such science knowledge restructuring, and what seems to make the difference for students who restructure their science knowledge, and those students who have difficulty?

In this study the researcher observed sixth grade children's writing to make inferences about their knowledge structures and related changes over a learning unit on the nature of matter and physical change. This study informs

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teachers and researchers about the possible thinking processes students experience as they restructure their thinking and knowledge develops, and provides clues as to the possible mechanisms associated with knowledge restructuring changes that occur within the constraints of classroom curriculum and discourse.

Assumptions. The most critical assumption the researcher made in undertaking this study was that all students in classrooms such as the one observed would be able to learn new concepts. I assumed that the students would participate in the lesson and attempt to learn the best they were able at the time. The students and the teacher were serious about the subject matter, and put their labors into accomplishing the learning that needed to be accomplished. Another assumption was that these sixth grade students would be forthright and honest as they could be when informing me about their ideas of content and their ideas about writing.

Another assumption is that learning is an active process, and that learners actively construct new knowledge from their prior knowledge. Thus, prior knowledge structures are always the basis for the construction of new knowledge structures. Knowledge is organized, and learners may differ in the ways in which their knowledge is organized. Knowledge structuring is a recursive process, non-linear, progressing forward sometimes, and regressing at others. The knowledge structure of individuals will influence their perceptions, understandings and how they remember information. Learners regulate their cognitive processes as they reconstruct new knowledge during learning and problem solving, and those who are able to call on metacognitive knowledge and experiences tend to be more successful with school learning. Learners will perform differently on different tasks depending on their personal needs and th

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needs and the demands of the situation; their different goals will also influence their choice of metacognitive strategies used during learning. Understanding what students are thinking as they actively construct new ideas during instruction might provide insights for teachers about how they can improve classroom instruction.

Another assumption by the researcher is that it is important that students in science learn to understand new concepts to the extent that the concepts become a meaningful and useful part of students' conceptual systems, and not just a list of memorized facts separate from their useful knowledge about science. And one way to accomplish meaningful learning is to teach students about what scientists believe, and how to use those ideas to make meaningful predictions and explanations about real-world events.

A last assumption was that conceptual change learning takes a long time (Nussbaum & Novick, 1982). As Nussbaum and Novick suggested, major conceptual changes occur over a long evolutionary process, with experience over time, even under conditions of good instruction.

Rationale for the study. For this study the researcher observed a middle school science classroom, where students wrote about their understanding of new information, and where the usual constraints encountered in educational settings were operating. Students wrote their ideas about new concepts in an activity book that combined textual information with study questions, and questions about plans and explanations for events. Students also freewrote about their ideas at several points during the lessons. All writing completed by students was collected. The writing ideas were analyzed by constructing semantic node-link networks of students' written statements. The node-link networks showed possible changes in students' thinking and demonstrated what kinds of

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what kinds of changes students might have made in their conceptions about the subject matter. The topics that students identified were charted to observe conceptual structure changes over time. The instructional events, teacher's talk, and students' interactions within their discussion groups and all teacher written feedback in activity books and on quizzes were analyzed for evidence of the relationship of any of these events to students' knowledge restructuring. Students' knowledge restructuring changes observed in their writing was compared to classroom events by charting the restructuring occurrences with classroom events, such as teacher use of metaphor and analogies, or questioning. With this data, I attempted to make grounded inferences about the following occurrences: Given the constraints of a typical classroom, can student writing inform teachers about how much students are thinking and restructuring their knowledge? And, given that thinking changes can be identified in student writing, what classroom events seem to encourage students to change their thinking, and what seems to make the difference for students who have trouble restructuring their knowledge?

Glaser (1982) identified four principles that should frame our research and development of teaching science for understanding. More emphasis needs to be placed on:

(1) Defining the instructional goals and student understandings that reflect the nature of competent performance, i.e. the background knowledge and strategies used by experts in the domain.

(2) Identifying the initial state of learners, and the prior knowledge that might facilitate or interfere with their learning. What do learners need to know about how to learn in the domain?

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(3) Identifying the learning transition processes students pass through on their way to competent performance, and the instruction that facilitates this learning.

(4) Devising diagnostic measures that help us assess students' understandings and identify the structures and strategies that lead to incorrect performance.

This study was designed to explore ways of identifying the processes learners pass through when learning about Matter and Molecules—their initial state, influence of prior knowledge, and learning transition processes that students pass through as they go from novice to more scientific thinking. The analyses in this study provide more information about the kinds of measures that teachers and researchers can use to assess students' understandings, and the structures and strategies that unsuccessful students demonstrate. The student writing analyzed in this study provides further evidence about how classroom writing might serve as a mechanism for students' changes in thinking, as well. As a result of knowing more about students' learning transition processes, their understandings, and the strategies students use to learn about matter and molecules, I expected to find some of the ***mechanisms*** or external experiences within this classroom that might have influenced students' knowledge restructuring, changes in their ways of connecting information and explaining real-world events.

In the following chapters I present a review of the literature relevant to this research project, discuss how I carried out the study, and present the results. In the first part of Chapter 2, I review the literature that helped answer my first question about whether students' writing shows evidence of knowledge restructuring, and to what extent their restructuring occurs. I address researc

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address research that illuminates the kinds of knowledge changes for which I might be looking, and outline what we know about how student writing displays knowledge. I review what has been done with writing to show knowledge changes, and what knowledge changes I expect to find when students study the nature of matter and physical change.

In the second part of Chapter 2, I review the research that shows what mechanisms might be operating in classrooms to influence conceptual change, how to identify the mechanisms within the classroom context, and how to cross-reference such information with students' knowledge restructuring evidence to help me answer the last question about the possible mechanisms that might be associated with knowledge restructuring.

In Chapter 3, I present the methods used to select the subjects, subject matter, and the design of the study. The procedures for data collection are outlined, along with the kinds of data observed, and reliability and validity issues stemming from the methods of analysis. Chapter 4 presents the findings, and in Chapter 5, I discuss the results and interpretations of the answers to the research questions. In Chapter 5, I also discuss qualifications of the results, limitations of the study, and tie the results to further research and practical implications.

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Chapter 2

LITERATURE REVIEW

In the previous chapter, I introduced the concept of knowledge restructuring, and pointed out that many researchers have described knowledge restructuring changes, but few have attempted to explain the mechanisms associated with such changes. Much of the knowledge restructuring that students must do to learn science concepts is difficult, and may not occur at all. Students have difficulty changing their ideas often due to the difficulty of conceptual change learning, and the persistence of their alternative conceptions about how the world works that students possess and that make sense to them. If teachers are to help students make these difficult conceptual changes, they need to understand how to get in touch with students' alternative conceptions. Teachers need information about how to make instruction effective for influencing students to give up their real-world notions about phenomena and begin to take a more scientific view of explaining the world. With more information about how students think about matter and molecules, and what parts of instruction are more difficult, or more effective, teachers can improve their success with students' conceptual change learning. In this study, I plan to use students' writing to better understand learning in matter and molecules, and provide teachers with more information about how they might improve students' success.

In Chapter 1 I proposed that observing student writing about new concepts might inform teachers and researchers about the knowledge restructuring that students are accomplishing, and help us understand the

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possible mechanisms within the instructional events that can be associated with students' conceptual change. In this chapter, I examine the literature about knowledge restructuring and using writing to observe how thinking develops. I review literature that suggested influences of classroom events on knowledge restructuring. This review provided a guide for my observations as I attempted to answer the first research question about whether students' writing shows their science knowledge restructuring, and to what extent this restructuring occurs.

Research on Knowledge Restructuring

What is Knowledge Restructuring?

Knowledge restructuring is a useful metaphor for understanding human beings' ability to accumulate new knowledge. The following section defines knowledge restructuring according to current thinking in the field of cognitive psychology and provides a framework for understanding how knowledge might be organized. The review will provide an outline for understanding the nature of knowledge restructuring, how it likely occurs, and the usefulness of observing writing for evidence of when and how knowledge restructuring occurs. This research review provides a framework for my understanding of knowledge restructuring, and a guide for my observation of the knowledge changes that might be evident in student writing. It helps frame my thinking about what students' writing shows about their knowledge and what other researchers have done to show knowledge changes through writing and verbal expressions. The review shows the knowledge changes I might expect to find as students learn about the nature of physical change.

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Accretion, tuning, and knowledge restructuring

Prior knowledge is important for learning to take place (Bransford, 1979). Thinking of knowledge in the form of schema or structures is a useful metaphor for understanding how individuals acquire new knowledge. When we think of knowledge in the form of schemata or structures, learners likely incorporate prior knowledge structures into new knowledge structures in one of three ways (Rumelhart & Norman, 1981): accretion, tuning, and restructuring. ***Accretion*** occurs when learners fit new information into existing schema. ***Tuning*** involves evolutionary changes in thinking over time to continually interpret, generalize, and improve the accuracy of schema fit to externally perceived data. Both accretion and tuning are similar to Piaget's (1950) ***assimilation,*** where new knowledge seems to "fit" with existing knowledge structures and becomes added to existing structures. Tuning involves refining and defining existing structures for more efficient use. ***Knowledge restructuring***, similar to Piaget's ***accommodation,*** involves changes the individuals must make in their existing schema to reinterpret prior knowledge information or account for new information that does not seem to "fit" with existing knowledge structures.

Concepts, principles, and theories

Restructuring of knowledge, concept changes, principles and strategies, schema or schemata, conceptual systems, and theories are terms I use throughout this report. In the following section, I define concepts, principles, and theories as I intend their meanings for this study.

Concepts and principles. A learner responds to information by either putting that information into a class and responding to any instance of the

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class as a member of that class, or by distinguishing that the information is not part of that class, but part of another. This thinking and responding to things or events as part of a class is known as ***concept learning*** (Gagne, 1985). For instance, learning the concept "house" entails that a learner understand that a member of the class "house" is an instance when the information fits not any particular instance of house alone, but refers to a category in which all houses fit. For this study, one concept the students will be learning is the idea of ***matter***, and they will be attempting to discern all instances of new information that fit into the category "matter".

Students' concepts are those categories into which they place all instances that fit criteria of the category, but students' conceptions are a different way of describing their thinking. Students' conceptions and conceptual systems are the ways they link various concepts together. I make this distinction between students' concepts, and their conceptions or principles, to which I refer when discussing students' conceptual understandings. Conceptions and principles are relationships that learners' understand ***between*** concepts. These principles might relate to how the learner sees two concepts ***influence*** one another, or how one might ***cause*** the other, and whether one concept ***always*** has a causal effect or ***sometimes*** has a causal effect. Learners' conceptions and principles can be purely conjecture, or they may have evidence for truthfulness (Reigeluth, 1983). Concepts relate to principles in the following way: Learners' concepts are their ***categories of phenomena***, whereas their conceptions and principles are the ***relationships*** they understand between two or more concepts, usually showing how one effects the other.

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Conceptual systems and changes. When learners' classes of information and their classification criteria change, they have made ***concept changes***. Concept changes can entail numbers of ideas involved in the concept, as well as the core ideas that support the concept. Problem solving strategies are ways that learners ***act upon*** their concepts, and know ***how to do*** something. Such strategies are also known as ***procedural knowledge*** (Gagne), as opposed to the ***verbal or declarative knowledge*** of their conceptual systems. Declarative knowledge, or knowing ***what***, makes up the object structures of a conception, whereas procedural knowledge, knowing ***how***, activates structures that produce action and conditions of applicability (Rumelhart, 1981). Schema (plural of schemata) are knowledge structures made up of one to many concepts, or classifications of facts, events, and ideas. I will use knowledge structure and schemata interchangeably throughout this work. It is the learners' schema about their science conceptions that I will attempt to observe through their writing. Conceptual systems are similar to schema systems. They are learners' systems of classes into which they have put their knowledge of facts and procedures--the concepts, linked by meaningful networks. An individual's theories are the core ideas by which they explain phenomena in their understanding of class and relationship--their way of accounting for their classifications, explaining events and underlying principles for relating their concepts. When I describe a students' semantic node-link network ***core concepts***, I refer to the individual's core ideas within their schema system. I identify these ***core concepts*** or core ideas by the number of links that connect the concepts to other concepts in the network, how central the concepts are to the network, and whether the concepts make up the theories or principles by which the individual attaches other concep

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other concepts to the structure. I explain *core concepts* further when I explain semantic node-link network construction in Chapter 3.

Global and domain-specific restructuring.

Restructuring has been conceptualized in two categories, either *global* or *domain-specific restructuring* (Vosniadou and Brewer, 1987). Global restructuring is a new way of thinking about the world, as children do when they begin to think differently during the characteristic developmental changes during *stage* attainment, as described by Piaget. When a child is able to decenter and consider more than one salient aspect of a problem, she has attained a more concrete operational stage. Such developmental change is a more global restructuring change and may involve thinking in many domains. Carey (1985a) described domain-specific restructuring as increasing knowledge of a domain that causes children to restructure their real-world or alternative concepts into new theories, and develop more sophisticated logical capabilities within the domain. The important aspect of domain-specific restructuring is its occurrence as a result of students' experiences and instruction, rather than as a result of biological maturation. Researchers in science education support the idea of a domain-specific approach to understanding how children develop from concrete to more logical thinking, as well (Driver and Easley, 1978; Novak, 1977; and Posner, Strike, Hewson, & Gertzog, 1982). The research on differences in novice and expert thinking in a domain also supports domain-specific restructuring development. For example, the work done in physics by Chi, Glaser, and Rees (1982), Clement (1983), and Larkin, McDermott, Simon, and Simon (1981) showed that novices and experts differ in their basic knowledge structures in the domain of physics.

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The logical thinking of experts within the domain seemed to arise from their rich background in encountering problems in the domain, their acquisition of a broad repertoire of strategies and schema for recognizing patterns in problems, and their possession of more explicit procedural knowledge.

Weak and Radical Restructuring

There have been two forms of knowledge restructuring described in the literature, ***weak restructuring*** and ***radical restructuring*** (Vosniadou and Brewer, 1987). Weak restructuring involves restructuring fewer numbers of more closely related concepts, than the extreme difference of concepts and numbers of concepts involved in cases of more radical restructuring. Weak restructuring occurs when the student learns a smaller amount of knowledge, and usually when the individual possesses more experience in the domain. Weak restructuring has been described by Chi, Feltovich, and Glaser (1981), Chi and others (1982), and Larkin (1979, 1981) in novice/expert shifts, and by Voss (1983) in the changes involved in developing expertise in social sciences. Chi, Glaser, & Rees (1982) described weaker types of restructuring in their study that showed as students learned new problem solving strategies, they demonstrated new relations among their concepts. They were able to show that new schemata arose for students as they learned solutions to new problems and changed solutions to old problems. The core concepts that students used to solve the problems, however, remained similar, thus describing a weak form of restructuring similar to what Rumelhart and Norman would call ***accretion*** and ***tuning*** (1981). In Figure 2.1 I have organized the concepts of weak and radical restructuring, and the kinds of thinking that seem related to both. Weak and radical restructuring are at opposite ends of a continuum of

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continuum of the amount of change in schema that learners must do to accumulate new understanding. I categorized the descriptions into two discrete categories to aid the reader's understanding of the differences between the two types of restructuring described in the literature, even though restructuring changes may occur anywhere along a continuum from mere

Weak Restructuring	Radical Restructuring
Accretion, Tuning Elaboration	Conceptual change
Concepts closely related and may be inaccurate	Conceptual system contains greater numbers of concepts
Addition of new strategies and new relations	Different relations among concepts-accounts for new domains
Addition of more procedural knowledge	Knowledge is related to principles and procedures
Reorganization of domain knowledge	May involve new theories
Core concepts are the same	Changes to core concepts, different and more varied
Learner may possess more experience in the domain	May be more difficult to accomplish

Figure 2.1 Differences between Weak and Radical Restructuring.

accretion of new knowledge to total restructuring in accordance with new theories.

Radical Knowledge Restructuring as Conceptual Change

Radical restructuring in a domain takes place for novices who lack sufficient knowledge base and procedural skill, compared to experts. Radical restructuring is similar to weaker restructuring as described above in Figure 2.1, but changes are added to the individual's core concepts requiring a

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structurally different conceptual system with different and varied core concepts, and the presence of *conceptual change*. Conceptual change is a restructuring of knowledge that represents different relations among concepts, and different patterns, new relations among schemata (Carey, 1985b). In the sense that both radical restructuring and conceptual change are defined as change in an individual's core concepts and conceptual structure, for the purposes of this study, I consider radical restructuring to be synonymous with conceptual change, and interchangeable with it. Radical restructuring shifts in an extreme manner, much like the revolutionary paradigm shifts described by Kuhn (1970). Novice thinking, as opposed to expert thinking, involves different and deficient concepts, and deficient or inaccurate schema for understanding and explaining the domain. The novice to expert shift in some domains may require individuals to change their theories (radical restructuring and conceptual change), just as changes have been observed in the history of science theories (Kuhn), or the shift may merely entail merely the addition of more procedural knowledge and reorganization of the domain knowledge (weak restructuring). The distinction between weak and radical forms of restructuring is a useful and important because it helps us understand the difficulty of conceptual change learning. For conceptual change to occur, students often must radically restructure their knowledge, adding new core concepts, and new domains within the structure. They must often find new principles or theories by which to explain phenomena, and reorganize their conceptual systems to account for all of the new concepts they add. All of this adding and reorganizing must be more difficult than just adding new information to an already existing structure. For instance, if an individual remodeled his house to add new cupboards and closets within the existing structure of t

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structure of the house, he would need to do some juggling of contents, but the room organization would stay the same, and direct where he put the new contents after the remodeling was finished. If, however, the individual remodeled his house and added a second floor, new rooms, another kitchen, and several bathrooms, the task of reorganizing the contents of the house with the new structures would be much more demanding, difficult, and take longer to accomplish, especially if the individual intended to retrieve his belongings in the future to use them efficiently. These reorganization demands may be similar to knowledge restructuring demands. And if that is the case, students who are attempting radical restructuring of their knowledge and conceptual change may need more assistance accomplishing the organization and "making sense" of putting things in their proper places for meaningful retrieval and use.

Summary

Researchers have described two general types of knowledge restructuring in the literature, global and domain-specific. Global restructuring occurs in more than one domain and may result from maturation and general experience, whereas domain-specific restructuring occurs in a single subject domain and results from individuals' experiences and instruction within the domain. Researchers have described both weak and radical forms of restructuring, based on the numbers of concepts, degree of organization, and relationships within the structure. Radical changes in core concepts, theories and principles that drive the organization of the structure are evidence of a radical form of restructuring, which is also known as conceptual change.

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Why is Conceptual Change Learning So Difficult?

Educators have found that students do not learn the concepts that they are taught in science (Carey, 1986; Driver & Easley, 1978; Roth, Smith, & Anderson, 1983; Smith & Lott, 1983). Driver and Easley (1978) found that children come into science classrooms with alternative cognitive frameworks that have been built from their experiences in the real world, and their imaginative attempts to understand events. These alternative frameworks are not the same as the confused connections that students make during learning a new concept, but exist prior to students' encounters with new information. Gunstone, Champagne, and Klopfer (1981) found that even following prediction-observation-explanation tasks with experiments and group discussions, students continued to retain alternative frameworks and real-world or alternative notions along with their new concepts. Only twenty per cent of the students in five different fifth-grade classrooms understood the key concepts about photosynthesis following a five-week instruction period (Anderson & Smith, 1983). Roth, Anderson, and Smith (1986) found similar results in nine other fifth-grade classrooms where students were studying about light and seeing. These researchers found that humans seem to have a strong capacity for storing conflicting ideas about phenomena. The learning that these science students needed to accomplish may have been much like the individual who radically remodeled his house. Students may have had to change their core concepts, add new ideas, and use new principles to explain phenomena. Even though the students may have added new facts to their knowledge structures, they may not have effectively reorganized and improved their scientific explanations of the phenomena. Indeed, learning that requires students to c

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students to change their core concepts about phenomena appears to be a difficult kind of learning to accomplish.

West and Pines (1985) distinguish more radical restructuring (conceptual change) from weak restructuring, by its difficulty for the learner:

> *Conceptual change involves abandoning one's commitment to one set of conceptual understandings by adopting another irreconcilable set. This abandonment is not always a component in conceptual learning, but when it is, it is a difficult and painful process which requires both a commitment on the part of the learner and special instructional techniques.* (p. 7)

Novice learners in science may have alternative schema for understanding science that prevents them from making new information part of their knowledge structures. Their learning processes are worth examining to better understand the relationship between novice to expert knowledge restructuring shifts (Vosniadou & Brewer, 1987) and conceptual change to more scientific thinking (Posner, Strike, Hewson, & Gertzog, 1982).

The question now becomes, if teachers are interested in assisting students with these difficult conceptual shifts, how can they document such knowledge restructuring or conceptual changes in students' thinking? Writing about thinking as students do in classroom writing episodes might provide such a record of student thinking changes over time. Later in this chapter, under the heading Research on Mechanisms Influencing Knowledge Restructuring, I describe the instructional changes that might support students' conceptual change learning. As far as students' conceptual change in matter and molecules is concerned, in the following section, I present the evidence for kinds of knowledge students display before learning, and the changes they make as a result of instruction in matter and molecules.

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The dynamics of conceptual change in Matter and Molecules. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990) studied the conceptual frameworks that sixth graders use to explain the nature of matter and physical change by administering clinical interviews and paper-and-pencil tests to students in 15 sixth grade science classes taught by 12 teachers over a two year period. They observed the students' conceptions both before and after a learning unit in Matter and Molecules, to assess the effectiveness of two alternate instructional units in helping students' change their initial conceptions. The classrooms were heterogeneous with regard to ethnicity, and primarily of lower SES background. For these sixth graders, Lee and her colleagues identified five general categories of common real-world or alternative conceptions in understanding the nature of matter and physical change, both at the macroscopic and microscopic level. They found that prior to instruction, most students had alternative conceptions at the macroscopic level and "did little more than guess" at the microscopic level (p. 15). The overall percentage of students who demonstrated adequate understanding of scientific conceptions on paper-and-pencil pre-tests was 3.8% in both the first and second years. Students demonstrated understanding by their "conception score" (p. 11) coded according to their responses on the tests that demonstrated either understanding of the scientific goal conception, ambivalence, or commitment to a real-world or alternative conception (see Table 2.1 for a detailed description of student conceptions in each category). After the first year of instruction, students showed ability to use molecular language in their discussions, but still retained many of the same alternative conceptions they had prior to instruction, and showed understanding of 26% of the scientific goal conceptions. Following a revised unit during the second

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2. States of Matter
3. Thermal Expansion

TABLE 2.1

Students' Real-world or Alternative Conceptions about Kinetic Molecular Theory				
	MACROSCOPIC		MICROSCOPIC	
1. Nature of Matter	Scientific: Solids, liquids, and gases are matter and take up space; other things (e.g. heat, light) are not matter and do not take up space. Matter is conserved in all physical changes.	Real-world or alternative: Classification is based on irrelevant properties, incorrectly classified. Transformations conserve substances but not necessarily mass; disappear and cease to exist.	Scientific: All matter is made of submicroscopic particles or invisible molecules, constantly moving, nothing but empty space between.	Real-world or alternative: No molecular motion initially. In learning about molecules, non-matter is described as molecular, molecules are in substances, comparable in size to dust specks, cells, germs, may be still or move by external forces.
2. States of Matter	Scientific: Gases can be compressed, and spread evenly through the spaces they occupy.	Real-world or alternative: Gases move from one place to another when compressed or expanded, and are unevenly distributed.	Scientific: Three states of matter are differentiated based on arrangement and motion of molecules; motion continues independently of observable movement.	Real-world or alternative: States of matter are differentiated based on observable properties only; attributed to the molecules themselves; molecules share in observable properties.
3. Thermal Expansion	Scientific: Substances expand when heated.	Real-world or alternative: Substances "shrivel up" when heated; expansion of gases explained in terms of movement of air.	Scientific: When a substance is heated, molecules move faster and farther apart.	Real-world or alternative: Molecules themselves are changed by heating; no relationship between molecules moving faster or farther apart.

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	MACROSCOPIC		MICROSCOPIC	
4. Dissolving	Scientific: The solute changes from a visible to an invisible form during dissolving.	Real-world or alternative: The solute "disappears", "melts", or "evaporates".	Scientific: Molecules of solute break away and mix with molecules of solvent.	Real-world or alternative: No molecular motion initially. Focus on observable substances, or molecules themselves "dissolve".
5. Changes in states of matter.	Scientific: Air contains invisible water vapor; water vapor in air condenses on cold objects.	Real-world or alternative: No recognition of water vapor in air, or liquid water changes into air; condensation is a reaction between heat and coldness.	Scientific: Heating and cooling make molecules move faster or slower, causing changes of state in terms of arrangements and motion.	Real-world or alternative: Heating and cooling make molecules themselves change; molecules share in observable properties of substances.

year, students demonstrated about 50% understanding, and again, retained many original alternative conceptions. I expected to find similar real-world or alternative conceptions about the nature of matter and physical change before instruction in this study. The Matter and Molecules unit that was used in this study was a revised version of that used by Lee and her colleagues. Thus, following instruction, I expected to observe changes in conceptions from real-world or alternative to more scientifically oriented similar to the ones Lee and her colleagues reported. Lee and her colleagues were more concerned with measuring whether students, on the average, gained more understanding of scientific principles. They did not report what occurred for individual students as each attempted to learn the concepts and restructure thinking. With the present study, I attempted to provide a clearer picture of the knowledge changes tha

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changes that occurred for individual students, and provide information about how some students begin to abandon their real-world or alternative conceptions and think more scientifically as a result of instructional events.

Summary

Conceptual change requires students to accomplish a more radical form of knowledge restructuring to change their core concepts, and the principles by which they explain events. Students must, at times, also change their theories about how the world works. For this reason, students often find it difficult to radically rebuild their conceptual schema to make it useful. In fact, researchers have found that even with special instruction, students do not complete the necessary thinking changes they need to make from their real-world conceptions to more scientific ways of thinking.

How Can Writing Show Knowledge Restructuring?

According to Langer and Applebee (1987), the act of writing facilitates the logical and linear presentation of ideas. The permanence of the writing then permits reflection on what has been written, and changes the development and shape of the ideas. In her review of writing in the content areas, Rosaen (1989) stated that researchers have found that the form of writing children chose shaped the details and information that the children paid attention to, and thus, influenced what they remembered. When students paid attention to text, and made notes on the text, they remembered facts from the text. When students wrote in more depth about their ideas related to the text, they remembered the ideas they wrote about, but did not remember as many factual details from the text.

Langer and Applebee (1987) observed six high school juniors as they approached writing about text and the effects that their writing had on their

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learning. The tasks students performed were common study tasks, completing short-answer study questions, taking notes, and writing essays. Each student met with the researchers individually for two sessions a week apart. Langer and Applebee used think aloud protocols while students completed writing activities. They found that extended writing activity presented their student subjects with opportunities to think about the information and to think about how to integrate the information into more organized units of knowledge in their writing. They also found that different writing study activities involved students in different patterns of thinking and lead to different kinds of learning. When students responded to study questions in writing, students tended to read the question and locate the information in the text. Students spent less than 15% of their time writing or thinking about ideas while doing this task. During notetaking activities, in contrast, students focused most on the content of the text passages, and spent 33% of their time reading the text, and 66% of their time writing or thinking about content. During essay writing activities, students read the text, seemed to consider the reading in the context of their question, brainstormed ideas, and constructed an interpretation and response. In essay writing activities, students gave more attention to generating, integrating, and evaluation their ideas in relation to the text. Students thought about more ideas, and spent more time reasoning, during essay writing. Langer and Applebee reported that students' topic knowledge increased most for essay writing, next for note-taking, and least for study question writing.

Langer and Applebee (1987) concluded that analytic writing tasks lead to more thoughtful focus on a smaller amount of information and is longer lived than summary and question-answering writing tasks.

In Langer and Applebee's study, the most successful use of writing for learning occurred when the students and teacher shared an understanding of the goa

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the goals of the activity and shared an understanding that the activity required collaborative interaction. It was important for this research that I find out if students and teacher shared understanding of the goals of students' writing activities, and shared the idea that the writing requires collaborative interaction with the teacher.

Langer and Applebee summarized their impressions from their research when they say they found

> *. . . clear evidence that activities involving writing lead to better learning than activities involving reading and studying only. Writing assists learning. Beyond that, we learned that writing is not writing is not writing; different kinds of writing activities lead students to focus on different kinds of information, to think about that information in different ways, and in turn to take quantitatively and qualitatively different kinds of knowledge away from their writing experiences.* (p. 135)

The writing that students did in the present study was answering of workbook questions about matter and molecules, which was similar to Langer and Applebee's study question writing, but relied more on students' ideas about content than on their repeating words from text. Students also answered questions to explain events and freewrote about their explanations and ideas, which was similar to Langer and Applebee's essay writing, but more informal. For instance, during the first lesson about pure substances and mixtures, students were asked to respond to the following in their activity booklets after attempting to separate various mixtures:

(1) How did you try to separate the mixture?

(2) How successful were you?

(3) What have you learned about pure substances and mixtures?

(4) Explain a pure substance. Explain a mixture.

(Anderson, Eichinger, Berkheimer, & Blakeslee, 1990).

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Here students were asked to think about what happened and what it means. They were writing their ideas about what they did, what it means, what they are thinking and why. They were expected to attempt explanations of their ideas. Students were led by the questions to focus on what happened when they attempted to separate a mixture, and how that related to the difference between pure substances and mixtures. In the same lesson students were asked to freewrite their ideas about how they might distinguish pure water and a mixture with water. This writing and some activity booklet writing to explain and make plans was like the short essay writing in Langer and Applebee's study, while some of the activity booklet writing to answer questions was similar the study question conditions that Langer and Applebee (1987) observed. Consequently, students' writing might have displayed their thinking about the meaning they made from the activity, and how it fit with their prior knowledge about pure substances and mixtures. Their writing activity focused their thinking on their ideas about how to tell a pure substance from a mixture, and how these concepts relate to one another. I believed this writing might provide a window into understanding how students connected the concepts of pure substances and mixtures.

Writing knowledge and content knowledge: Complex interactants

Langer and Applebee (1987) found that writing and learning activities are not all the same: Different kinds of writing activities influence students to focus on, and thus remember, different aspects of content. Rosaen (1989) noted that not only do different writing tasks lead to different kinds of learning, but teachers may encounter difficulties when they attempt to use writing to foster their students' knowledge development, since there is a complex interaction between students' knowledge about writing and their knowledge about content. Writing to learn engages students in cognitive activity that promotes students' use of higher order thinking as they learn subject matter, but students may need instruction in how to write to foster their own learning. Teachers need to assure that they provide opportunities for students to *develop* knowledge and skill not only in the subject matter content, but teachers need to help students develop their knowledge and skill with writing, and how to manage the writing process--to go beyond mere knowledge telling in their writing (Rosaen, 1989).

Writing can enhance learning and provide teachers with a means of engaging students' minds with the subject matter. At the same time, the kinds of writing that students are asked to do will influence what they learn (Langer & Applebee, 1987) and influence the difficulty of their writing-to-learn task (Rosaen, 1989). For this study, it was important that I ensure that the kinds of writing that students were asked to do would foster the kinds of thinking I wanted to observe. The questions I presented in the last section from Anderson, Eichinger, Berkheimer, and Blakeslee's (1990) Matter and Molecules Activity Book and the freewriting exercises the students did, seemed to foster the kinds of student thinking that I wanted to observe. For instance, when students explained the differences between pure and mixtures, they wrote their ideas about how their conceptions of pure and mixtures fit together and were the same or different from one another and how they might be related. I wanted to observe the way students put these conceptions together when they tried to explain in writing. It was also important that students were familiar with the writing task, and did not view the writing as difficult. Once students have some control over a writing task, what can their writing tell us about their content knowledge?

How student writing displays content knowledge. Not only will students' knowledge of content and writing influence their ability to use writing-to-learn activities effectively, the particular forms of their content understanding are likely to influence both what they say and how they say it (Ammon & Ammon, 1987). In a study observing the effects of content difficulty on how students from sixth to tenth grade performed various writing tasks, Ammon and Ammon interviewed students prior to their experiments using semi-structured questions and follow-up probes to assess students' content understandings. They asked students to describe and explain in writing what happened in their experiments. They then asked students a series of debriefing questions after students completed the writing task. Each student was asked to write about two different content areas (displacement and buoyancy) using two different writing forms for both. The two writing forms students used varied in complexity: The two tasks consisted of a description task (expected to be an easier writing task) and an interpretation task, which was expected to be more difficult. The interpretation task asked students to describe and explain a single puzzling event that occurred during the experiment, write a summary of the observations, and interpret their observations.

Ammon and Ammon's preliminary findings were that students' limited scientific understanding could inhibit the writing that students were able to do. When students had fuzzy understandings about content or difficuly understanding the content, they were unable to write clearly about the ideas. When the content was difficult for students to understand, they had difficulty writing about their reasoning in proper form, because they skipped steps they did not understand, or they did not see the importance of reporting some steps.

Also, students may need to be familiar with the discourse form they are to use: A difficult discourse form could interfere with students' idea production. When students were familiar with the discourse form some learned to write more clearly about their ideas even when they were still at a lower level of scientific reasoning. Learning the discourse form may have helped some students achieve new understandings while they wrote about their experiments. For instance, when students were comfortable with the writing task, they wrote about ideas, and sometimes got a clearer understanding of what they knew as a result of the writing. Ammon and Ammon found that when students had a better command of the concepts, they tended to focus more on explanations in their writing. When they were unsure, they tended to focus more on background description.

Ammon and Ammon found that students' writing about a problem showed their trying out of various ideas and their uncertainties. They found that interactions between content understanding and written form are complex---content generation involves interaction of the students' cognitive abilities with the difficulty of the topic and the demands of the writing task. Thus, difficult conceptual content can have a negative effect on student writing; specific aspects of content that students find problematical can affect their writing performance, and their interpretation of the writing task. Ammon and Ammon suggested that teachers assess the content difficulty from the student's point of view before assessing knowledge from their writing. They found that

> *. . . students who have arrived at a new level of content understanding during an experiment, and are satisfied with it, appear to write with more clarity, and seem more likely to assume appropriate focus in their expository writing. . . new content understandings can be achieved in the process of writing itself, If the student is ready with appropriate content understanding and writing skills* [when they have previously

grappled with conflicting ideas and find the writing form easy to accomplish]. (p. 8)

Chi, Glaser, and Rees (1982) supported Ammon and Ammon's findings with their study asking students to summarize a chapter of a physics text. They asked four experts and five novices to review the chapter for 5 minutes and then summarize out loud the important concepts. The book was available during the summarizing, so that the differences could not be attributed to differences in retrieval ability. There was no difference in the length of the summaries, or in the number of relationships the subjects made. There was a difference, however, in the complexity and completeness of experts' statements compared to the novices' statements. The experts' statements were more complete about the physical laws, and contained on the average three subcomponents, whereas novices mentioned an average of two subcomponents. Even though Chi, Glaser, and Rees used verbal rather than written reports in their study, it appears that the expressions that learners use to describe their ideas provide some understanding of their conceptual structures. If Ammon and Ammon are correct about writing as a window to thinking, Chi, Glaser, and Rees might have gained similar results if their subjects had written about their ideas rather than stating them verbally. This seems especially so if their subjects were familiar with the writing form. In this study, I compared the written and verbal explanations of six target students to see how closely students' written expressions matched their verbal descriptions of the same concepts, to provide evidence that such similarity is likely.

Though the interactions between content knowledge and knowledge of writing form are complex, research findings indicated that student writing can show their experimentation with new ideas and uncertainties about content. Ammon and Ammon were able to discover students' unresolved problems in understanding in their writing. They found that students who had previously displayed understanding in their interview, but could not communicate an understanding in their writing, had problems with the concepts that they had not settled.

> *. . . knowing about a student's thinking about a problem, and about the aspect of the content he or she is struggling with, provides another window through which a teacher can view and understand why students write the way they do.* (p. 8)

In the present study I looked at student writing to gain insight into student understandings. I needed to keep in mind that the difficulty of the content, and difficulty of the writing task, could confound my efforts to get at what students were thinking. For the purpose of this research, it was necessary that students were familiar with the writing discourse form they were to use to lessen the likelihood that the act of writing interfered with their ability to express their ideas about content. The writing that students did was in response to questions in their activity books and freewriting about the concepts. I expected the writing students did in response to activity book questions to be more difficult, because students might attempt to write in more scientific genre and write what they think might be the "right answers": Students knew the teacher would be grading their responses in their activity books. In their freewriting activities, students were instructed to write freely about their ideas in their own language. The teacher was to make it clear that there were no right or wrong answers during the freewriting, nor would the freewriting effect their grade. The freewriting activity was a chance for students to put their ideas on paper in their own words without penalty. I expected the freewriting activities to be an easier form of writing for the students. By having both forms of student writing available, the subtle differences between the knowledge displayed in more difficult writing tasks and the knowledge displayed in easier writing tasks might show through. I also wanted to find out how easily students expressed their ideas about content in both forms of writing. Once students were familiar and comfortable with the writing tasks, what they wrote about the content could provide me with clues about their content knowledge. If a student wrote mainly descriptions of what he did and saw, he may be unsure about his understanding of the content; if a student wrote more explanations about what he saw, he may have better command of content understanding. Or he may be better able to use writing to express his thinking.

Summary

The kind of writing activity students do involving content tends to focus their attention on that information. Also, the difficulty of the content can interfere with students' ability to use their writing fruitfully to focus on information. And if the writing task itself is difficult, the task further confounds students' abilities to focus attention on their ideas about content. But when students have some facility with the writing task, their writing provides another means of learning content and opportunity for students to explore their ideas. Most important for this research, students' writing offers an opportunity to look at students' understanding and problems with understanding—their new ideas and uncertainties.

Students' writing can provide a record of students' thinking development as a result of dialogue, and has been documented in written dialogic student-teacher journals by Staton (1982, 1988). I review Staton's findings in the next section.

Research on Students' Thinking Development as Evidenced in Students' Writing

Staton (1982) and Staton and Kreeft (1988) reported the results of a study in which Staton analyzed written dialogue journal interactions to show how a student grew in concept understanding in a specific domain, math. Staton followed one eighth grade student's interactions with his teacher, and traced the student's talk throughout one year. Staton analyzed the student's dialogue with the teacher as he talked about, and elaborated on his ideas about math. She found evidence that, over the period of the year, the teacher-guided interactions lead the student to develop an understanding of general principles about how to learn, and what constitutes learning in math.

Staton's methods for the longitudinal case study included a first holistic reading and describing of topics the student discussed in the journal, then an intensive analysis of the student's talk to the teacher, the dialogic interactions between the teacher and the student, and the changes in the student's reasoning as response to teacher questions and initiations. To understand each writer's intentions and meanings, she analyzed the student's, teacher's, and student-teacher's dialogue by approaching each as an extended set of symbolic statements.

Staton provided evidence that students' writing can show their knowledge restructuring as they come to a new understanding. At the beginning of the year, the student made nonspecific comments about math that lacked any explicit reference to anything concrete or real, and offered no new information, statements such as "I enjoyed math today. But its not like I didn't learn anything" (1988, p. 262). As the year progressed, the student's thinking showed a marked shift toward developing more specificity in describing his actions, identifications of math learning, and identifications of his feelings. By the end of the year, the student was specific about math concepts, and showed ability to classify, and compare experiences from one day to the next, for instance "Math was pretty good for me today. I like the Confucious Say puzzle. But both of them were fun. I like it when we do puzzles like that in math class. Its working, but having fun at the same time. I am glad that I was kinda good in math today. It really makes me happy." (1988, p. 273). Staton reasoned that the student had developed a better understanding or knowledge of the concepts because he was able to combine specific accounts of his *experiences* (I like it when we do puzzles like that in math class) with some explicit formulation of their *meaning* with regard to *cause* or *general principle* (Its working, but having fun at the same time). Though this change in the student's dialogue may seem inconsequential in this small evidence, it showed Staton that though the student had consistently talked to the teacher about "moving up in math", he had not connected that moving up in ability required hard work. After several teacher written explanations that moving up in math required hard work, the student eventually began to internalize the principle that working hard in math was what made math fun, and he began to talk about the meaning he made from learning this principle in his journal writings.

The importance of Staton's work for this study is its demonstration that writing can provide teachers with a picture of students' thoughts about content. Staton was able to show a change in student thinking by observing his writing over time. In the present study, students wrote about their thinking to the teacher to demonstrate their understanding of the science lesson in their activity book worksheets and freewriting activities. By observing students' activity book- and free-writing throughout the learning unit, I attempted to observe changes in student thinking just as did Staton.

Summary

At least one researcher has documented the careful analysis of a student's writing to show a student's changes in thinking over time, thus demonstrating that students' writing as they attempt to understand science content might very well provide information about similar thinking changes. Staton's methods of holistic readings, then intensive analysis of dialogic interactions and changes in reasoning responses in the student's writing informs this study for methods of following students writing over time.

How Might I Analyze Student Writing to Find Knowledge Restructuring?

Identifying topics. The work of Staton (1982), and Staton, Shuy, Peyton and Reed (1988), provided methods of identifying how the student identifies and elaborates on a topic. Figure 2.2 shows a one day chart used by Staton and her colleagues (1988) to track student topic discussion across time, and on any given day. The charts I used were similar, but showed explanations about matter and molecules over time from just one student. My

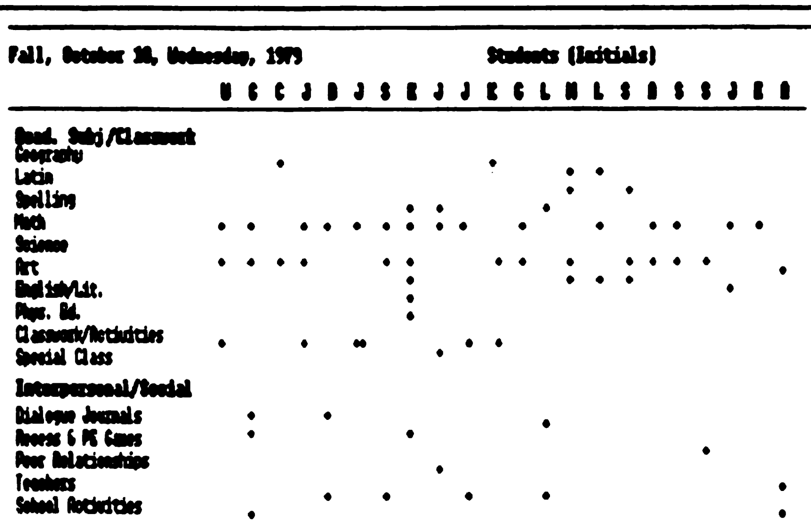

Figure 2.2 Student topics across the class on any given day. (from Staton, Shuy, Peyton, & Reed, 1988, p. 250)

charts provided a schematic map of the conceptual thinking patterns occurring for a student across each unit, and was intended to inform my understanding of the movements of the matter and molecules conceptions as a student displayed her thinking over time, just as Staton observed students' discussions across time (see Figure 2.3).

Student: Ima CONCEPTIONS ABOUT DISSOLVING

Pretest	Dissolving SB	Explanations	Posttest
sugar dissolves into the water and becomes part of it; dissolves faster in hot water; because hot might melt it	put the teabag in water and dissolve the sugar out of the bag; sugar is too big for the holes; sugar will dissolve and maybe become a mixture with the water; the molecules will become a little farther apart in the sugar; sugar is becoming a different form and the water is mixing with the sugar to become a mixture;	sugar cube dissolved very quickly after we stirred, because the water molecules were moving so quickly and the water molecules hit and bumped the sugar cube to break it down; when the sugar was broken down, it became sugar molecules; mixed together and became a mixture;	molecules hit against the sugar to break it down; when the water (H_2O) molecules have broken it down, the sugar dissolves and forms a mixture with the water; sugar dissolves faster in hot water; the hot water makes the molecules move faster and farther apart, so they will break the sugar down faster and it will dissolve a lot quicker.

Figure 2.3 Chart for concepts one student identified in her writing about dissolving.

The charts helped identify the concepts from the Matter and Molecules unit that a student discussed according to the text/activity booklet questions, activities, and freewriting topics on which the teacher and curriculum materials focused, and students' concept development across time. These charts provided a record of the number and the time that the student, teacher, or activity book initially brought up a concept, and when and how each discussed additions to the topic.

Staton's (1988) method of charting topics provided her with a quantitative description of the structure of elaboration, and used the students' initial topic-comments as an underpinning for successive elaborations. For the present study, I used Staton's information to help me organize the various student statements about the same concepts. This evidence only provided me with information that knowledge has been changed—***accreted***, or ***tuned***—and not necessarily restructured. There might be some ***weak restructuring***, if there is some schema change shown by studnets' connecting concepts in new ways. But the researcher needed criteria to help discern the presence of more radical restructuring. Other researchers provided assistance for finding conceptual change with the following criteria.

Identifying radical restructuring through semantic node-link networks. There are three criteria generally accepted as evidence of conceptual change or a radical restructuring of existing schema (Kuhn, 1970; Carey, 1985b; Wiser & Carey, 1983). A new schema differs from old schema

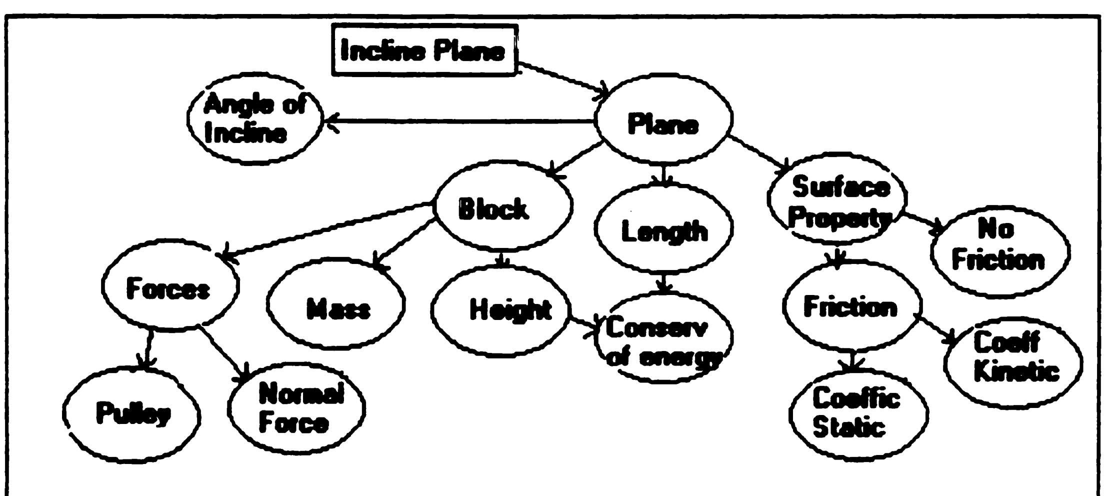

Figure 2.4 Node-link network of Novice H. P.'s schema of an inclined plane. (from Chi, Glaser, & Rees, 1982, p. 57)

when (a) the individual concepts within the structure differ, (b) the structure itself differs, and (c) the domain of phenomena the structures explain differs.

Chi and her colleagues (1982) were able to determine the knowledge contained in the schemata of experts and novices by using a node-link network of key terms mentioned by the subjects in their elaboration protocols. The nodes are key terms linked to the identifiers that subjects mentioned

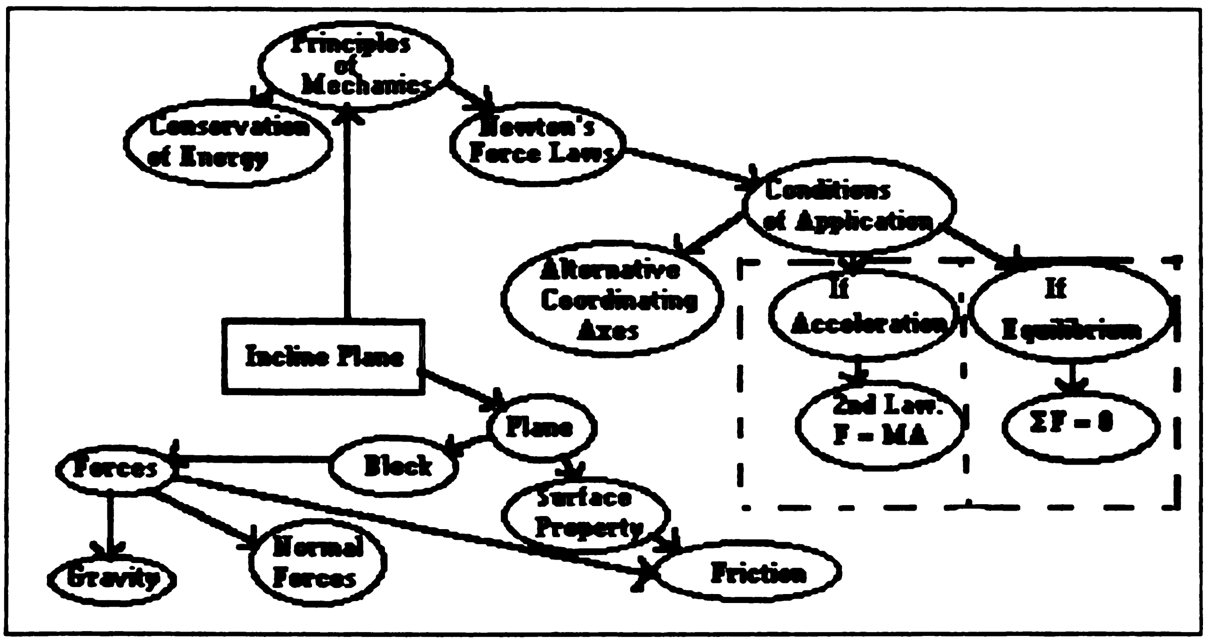

Figure 2.5 Node-link network of Expert M. G.'s schema of an inclined plane. (from Chi, Glaser, & Rees, 1982, p. 58)

contiguously. The links are usually unlabeled, and are <u>relations</u> that join the concepts that the subjects mentioned contiguously (p. 55, see Figure 2.4).

The novice and expert networks represented a ***potential schema*** and allowed the researchers to observe the elaboration of the principles and conditions of how each applied their knowledge to a presented physics problem. Chi and her colleagues asked two experts and two novices to elaborate on a selected sample of 20 concepts, ranging from labels provided by the experts, to some provided strictly by the novices. They presented each

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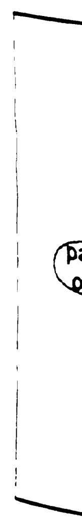

Figure 2.6

subject with a concept individually and allowed each three minutes to tell everything they could think of about the concept. They also asked each subject to tell how a problem might be solved using the concept. Chi and her colleagues were able to show with these schematic networks that novices and experts possessed different schema. Both possessed a fundamental knowledge of the problem and its properties, but experts possessed more levels of interconnected knowledge, and related that knowledge to principles and procedures. As can be seen from comparison of the two semantic node-link networks from Chi and her colleagues, (see Figures 2.4 and 2.5), experts demonstrated in their schema ***more*** individual concepts, ***more elaborated*** structure with more and more varied connections between concepts. The schema explained a different domain of phenomena, the core concepts and how they related was often more elaborate. Hence, Chi and her colleagues were able to demonstrate the differences between individual concepts within structures, the structures themselves, and the domain that the schema explain with the use of node-link network of key terms that the

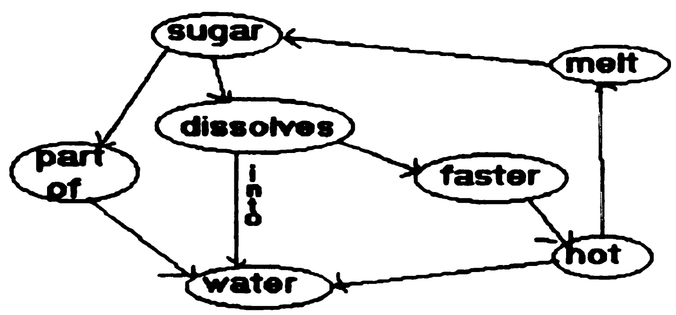

Figure 2.6 Representation of Irma's conceptions of dissolving on pretest.

subjects stated about a problem. In Figure 2.6, I represent Irma's written pretest ideas about dissolving in a semantic node-link network from her writing illustrated in Figure 2.3.

Semantic node-link networks allow researchers to picture a student's specific propositions in a conceptual area, but I needed to assume that an important feature of such a representation is that it is propositional, and merely a potential schema that the learner may possess at any given time. Semantic node-link networks, as helpful as they can be for researchers to understand student thinking, do have their limitations (Stewart, 1980). The number of concepts we can examine are limited. The more concepts we're interested in observing increases by four or more when all the relationship pairs are considered, and the enormity of the task may limit what we are physically able to analyze. A second limitation is the incomplete picture of any given student's cognitive structure that this assessment technique provides. Students can often ***recognize*** relationships that they do not spontaneously volunteer in interviews or on paper-and-pencil explanations. Stewart (1980) proposed that the use of such cognitive assessment techniques focus primarily on significant science content and any study that attempts such description needs to provide detailed records of the lecture and text materials, tape recordings, and portray the semantic information in these events also as networks, for a meaningful record of the concepts presented. He emphasized that cognitive structure be assessed before the instructional treatment to determine relevant prior knowledge and assessed following treatment to show what types of changes occur in cognitive structure as a result of instruction. He proposed also that researchers in science education use semantic techniques to answer questions about how students' existing cognitive structu

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structures interact with instructional content, and what the results look like to enhance our knowledge of "what science is learned and why" (p. 387).

In this study, I present representative networks of student thinking before instructional treatment, during, and following instruction, in an attempt to determine relevant prior knowledge and the types of changes that occur as students attempt to learn about matter and molecules. The use of semantic node-link network mapping might show students' core concepts, structure, and organization changes better than merely observing the writing and describing what they wrote. I hoped to discover how students' existing cognitive structures interacted with the instructional content in matter and molecules to show what science students learned, and possible reasons why they learned what they did. Placing students' written ideas into semantic node-link networks might highlight the changes in structure students accomplished as a result of instruction.

Identifying conceptual change in Matter and Molecules. From the work of Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990, described on pages 26 to 27, this document) I expected to find similar real-world or alternative conceptions at the beginning of the lesson unit with the sixth grade students in this study. Lee and her colleagues provided me with a picture of what scientific thinking about the nature of matter and physical change looks like. I was able to construct semantic node-link networks of the scientific goal and real-world or alternative conceptions outlined by Lee and her colleagues, compare those networks to those I constructed from students' writing, and their pre-test and posttests, and observe the changes that appeared to be evidence of conceptual change.

Summary

Staton (1982; 1988) demonstrated a method for identifying student elaborations on a topic by charting what a student said over time. Such charts were useful for analysis in this project, to map what a student said verbally or in writing about a concept over time in the matter and molecules lesson. Chi, Glaser and Rees (1982) demonstrated a method of graphing potential schema by constructing semantic node-link networks based on what individuals mentioned contiguously in their verbal statements. Semantic node-link networks constructed from what students wrote and said in this study helped me analyze students' schema for the concepts, prior knowledge, and changes in core concepts over time. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990) provided a picture of sixth grade students' common real-world or alternative conceptions about matter and molecules, and showed where students needed to go to develop more scientific thinking about the content.

Research on Mechanisms Influencing Knowledge Restructuring

What Are the Likely Mechanisms?

From where do new ideas and uncertainties arise in students' attempts to understand science? In Chapter 2, I defined the ***mechanisms*** for knowledge restructuring as some external experience that triggered internal changes in understanding. Studies on classroom discourse have demonstrated that these changes in understanding may arise from interactions with the teacher, other students, and text-like information about content in classrooms. The following research review was used to guide my observation as I attempted to answer the second research question about the possible mechanisms operating within classrooms that might be associated with knowledge restructuring, how to identify the mechanisms within the classroom context, and to cross-reference such information with students knowledge restructuring evidence.

In the following section, I suggest several classroom events and influences that might be associated with knowledge restructuring based on researchers' reports of learning in classrooms. This list is not exhaustive, but represents the events that appeared to stand out most to me as I perused the literature about effective science classroom learning. The likely mechanisms influencing science knowledge restructuring might be various kinds of dialogue—argument or controversy, Socratic dialogue, cognitive conflict, surprise, reflection, writing, metaphor or analogy, student peer interactions, and talk with the teacher. Also likely influencing student science knowledge restructuring is students' prior knowledge, and their learning goals and strategies. I discuss each variable in the following review.

Dialogue. Dialogue with an adult or more experienced peer eventually results in thought, and those mechanisms underlying higher mental processes are an internalization of dialogues previously held in social interactions (Vygotsky, 1986; Wertsch, 1985). Students most likely restructure knowledge through argument or controversy (Johnson & Johnson, 1979) and Socratic dialogue or periods of cognitive conflict (Collins, 1977; Posner, Strike, Hewson, & Gertzog, 1982; Stavy & Berkovitz, 1980; von Glasersfeld, 1984; Vosniadou and Brewer, 1987), or surprise (Lawler, 1981), and during periods of apparent inactivity and reflection (Cobb and Steffe, 1983). Social conflict that arises when students work together to co-construct meaning mediates cognitive change (Murray, Ames, & Botvin, 1977). Dialogue with the self, and reflection on thinking, as students do when they write, might also be a mechanism that provokes knowledge restructuring (Langer & Applebee, 1987; Ammon & Ammon, 1987).

may have disregarded that will provide more information about how to classify the object (von Glasersfeld, 1984). Piaget stressed cognitive conflict through social encounters as a way to confront the individual with alternative points of view, and help her realize the limitations of her own ideas (1950, Ch. 6). The learner must then "fit" the concept of the object into her knowledge structures, and if it does not "fit", the learner needs to consider building new knowledge structures to accommodate the new information. This action on the part of the learner is an instance of Piaget's accommodation, and Rumelhart and Norman's restructuring.

Stavy and Berkovitz (1980) examined the effectiveness of conflict training procedures on advancing children's cognitive development of the concept of temperature. They observed 77 fourth-grade children, primarily of middle class background, in three groups: One group received conflict training during their classroom study, the second group received conflict training individually, and the third group served as a control. All children were interviewed individually for pre- and posttest. Stavy and Berkovitz found that the conflict training improved children's understanding of the concept of temperature in both the classroom and individual training settings. They claimed that the conflict training helped make children aware of conflicts between their different ways of thinking about temperature. Children were more likely to change their thinking when the conflict situations showed more intense differences. In this study, I attempted to observe the cases where the six target students might have demonstrated they were experiencing cognitive conflict, and see how they resolved their thinking in such instances.

Surprise. Lawler (1981) noticed as he was studying the natural arithmetic learning of his six-year-old daughter that she experienced insight as a result of surprising confluence of results from adding numbers two different ways

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ways, ways that she had previously considered part of independent worlds. One method resulted from her understanding of tens, and the other from her finger counting experience. She was able to see through her father's questioning, that both worlds of understanding could be integrated to find the right answer to an addition problem. Lawler suggested that it was the surprising confluence of her results that led to the spark of a cognitive event for his daughter. She changed a non-relation (between finger counting and counting by tens) into a relation, and thus, created a new knowledge structure. I attempted to observe and analyze all instances of surprise that the six target students showed in this study.

Inactivity and reflection (dialogue with the self). Alton-Lee and Haberfield (1982) studied three upper elementary children's learning in conservation by tape recording class discussions, monitoring student activities, and observing all student written and art work. Based on student responses on a posttest, interviews before and after the unit, and again one year later, Alton-Lee and Haberfield found a positive relationship between what students learned and the time they spent in inactive or reflective moments such as verbalizing to themselves, or writing. Children were inactive when they were not involved in the classroom activities of reading, listening to the teacher, talking to peers, or other learning activity, whenever their actions did not appear profitable for learning or busy with learning activities. An example of inactivity would be staring out the window. Reflecting activity is pondering or meditating one's thoughts. Students may be seen reflecting when they stop working and look away as they accomplish learning tasks, or stop during writing to look back and think about what they have written. In this study, I observed and analyzed any evidence that the six target students might be taking time to reflect on their thinking as evidenced on the videotapes of classroom activities.

The act of writing (another form of dialogue with the self and others). When students write, they put their words on paper where they can re-read and reflect on what they have said, and how they have shaped their ideas. The manipulation of content with writing activities provides students with a means of focusing attention, and then, reflection (Langer & Applebee, 1987). Ammon and Ammon's research (1987) supported this aspect of learning from writing, as they demonstrated that learning the writing form they were to use allowed students to move to new levels of understanding as they wrote (see quote, page 22, this document). The writing that students did in the present study provided them with a permanent record that they could re-read to reflect on their own thinking. If students change their thinking as a result of reflecting on their ideas in writing, they may show this by actually stating it in their writing, or less overtly with their cross-outs and insertions into their writing pieces (Ammon and Ammon, 1987). A debriefing interview with selected students following their various writing episodes during the learning unit helped me illuminate such occurrences.

Metaphor and Analogy. Another source of student understanding development may be rooted in the linguistic metaphors of their history and culture that attempt to explain physical phenomena (Hewson, 1985). A metaphor is a figure of speech in which a word, phrase or event is used to imply the form of another similar, but not exact form of a word, phrase or event. An example of a metaphor is to speak of fog as "creeping in on cat's paws" to convey the quiet, creeping of the fog with greater understanding and fewer words. Metaphor helps us convey meaning by providing a continuum of experience that words alone cannot convey. Metaphor allows us to convey inexpressible ideas. Metaphor is more vivid because it is closer to our perceived experience, and more compact than a linear progression of words. Metaphor allows us to transfer large chunks of linguistic information in fewer words and in a more continuous mode (Ortony, 1975). Ortony claimed that metaphor contains pedagogic value in its ability to transfer coherent chunks of perceptual, cognitive, emotional, and experiential features from a familiar subject to the unfamiliar.

As metaphors are figures of speech containing an implied comparison, and applying a word or phrase ordinarily used to describe one thing to another thing, analogies are ways of explaining something by comparing it point by point with another thing. Analogies are more explicit forms of comparison. Both metaphor and analogy may be important classroom events for helping students make an unfamiliar concept more familiar. In this study, I observed and analyzed all instances in which the teacher or the curriculum materials presented metaphor or analogies to help students understand concepts, for evidence that such events helped students restructure their thinking.

Support for the cognitive value of collaboration and dialogue in the classroom comes from Forman (1981); Forman and Cazden (1987); Newman, Griffin, and Cole (1987); Clark (1988); Zeidler and Lederman (1989); Alton-Lee and Haberfield (1982); Roth, Anderson, and Smith (1986); and Edwards and Mercer, (1987). I will briefly review the findings of each study to show how important students' and teacher dialogue is for learning.

Interactions between students. Forman (1981), and Forman & Cazden (1987), pre- and post-tested children on logical reasoning, then had them participate in collaborative problem-solving about chemical combination tasks. During their collaborative problem solving sessions of chemical combination tasks, the students were videotaped. When the researchers analyzed the videotapes they found that collaborative partnerships differed in interactional patterns and cognitive growth. Collaborative pairs solved more problems than students acting alone, but post-tests were not statistically significant for growth in understanding. Forman and Cazden's results were supported by Newman, Griffin, and Cole (1987), who reported an observation of 27 children's problem solving for similar activities in two different settings, the classroom and an after school club setting. Students were to perform the same kind of task, only the content was changed. They found that when students participated in collaborative problem-solving, they socially reconstructed the tasks, and made them different. Students' solved more problems than the researchers' expected them to, but they did not measure how much the students learned and retained from the activity. There appears to be some benefit for exploratory talk when students are allowed to collaborate on problems. It is possible that the methods researchers used to test cognitive growth did not measure the variable that would show important changes in thinking. If students solve more problems, and talk at higher levels, they may be internalizing the talk over time. Instruments for measuring student growth need to assess changes in concept understanding and articulation. The methods used by these researchers may not have tapped that information. In the present study, I paid particularly close attention to what students said in groups and in the larger classroom activities, and related their statements to the knowledge evidenced in their writing. Such a connection provided more concrete evidence for what students might have understood about concepts.

Influence of teacher talk. What the teacher says, how sensitive the teacher is to student responses to instruction, and how the teacher responds to what students say critically influence student learning (Roth, Anderson, and

Smith, 1986). I refer to this particular study in greater detail toward the end of this section.

Clark (1988) studied the structure of classroom dialogue over four years in 8th grade science classrooms in a large metropolitan secondary school in Australia. Clark observed three teachers and 113 students in four classes, that consisted of a representative socioeconomic cross section of students in the country. Clark used the co-occurrence of words with the context of the words as a fundamental aspect of the analysis from a collection of dialogue on audiotape. He found that the most influential variable having an effect on science achievement was the ***structure*** of the teacher-student dialogue. Clark urged that teachers take responsibility for providing the structural support necessary for effective learning in their classrooms by using their own organization of knowledge to provide structure for student learning, even if the structure is deficient or incorrect, Clark believed that students learn more effectively if the teacher provides structure. The learning unit in this study provided an organized structure that helped the teacher tie new information together with old information as the unit progressed. The structure of the unit provided an overall meaningful structure to the lessons. The teacher also provided some of her own ideas as structure.

Zeidler and Lederman (1989) observed 18 high school biology teachers with their 409 students, randomly selected from one class of each teacher, to observe if teachers' realist or instrumentalist theories of science influenced the way their students conceptualized the taught scientific concepts. They conducted intensive qualitative observations of each classroom, and analyzed complete transcripts of teacher/class verbalizations, records of chalkboard notes, handouts, assignments, teacher mannerisms, nonverbal cues, and physical classroom plan. They observed each teacher three times throughout the fall semester. They pre- and posttested students with regard to their orientation toward the nature of science (realist or instrumentalist direction). Zeidler and Lederman found a relationship between the teacher's language and the student's conceptions. They proposed that teacher's language reveals implicit connections between concepts that become conveyed to the students through classroom discourse. They concluded that "the ordinary language teachers use to communicate science content *does* provide the context in which students formulate their own conception of the nature of science" (p. 77). Zeidler and Lederman proposed that without precise language on the part of teachers, and teachers' forethought about how they present information, students may not make the expected connections between concepts. Thus, I expected that the teacher's language, and how she explained concepts and provided examples, might influence the connections that students made between concepts in the Matter and Molecules unit used in the present study.

Alton-Lee and Haberfield (1982) observed three upper elementary children's learning of conservation during a science unit by tape recording class discussions, monitoring student learning activities, talk, and all written and art work accomplished by the three. They found that neither the researchers nor the teacher were able to predict what children would learn, or forget. Alton-Lee and Haberfield were able to demonstrate a positive relationship between learning and time spent verbalizing to self, talking with peers (even during teacher lessons), and writing----behaviors that often are considered off-task in classroom discourse studies. Those items that students learned initially then later forgot seemed due to lack of prior experience, failure by the teacher to identify and change real-world or alternative conceptions, and lack of any activity to fix, or attach, the learning. The same factors might influence student learning in the present study. It was important in my study that I observe off-task behaviors, pay attention to students' prior experience, real-world or alternative conceptions, and the activities intended to anchor students' learning.

Roth, Anderson, and Smith (1986) observed three fifth-grade teachers who appeared to be effective teachers (good managers, used directed teaching methods, and high rates of factual level questions). They used detailed propositional analyses of the curriculum materials, interviews with teachers and target students, pre- and posttests of student learning, and classroom observations and tape recording of teachers and students to investigate the relationships among curriculum materials, teacher's thinking, teaching, and student learning.

Roth, Anderson, and Smith found that Teacher #1 depended on the text to provide explanations of scientific concepts for the students. She did not usually rephrase the explanations unless she was attempting to answer a question from the text. She used discussions that focused on students' repeating the right answers rather than applying principles and understanding concepts. Students were exposed to a lot of ideas, but not stimulated to think about the meaning of the ideas, only the memorization of the right answers.

Teacher #2 asked questions that encouraged students to reword and develop their answers. She carefully probed students' conceptions for their understandings. Another feature of her teaching was repetition of key ideas in different contexts. 64% of this teacher's students demonstrated understanding of the photosynthesis process on the posttest, compared to 15% in teacher #1's class.

Teacher #3 encouraged students to have ideas, and generate their own explanations for their observations, but she did not provide information or feedback about the appropriateness of their thinking. She hoped that students

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would come to their own correct conclusions about the concepts. She emphasized the process of doing experiments, rather than understanding the concepts. At the post-test, only 7% of teacher #3's students understood the new concepts.

After training teacher #3 to use more verbal strategies to uncover student alternative conceptions and understandings, and providing her with more effective teaching materials, she was able to talk with her students in a manner that was more directive to students' understanding, and began to repeat the key concepts more often. As a result, 79% of her students understood the new concepts on the post-test. In my study, the teacher's verbal strategies and teaching materials were an important part of the data, and served to direct student understanding.

The above findings are supported with studies conducted by Edwards and Mercer (1987). They observed classroom discourse in actual classrooms of 8-10 years olds in mainstream junior high schools in England, and followed the development of shared understandings in a series of video-recorded classroom lessons, and the linguistic, psychological, sociological and anthropological contexts that informed their understanding of the discourse, shared knowledge and education.

Edwards and Mercer (1987) found that even though lessons were organized to have students perform practical and small-group activities, the learning that occurred was more a function of the teacher's shaping the general pattern and content of the lesson, and in verbally defining what was done, said, and understood, than was the learning a matter of students' experiences and communications. They also found that teacher control over the lesson can lead students to understand only what was done, and what they are required to say, rather than improving students' depth of principled understanding. Students and teachers establish joint understandings about the lessons through classroom discourse, and share frames of reference and ideas. This shared understanding introduces students to the conceptual world of the teacher and her scientific educational community--students become cognitively socialized through language.

In a report of the same group of studies, Edwards (1987) showed that students do not learn all they need to know merely from their own activity and experience, even when they perform practical experiments and make empirical observations. Students need a verbal interpretation put on their experience to define and communicate the experience, and derive principles from it. Edwards insisted that it is the teacher who needs to provide the words to help students define and make sense of their science experiences--as a kind of guide, providing a liaison between the student and the "collective wisdom of the educated world." (p. 47)

Since both Edwards and Mercer, and Roth, Anderson, and Smith (1986) found that the teachers' verbal definitions shape the pattern and content of the lessons more than students' experiences and communications, I expected to find similar results in this study. It was important for me to carefully record the teacher's verbal shaping of the definitions and understandings, as well as the students' experiences and communications. The classroom dialogue with teachers, peers, and texts, in which students participated to learn new science concepts, was important for understanding their knowledge growth for this research. It was then necessary that I pay close attention to the events that occurred in the classroom setting during lessons. There are important connections that can be observed between what students hear, read, and say, and what sense they make of new science information.

Students' prior knowledge. Students' prior knowledge in a domain can effect their ability to remember information, and interfere with their ability to make inferences about the conceptual connections between concepts presented in the instruction. Pearson, Hanson and Gordon (1979) examined the prior knowledge of second graders before they read a basal reader on a topic, then compared students' comprehension scores with their prior knowledge. They found that students with more prior knowledge about the subject could remember more about what they read. Students with less prior knowledge, remembered less. Pearson, Hanson and Gordon concluded that students with stronger schema for the topic will comprehend text better than will students with less prior knowledge schema. The same factors may have effected students' attempts to comprehend classroom information and presentations.

In this present study, it was important for me to observe students' prior knowledge schema about each new topic, and analyze the possible influences such schema, or lack thereof, might have on students' understandings.

Students' learning goals and strategies. Roth (1985) observed nineteen middle school students as they read text about photosynthesis, and translated their understanding about the readings into their own words in writing, and by answering researcher-posed clinical interview questions. Students were selected by stratified random sampling into three treatment groups, each reading a different kind of text. Each group contained students who read above, below and at grade level. Each student took a pretest and the same posttest after the reading treatment. Books were matched in content coverage, reading level and length of text. One of the texts was designed by Roth to elicit conceptual change learning by helping students become aware of their alternative conceptions, and begin to use new scientific information to apply, predict, and explain real-world events. The other two texts were standard commercial school texts published for use in classroom learning.

Roth found that the experimental text, designed to enhance conceptual change learning, was more successful than the commercial texts. Students learned more of the scientific goal conceptions of photosynthesis using the experimental text than those who used the commercial texts. The importance of Roth's work for my study was her findings about how students approached their learning tasks, and the role those learning goals played in their reading comprehension. She found that the reading strategy a student used was the main determining factor in how well a student understood and explained the scientific goal conceptions at the posttest. Students using a conceptual change sense-making strategy (Strategy 5, below) were successful on the posttest no matter which text they read. Students using other reading strategies were more successful with Roth's experimental text, but considerably less successful with the commercial texts. Roth found that when the curriculum materials supported students' attempts to use conceptual change strategies, students were influenced to use these strategies, and learn more successfully. I outline the strategies Roth found students using to read and comprehend text, and that were again clarified by Anderson and Roth (1988) in Table 2.2. It seemed likely that the middle school students I would observe in my study might demonstrate similar learning goals and strategies that would influence their understandings, and play a role in what they learned as a result of classroom events.

Summary

From researchers' reports of classroom learning, in and out of science classrooms, there are several events that might strongly influence students to

TABLE 2.2

STRATEGIES USED BY STUDENTS TO PROCESS AND COMPREHEND TEXT	
1. Strategy 1 - Overreliance on Prior Knowledge	Using this strategy, students tended to interpret text in terms of their real-world prior knowledge, and used that knowledge as a source of information, rather than the text. Students' learning goals were to finish the task.
2. Strategy 2 - Overreliance on Words in Text	Using this strategy, students tended to focus on details in the text without making sense of their meaning. Words were isolated without any relationship to each other or the student's prior real-world knowledge. Learning goals were to finish the task. They produced acceptable answers to questions about the text, but totally relied on real-world knowledge to answer real-world problems.
3. Strategy 3 - Overreliance on Unrelated Facts; Separation of Disciplinary Knowledge and Real-world Knowledge	Using this strategy, students were usually better readers, and had higher goals for their learning than just finishing a task. They tended to learn a list of facts and add them to memory without integrating them with their prior real-world knowledge. They remembered facts from the lessons, but did not use them when attempting to explain real-world events. They remembered trivial concepts as well as they remembered main ideas. They drew on textbook schema to answer textbook questions, and real-world schema to answer questions about real phenomena.

TABLE 2.2 (continued)

4. Strategy 4 - Overreliance on Prior Knowledge to Make Sense of Disciplinary Knowledge	Using this strategy, students were usually reading at or above grade level but expected the text to confirm their prior knowledge rather than challenge and modify it. These students remembered new information and integrated it into their existing schema, but distorted or ignored some of the information to make it fit their real-world prior knowledge. These students often retained concepts from their prior real-world knowledge along with new, and even contradictory scientific knowledge.
5. Strategy 5 - Conceptual Change Strategy Using Text Knowledge to Change Real-World Ideas	Students using this strategy were able to abandon real-world or alternative conceptions and replace them with more scientific thinking. They used their new knowledge to change their schema, and integrate the new knowledge with their real-world prior knowledge. They recognized the conflicts between new and old theories, and attempted to use their new knowledge by applying it to real situations, and explaining, predicting. They were actively involved in trying to make sense of the text.

change their conceptions. When students disagreed with one another, or with the teacher, and were able to debate their thinking, and when they engaged in Socratic kinds of questioning dialogue with the teacher, students were persuaded to reconsider their alternative conceptions. Being faced with the proposition that their conceptions might not agree with scientific thought, and being unable to "fit" new conceptions into their present schema influenced students to modify their conceptions, as well. Teachers might help students see connections between previously unrelated structures, and help them reach a surprising confluence, influencing restructuring. And opportunities for students to reflect on their thinking by responding in writing to explanation questions, or going back to look at old ideas and compare them with new ideas, might have influenced knowledge restructuring. Writing offers such reflective opportunities for students, and offers them a way to dialogue with themselves about their understandings.

When teachers used metaphor or analogy to explain events and concepts, students could draw from their prior knowledge and more easily fit new knowledge into their existing structures, or at least, receive guidance for building new structures based on what they already understand. Opportunities to dialogue with other students about their ideas, helped students make more connections from what they already know to new information. The exploratory talk that students experienced in small group dialogue might have influenced them to restructure their thinking.

And there is overwhelming evidence that what the teacher said in the classroom, and how she said it, influenced what students used in constructing their new schema about phenomena. Some have found that what the teacher said is more important than students own activities and experiences alone. Teachers' interpretations were necessary to help students make sense of their science experiences. The text and curriculum materials were also important for helping students to see the connections between their real life experiences and scientific thinking.

From the student side of classroom dynamic interactions, students' prior knowledge influenced how much sense they made from the instruction, and their learning goals and strategies influenced how they used and manipulated the instruction.

As I mentioned before, this list is not exhaustive, but represents the events that were reported most often in the science learning literature. In this study, I observed all the above classroom events, and attempted to find others that I do not mention here, in the event that there are other factors that I did not find in my review of the literature that influence classroom learning. The next question that I undertake to answer with my literature review is how I could detect classroom instances of cognitive conflict, or influential teacher talk or the like, within the classroom events.

How Might I Detect the Mechanisms Associated with Knowledge Restructuring and Conceptual Change?

Much of the work done to date in knowledge restructuring and conceptual change has taken the form of description, and few researchers have interpreted the mechanisms, or agents of change, through which the restructuring occurs. But some researchers have offered their informed opinions about what might operate in the classroom context to influence students to change their conceptions. Johnson and Johnson (1979) proposed that students are influenced to change their knowledge structures through argument or controversy (see also Confrey, 1981; von Glasersfeld, 1984; and Lawler, 1981). Johnson and Johnson stated

> *disagreement among students' ideas, conclusions, theories, and opinions is an important source of learning in all instructional situations. When occurring within facilitative conditions, there is evidence that such conflicts will create conceptual conflict, feelings of uncertainty, and epistemic curiosity; increase students' accuracy of cognitive perspective-taking; promote students' transitions from one stage of cognitive and moral reasoning to another; increase the quality of students' problem-solving; and, increase students' creativeness* (p. 62).

Rumelhart and Norman (1981), and Vosniadou and Brewer (1987), anticipated that the most likely mechanisms that provoke radical restructuring in their view were Socratic dialogues (questioning), and analogies, metaphors, and physical models. Socratic dialogues and questioning helped individuals recognize inconsistencies in their present schema; and analogies, metaphors, and physical models helped individuals relate prior knowledge from another domain to the new knowledge.

If classroom instruction supported conceptual change and knowledge restructuring, I expected to detect the presence of controversy, Socratic dialogue and questioning, and use of metaphor or analogy and surprise, or periods of reflection, based on my literature review of the dialogic influences on conceptual change. If such events are influential in students' knowledge restructuring, they may express some of their ideas about these events in their writing. Evidence for the presence of such events provided the confrontations to student thinking that were associated with the conditions Posner and his colleagues (1982) proposed were necessary to influence knowledge restructuring:

·Students must be dissatisfied with their existing conceptions.

·Any new conception of knowledge must be understandable.

·A new conception must appear plausible.

·A new conception must be useful.

For the present study, I attempted to document student dissatisfactions with their existing conceptions when I found expressions of dissatisfactions and considerations, uncertainties, and grappling with conflicting ideas in their writing---questioning of their ideas, inconsistencies in their explanations, unfinished sentences, cross-outs and inserts (Ammon & Ammon, 1987). Such writing often precedes some resolution and knowledge restructuring. To help me interpret these writing idiosyncrasies as expressions of dissatisfaction, I periodically interviewed target students about what they were thinking during their writing, and why they thought they wrote in the ways they did.

Another event that could offer evidence for the mechanisms associated with knowledge restructuring is the teacher's talk itself. According to Roth, Anderson, and Smith (1986), teachers who were successful at getting students to change their real-world or alternative and commonsense conceptions about science use systematically different verbal behaviors in their classrooms.

(1) They asked questions that elicited students' alternative conceptions and considered how these conceptions influence student responses, and challenged them.

(2) These teachers focused their talk on the critical "whys" of science concepts at a meaningful level--making each piece of information important, and fitting it together with other important pieces.

(3) They responded to student statements with "why" questions when they are incorrect or incomplete.

(4) They balanced open-ended verbal interactions with directed, structured discussions leading to closure and consensus about why certain answers were better than others.

(5) They provided practice for students to apply their new conceptions to a variety of real-world situations.

Roth, Anderson, and Smith (1986) pointed out that the text and curriculum materials need to emphasize critical points in the lesson as well. The teacher in the present study performed teaching acts similar to those Roth and her colleagues identified as being successful in getting students to change their conceptions. If such acts are associated with instances of student knowledge restructuring, I can provide more evidence to strengthen the importance of certain influential teacher behaviors, and the structure of the text and curriculum materials for science lessons.

Minstrell (1984) supported Roth, Anderson, and Smith's (1986) contentions that teacher talk, text, and curriculum materials need to emphasize the critical points in lessons. Minstrell found in his high school physics classrooms that students' alternative conceptions often continued to exist even after instruction. He noticed that students could give correct responses to questions, but failed to transfer the ideas to applications in new contexts. He assumed that when students conceptual structures did not change to accommodate new ideas, the student soon forgot meaningless ideas that were learned by rote. Minstrell experimented with different forms of instruction to help his students articulate their initial real-world ideas about physics, then pressed students to resolve the differences between their real-world explanations and more scientific explanations from experiments and text. Minstrell proposed that making students aware of their initial conceptions, then juxtaposing different experiences related to those ideas, while encouraging students to resolve discrepancies between their initial conceptions and their explanations in different contexts, helped students change their conceptual structure about phenomena. He reasoned that firsthand experiences that are related to students' initial conceptions are necessary for students to recognize their own faulty thinking and begin to revise it.

Minstrell emphasized Piaget's (1958) theory that reasoning from the concrete to the abstract is easier than from the abstract to the concrete. Thus, Minstrell designed his instruction to present concrete firsthand experience before he presented more abstract situations. He found that students also needed opportunities to think and talk through examples that require explanations using scientific knowledge to help them attach their understandings to other concepts and contexts. Minstrell drew inferences from his series of physics instruction investigations with six instructional principles for teaching for conceptual change:

(1) ***Engage the students' initial conceptions.*** Help students verbalize and be aware of their initial real-world knowledge about the subject. Teachers need to also be aware of these ideas.

(2) ***Provide several laboratory activities, demonstrations, and other experiences*** directly related to students' initial conceptions. These experiences should be firsthand and concrete, and consistent with earlier ideas to confirm them, inconsistency may help them rethink their ideas.

(3) ***Provide opportunities for discussions that encourage students to resolve discrepancies between their initial real-world conceptions and their observations.*** Most students need guidance and support to resolve such discrepancies.

(4) ***Sequence the instruction to begin with accessible, concrete ideas and experiences, and gradually build toward ideas that require more abstract thinking.***

(5) ***Provide students with repeated opportunities to reuse their new idea arguments, review them, and apply them in new contexts.*** This provides students with a network of integrated, logically consistent ideas.

(6) ***Students begin instruction with different initial conceptions, and reasoning abilities.*** The instruction should attempt to match these limits.

The curriculum materials used in the matter and molecules unit for this present study were designed to encourage students' conceptual change thinking by providing opportunities for students to write and talk about their initial conceptions, then compare their conceptions with scientific knowledge, make observations from concrete experiences, and discuss their new thinking with the teacher in large group discussion, and with other students in small group problem-solving activities. The curriculum materials used in this study might have contributed to students' knowledge restructuring. It was important for me to observe how students responded to and interacted with the curriculum materials to understand the influence these materials might have on students' understanding.

Summary

Based on the science learning literature, when conditions were right for knowledge restructuring to occur, several elements of instruction were also present: Students felt dissatisfied with their present conceptions, and saw new conceptions as more plausible and useful; the teacher confronted students with their alternative conceptions, asking "why" questions, and challenging students' conceptions; and the teacher and curriculum materials provided opportunities for students to confront their alternative conceptions by explaining their experiences and using new ideas in varied contexts. If these classroom conditions are necessary to induce knowledge restructuring, the teacher's use of controversy, questioning, metaphor and analogy in her classroom discourse and instruction in my study might be related to student knowledge restructuring. And students' writings might show their dissatisfactions with existing conceptions, and how they consider new conceptions. As the teachers enlisted a conceptual change teaching strategy to expose students' alternative conceptions, and made students aware of theirs and others' alternative conceptions through discussion and debate, they might have created cognitive conflict and guided students' cognitive accommodation. Since Cobb and Steffe (1983) found that students might reorganize their thinking during periods of apparent inactivity and reflection, the writing that students do in science might provide opportunities for reflection, influence re-thinking, and provide evidence that restructuring has occurred. The evidence for cognitive conflict and reflection of some sort, if I can associate it with students' demonstrated knowledge restructuring in their writing, might provide further interpretation of the mechanisms that influence students to restructure their knowledge toward more scientific conceptions.

How Might I Apply Other Researchers' Techniques in This Study?

In the present study, I cross-referenced instances of knowledge restructuring that I found in students' writing with the classroom events that I suspected might be associated with knowledge restructuring. To my knowledge, few researchers had reported their attempts to make such connections. The waters for my voyage were essentially uncharted: I found few previous studies connecting classroom events and instances of knowledge restructuring to guide my investigation. Minstrell's (1984) and Anderson and Roth's (1988) work demonstrated connections between classroom instruction and conceptual change learning. Roth's (1985) work especially provided some insight into how students make use of text information to learn science concepts, and that information might extend to classroom learning events as well. One study described a student's thinking changes as a result of written dialogue with the teacher (Staton, 1988). In her study, Staton analyzed her data by charting the student's written comments over time, and overlaying those comments to coincide with the teacher's written comments. In this way, she was able to see a connection between what the teacher wrote, and what the student eventually wrote about his understanding of events in math. I was able to apply some of Staton's methods to organize what students said over time about the same concepts. Figure 2.7 is a chart used by Staton and her colleagues (1988) to track a student's and teacher's thematic movements in one topic over time and journal interactions. The chart allows the researcher to indicate repeated statements that the student made about the same

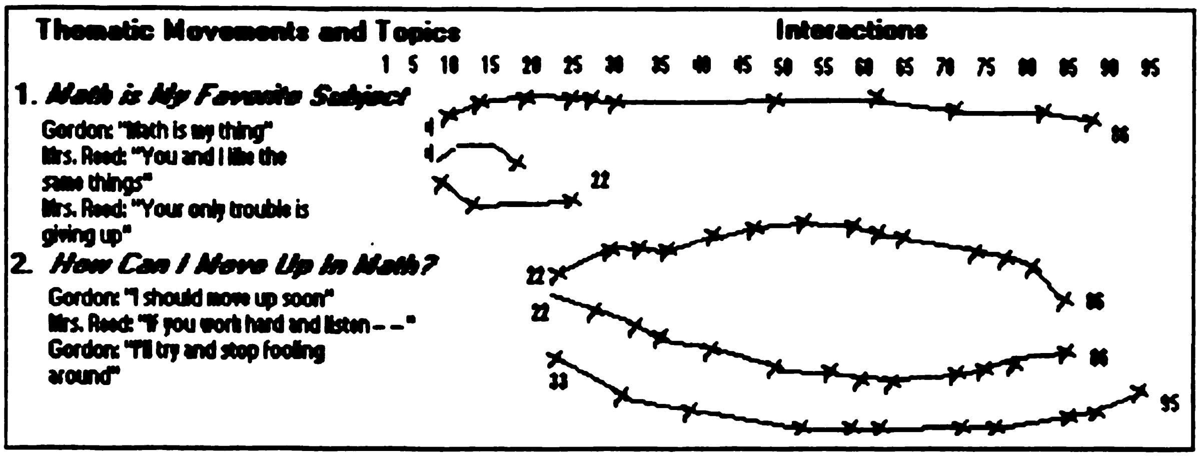

Figure 2.7 Thematic Movements and Topics in Math (from Staton, et al., 1988, p. 260)

information, and growth of the topic into new elaborations. Figure 2.8 is one of the charts I used to follow statements and conceptions the student returned to time after time in his writing. By following a student's repeated statements and elaborations on a concept over time, I detected changes in thinking indicated in the elaborations. In the chart in Figure 2.8 the student repeatedly mentioned the motion of molecules, and showed a change in his thinking about motions of molecules over time. He may also have shown elaboration and weak restructuring in his addition of more information, more details, or even further classifying the concept (see definitions, page 21).

I used Chi, Glaser, and Rees' (1982) methods for constructing semantic node-link networks to assess cognitive structure before, during, and after instruction. When I found evidence of students' elaborations based on a constructed semantic node-link network, I further studied the student's

Student: Jose — **CONCEPTIONS ABOUT MOLECULES**

Pretest	Clinical Interview	Molecules Freewrite
molecules are things you can't see but are in the air that help you breathe same size as speck of dust move in windy and still air; do not move in rock; don't stop moving in air because we need molecules to breathe and so do fish in their water or else if they didn't fish would be dead so we need molecules	molecules are in liquids, solids pure substances and pollution molecules can be in gas because that's a liquid, kind of molecules in air move around fast because it's closed; there's no air from outside air has molecules there is air between molecules same size as speck of dust; if there are molecules in something there has to be air because molecules	molecules are trillions of smaller than a small dot, and molecules are around us always, they don't change shapes but they the formula for water molecule is H_2O and you draw it like this (draws water molecule) 2 atoms of hydrogen

Figure 2.8 Student Jose's conceptions about molecules across time in the Matter and Molecules unit.

thinking changes to detect instances of restructuring. I then overlaid the data about student thinking changes shown in the student's writing with classroom episodes that might have provided opportunities for him to experience cognitive conflict and reflection, or other instructional events. I was able to observe student responses to new ideas during videotaped classroom sessions, and primarily during small group interactions with peers. These rich sources of data provided several views of possible student thinking processes.

I used Staton's methods of journal writing analysis to observe evidence for the conceptions that students identified, and Carey's (1985a; see page 42, this document) assertions about the evidence for restructuring to analyze the presence of knowledge restructuring. Then Staton's methods helped me think about how I might overlay students' conceptions to coincide with events in the classroom in chart form. Roth, Anderson and Smith's (1986), Roth's (1985), Anderson and Roth's (1988), and Minstrell's (1984) work helped guide the analysis of student learning strategies, classroom events, teacher talk, and curriculum materials that might influence conceptual change.

Summary

The literature indicated that knowledge restructuring is a useful metaphor for thinking about how knowledge changes. Knowledge becomes restructured globally and within a domain, as a result of instruction. Both weak and radical forms of restructuring are found as a result of learning in science. Radical restructuring takes the form of changes in core concepts, principles, and theories driving the structure's organization. More radical restructuring is the same as conceptual change.

Conceptual change learning is often difficult for students, because it requires that they adopt new ways of looking at the world. As students attempt to learn new concepts in science, they may or may not restructure their knowledge to accommodate new information. Because this kind of conceptual change is often difficult for learners, the processes of such changes need further study for teachers and researchers to better understand how knowledge acquisition processes proceed, and how we might improve students' opportunities for changes to occur.

The literature revealed that students' writing showed their attempts at knowledge restructuring, and can be used to observe students' thinking changes over time. Some researchers report success using writing to follow students' elaborations on topics, and the use of semantic node-link networks to graphically picture students' possible schema about concepts. By combining these techniques, I was able to follow the changes in students possible schema across lessons in matter and molecules in this study, and chart their occurrences in conjunction with classroom events.

The literature provided clues about what classroom events might influence students to restructure their knowledge. On the teacher and text side of the equation lie cognitive conflict, questioning, argument and controversy, use of metaphor and analogy, opportunities for reflection through writing and dialogue with other students, and teacher's interpretation of events, teacher guidance, and curriculum materials support. On the student side of the equation lie students' prior knowledge, and their learning goals and strategies to influence how they respond to classroom events. The observation of classroom events was based on these possible occurrences to see if any of these variables might relate to students changes in knowledge.

The present study builds on the knowledge we have about how writing displays thinking, and the interactions between knowledge of writing and knowledge about content. This study provides more information about the usefulness of constructing semantic node-link networks for understanding the conceptual structure of student knowledge. Most important, the present study builds on the knowledge that researchers and educators possess about knowledge restructuring by providing further accounts and descriptions of knowledge acquisition processes in the domain of sixth grade learning about the nature of matter. It describes the changes that occur as student knowledge develops, and illuminates some of the mechanisms that might be associated with these developmental changes.

Chapter 3

METHODS

Overview

The purpose of initiating this study was to observe if students' writing in the classroom reveals students' understanding and misunderstanding of science concepts. Another purpose for the study was to look for classroom events that might be associated with knowledge restructuring. Middle school students in a science class were observed as they participated in the second year of a larger study investigating problem solving through collaboration, headed by Charles Anderson and Annemarie Palinscar. Anderson and Palincsar were investigating accounts of learning and problem solving by middle school students. They were in the process of developing instructional strategies and materials to improve students' conceptual understandings and abilities to regulate their own learning. Anderson and Palincsar, and selected teachers, taught a revised unit on Matter and Molecules (Berkheimer, Anderson, and Blakeslee, 1990) that integrated content and collaborative problem solving activities. During the instruction, students wrote about their thinking. I observed this writing to answer my research questions. To help answer the first question about whether students' writing shows their knowledge restructuring and to what extent, and the second question about the possible mechanisms in classroom events that might be associated with knowledge restructuring, I collected the following data:

(1) Student writing about content before, during, and after the lesson unit on Matter and Molecules.

(2) Clinical interviews with six target students about the content before and after the unit of instruction, and about their perceptions of writing before, during and after instruction.

(3) Videotapes of classroom lessons of both whole group, and two small target groups, and written summaries of classroom observations recorded during the lessons.

(4) Interview with the teacher to understand her purposes, goals, and how she perceived the lesson should be taught.

(5) All text materials used by the students.

Looking for knowledge restructuring and conceptual change in students' writing about content. To answer the first question about whether students showed in their writing they were restructuring their knowledge, and how much, I needed to assure that what students wrote was close to what they were thinking. I began by observing the ideas students wrote in their lessons. I collected all of the writing students accomplished to complete their Matter and Molecules activity booklets and lesson unit requirements, and samples of student writing about content before and after instruction on a pretest and posttest. Proposed schema were constructed for the concepts students identified, using semantic node-link networks based on the concepts students' identified when they wrote their ideas about content. For six target students, I compared what they wrote to what they said verbally during clinical interviews about the same information, to see if what students wrote about content was close to what they said verbally about content. Semantic node-link networks of students' verbal propositions from their clinical interviews were compared with the semantic node-link networks constructed from student writing about the same content. A match, for instance, between the ***core concepts*** within the networks from one student's paper-and-pencil pretest and the ***core concepts*** within the networks from the same student's pre-clinical interview, would indicate that what students wrote was close to what they were thinking.

I was also concerned about how easy it was for students to put their ideas in writing, because both the difficulty of the content, and difficulty of the writing task, can interfere with students' abilities to write their ideas (Ammon & Ammon, 1987). Each of the six target students was interviewed before, during, and after instructional units about their writing tasks---How much prior experience did they have writing their ideas? How easy or difficult did they perceive the tasks to be? What strategies did they use to accomplish the writing tasks? If a student felt he had some experience with writing his ideas, that writing tasks were easy, and that he could put his ideas on paper without much trouble, the writing task might not have interfered with the student's ability to write his ideas. What a student wrote about content was more likely to be close to what he was thinking about the content.

Once I had a picture of the students' propositional networks about their thinking, and their writing seemed to be a close match to their verbal displays, and the writing task did not seem to interfere with their ability to write their ideas, students' writing was used to study the changes in students' thinking as they attempted to learn content. Students' propositional schema in the semantic node-link networks were analyzed across time to understand the thinking processes these sixth grade students passed through as they learned about the nature of matter, molecules, and physical change. I observed phenomena such as changes in ***core concepts*** and schema from pretest to posttest, persisting alternative conceptions, how much restructuring students' accomplished, and how close each came to scientific understanding of matter and molecules at both the macroscopic and microscopic level. Once I had a picture of students' patterns of thinking across the unit, their thinking was analyzed for weak or radical restructuring during each lesson cluster, and their attainment of the learning goals was assessed based on their statements throughout each lesson cluster.

Looking for mechanisms associated with knowledge restructuring in classroom events. The second research question asked whether there were any classroom events that might be associated with students' knowledge restructuring. I assessed differences in the effects of classroom events by comparing two lessons, a lesson in which most students attained the scientific goal conceptions, and restructured their thinking to use a conceptual change strategy for learning, and a lesson where students seemed to have more difficulty changing their ideas, attaining the scientific goal conceptions, and using effective learning strategies. I assumed that by comparing these two experiences for learners, I might get some indication of the mechanisms that were associated with the different kinds of thinking I observed. Videotapes of classroom learning sessions were collected during the unit, in both whole class, and small group interactions for target students, across the learning unit. These served as a record of classroom interactions about content. To assist the organization and interpretation of the classroom material, and interpretation of it, summary observation forms were completed about teacher's and students' activities observed during each class day. These observation notes helped flag student conversations, teacher dialogue, and text activities that might provide rich data for understanding students' thinking about the new content.

In the following sections of this chapter, I discuss each aspect of the data listed above, and report the methods used to analyze the data. In the first section, Subjects and Data Collection, I describe the subject population, how they were selected, describe and provide rationale for studying this particular subject matter, describe the classroom context, and the design of the study. In the second section of this chapter, Data Analysis, I describe the procedures for analyzing students' writing samples, interviews, and the classroom events. I also discuss the limitations of my analysis procedures.

Subjects and Data Collection

Subject Sample and Selection Procedure

This classroom of sixth grade students studying matter and molecules was selected because the students would be writing in response to their learning. I was originally interested in finding an upper-elementary classroom where students were writing more expressively in journals or learning logs, but was unable to locate such a classroom. When I found this classroom, and studied the curriculum materials, it seemed that students would be writing their ideas enough for me to use their writing to understand thinking changes. This particular classroom was participating in a study for conceptual change, and so I found it an opportunity not only to observe students' writing for changes in their thinking, but an opportunity also to observe the effects of conceptual change instruction on students' knowledge restructuring. This classroom sample was part of a three year investigation of collaborative problem solving in science under the direction of Charles Anderson and Annemarie Palincsar.

My observation data were collected during the second year of their three year study. During the first year of their study, Study One, Year 1, Anderson and Palinscar identified a total of eight middle-school science classes, instructed by two classroom science teachers and the two principal investigators, Anderson and Palincsar. All classes were composed of heterogeneous groups of students attending middle schools in an urban setting. At the end of Study One, Year 1, Anderson and Palincsar evaluated the success with which desired outcomes were achieved across the various conditions, and revised the instructional procedures to be implemented in Study One, Year 2. My study took place in conjunction with Anderson and Palincsar's Study One, Year 2, in which they implemented an instructional program based on the results they obtained in Year 1. Essentially, they implemented a revised Matter and Molecules Unit with instruction and practice using social norms and self-regulatory activities within small group problem solving, with scientific forms of argument. The instruction was designed to elicit students' alternative conceptions about matter and molecules and provide opportunities for dialogue, writing, planning, and explaining new ideas during and after activities and instruction. It was my belief that the students participating in this study could serve as subjects for my study as well. They were writing in response to learning. They were participating in part of a three year study to determine the effectiveness of conceptual change instruction and group problem-solving for self-regulated learning, so the teacher would be presenting students with information structured in a conceptual change format, and allowing students to collaborate in groups about their thinking. This environment would supply rich classroom data—student writing, a teacher attempting to encourage conceptual change, and opportunities for students to talk about and try out new ideas in groups.

The student sample for this study came from one of Anderson and Palincsar's selected classrooms. The study began with 29 students, but two students moved out of the school district during the unit, so I was able to follow 27 students from the beginning to the end of the unit. The students came from primarily middle and low SES homes, and were heterogeneous in culture and ethnicity. Twelve students were white, six were African-American, and six were Hispanic. There was one Iranian, one Laotian, and one Native American Indian student. Some of the students in this study spoke languages other than English at home, and before they entered school. However, all of the students were fluent in English at the time of this study.

Selection of the six target students. The six target students came from within a group of eight students that Anderson and Palinscar had previously identified as part of two small target groups within the classrooms of their study. Anderson and Palincsar, and the teacher, had already selected these students to be videotaped during small group discussions, and interviewed before and after instruction about content understanding. Participation in each group of four students was designed so that there was at least one high ability student, one low ability student, and two students who fell somewhere in between in ability. Students' abilities were based on the teacher's review of their test scores and grades from previous years' work in school. The groups were also selected for racial and ethnic heterogeneity. One group contained a Hispanic male, an Iranian-American male, and two white Anglo-Saxon children, one male and one female. The other group contained two African-American males, one Laotian-American female, and one white Anglo-saxon male student.

Of these eight students, I chose six who seemed diverse in ethnicity, because I thought these students' differences in learning might be interesting for this study: The six target students consisted of two females, (one Laotian-American, and one white Anglo-Saxon), and four males, (one Iranian-American, two African-American, and one Hispanic). I did not know ahead of time what the abilities of the students were, nor their ethnic backgrounds, specifically. I discovered this information as part of my inquiry.

The teacher in this study was one of the teachers involved in the Anderson and Palincsar three year study. She was appropriate for observing in my study because of her experience and confidence in teaching. She could carry on teaching and responding to students while being recorded and observed. The teacher and students were observed in varied styles of interaction---large group discussions, small group interaction, and science activities---for the <u>effect</u> of these various styles of classroom interaction, rather than the opportunity to observe any particular style of teaching. This middle school science classroom environment would supply rich data--student writing, a teacher attempting to encourage conceptual change, and opportunities for students to talk about and try out their ideas in groups. The subject population, then, had already been chosen: Anderson and Palincsar had previously selected the sixth grade classrooms from middle school, attained volunteer teachers, trained them, and begun an important study of student learning processes.

<u>Subject Matter</u>

The subject matter for this study was the nature of matter and physical change, named as a Matter and Molecules Unit, designed by Berkheimer, Anderson, and Blakeslee (1990) and revised by Anderson and Palincsar (1990). This is an appropriate subject for the study because researchers have described the kinds of alternative conceptions students possess prior to learning, the difficulty for students to make the necessary conceptual changes, and the scientific goal conceptions for students' learning following instruction in this domain (see pp. 18 and 19 this document, for a list of alternative real-world and goal conceptions for the Matter and Molecules Unit). The nature of matter and physical change, and molecular behavior, are difficult subjects for students to master at any age because of the abstract nature of the concepts. Molecules cannot be seen, even under powerful microscopes, so students have to take their existence on faith, and build knowledge structures to understand molecule existence and molecular behavior, without having direct experience with molecules. Also, understanding matter, molecules, and molecular behavior forms the basis for understanding other science content that students will encounter later in biology, chemistry, and physics. If we can effectively teach molecular concepts to sixth grade students, and provide them with schema for understanding substance and molecular behavior in changes of state, dissolving, and other physical changes, we provide them with appropriate prior knowledge schema for understanding more difficult science concepts later in their education. Other researchers have observed sixth grade students as they attempted to learn the matter and molecules concepts, and found that it is difficult subject matter for sixth grade students to master, but student learning improves when the curriculum and teaching approach directly confront students' real-world knowledge and alternative conceptions about how the world works (Lee, Eichinger, Anderson, Berkheimer, and Blakeslee, 1990). In this study, further careful observation of sixth grade students' attempts to learn about matter and molecules will provide more information about instruction that enhances learning of matter and molecules concepts, and the classroom events that might be associated with students' knowledge restructuring in this domain. The subject matter and curriculum materials are described in greater detail in the section titled Lessons and Curriculum Materials that follows.

Classroom Context

The school. This sixth grade classroom was a middle school classroom located within a mid-western city with a population just over 130,000. The school was located in an older neighborhood within the urban setting, mostly single-family dwellings, near one of the city's large hospitals, and a shopping district. Many of the children walked to school, and some took the bus in from neighborhoods farther away from the school. The classroom was located on the second floor of a three-story brick middle school built circa 1920. The classrooms had been modernized, halls and stairways were marble-floored, and the halls were lined with lockers. The classroom had a varnished hard wood floor, desks lined in rows facing the teacher's lab bench and, at the front right of the room, the teacher's desk, which faced the students' desks. Laboratory tops and sinks lined the back and right sides of the room--the room was designed as a science classroom. There was a blackboard and overhead projector and screen at the front of the room. The teacher had posted student work on the board from their previous work with "Consumers and Producers", and displayed around the room extra credit art work students had completed earlier in the fall.

The school was well-disciplined, and students were expected to complete all work satisfactorily before they could move to the next grade. The principal of the school was interested in student performance, and visited the classroom several times while I was there to question students about incomplete work, and encourage students to work hard. The school offered rewards to students who completed all work on time, such as a pizza party at the end of the second marking period.

In this school, students attended from 8:00 a.m. until 2:30 p.m., with six fifty-minute periods, and a lunch break in the middle of the fourth period. Students passed from class to class with different teachers and subjects each period. The science class met first period, and followed a twenty-minute homeroom time designed for signing assignment books, and completing administrative tasks, such as announcements, money collection, keeping track of late homework assignments, tardiness, and absence excuses. The teacher expected students to be in their seats when the second bell rang at 8:10 a.m., quietly reviewing or completing work, or reading. One appointed student took attendance, and another read to the class from the announcement bulletin. There was usually a public address good morning and announcements from the school principal or his assistant during homeroom time. The regular science class period began at 8:20 to 8:25, depending on the amount of administrative loose-ends the teacher had to complete for the day. Students often talked quietly, sometimes loudly, sharpened pencils, and caught up on each other's gossip during this homeroom period. The teacher occasionally had to ask the students to be quiet and find something productive to do until they were ready to start science class.

<u>The lessons and curriculum materials</u> The Matter and Molecules Unit was presented in six lesson clusters. The unit began with a lesson cluster about pure substances and mixtures, then moved to a second lesson cluster, understanding powers of ten and introduction to molecules, their size, behavior, and relationship to matter and non-matter. The third lesson cluster taught molecular behavior in the three states of matter, and introduced students to weight and volume changes when substances change state. The fourth lesson cluster introduced students to dissolving, and substance and molecular behavior when dissolving sugar in water. It also dealt with complex solutions, but due to time constraints, the teacher did not cover this section of the lesson cluster. The fifth lesson cluster covered substance and molecular behavior in thermal expansion of solids, liquids, and gases. This was the last lesson cluster the teacher had time for, although she briefly discussed the ideas that would have been presented in the last lesson cluster, substance and molecular behavior in evaporation and condensation.

Each lesson cluster was similar in design. Most began with a story, either a fairy tale, or a story that related to students' interests and backgrounds. The second lesson cluster that introduced students to powers of ten began with a parody on the movie, "Honey, I Shrunk the Kids". The story was titled, "Honey, I Shrunk and Shrunk and Shrunk the Kids", and told of the kids being shrunk by 10 times each time they were zapped with the ray gun. The teacher could tie the size of the kids at each zap with familiar objects progressively smaller on the powers of ten chart until they were no longer visible to the naked eye, and then until they were visible only with a microscope, to the point where they were unable to be seen even with powerful microscopes. This scenario opened the discussion of powers of ten, and what for instance, ten to the negative three (10^{-3}) meant in terms of relative size and the size of molecules.

The teacher usually began the class with a lecture, or review, and requests for answers to her questions from the students. She insisted that only the work at hand be on top of students' desks, and all other work be placed under their seats. If the lesson began with reading from text, she often had students volunteer to read a section of the text. If she thought students needed more clarification on the text, she would explain, draw analogies, and question students at random about their understanding. For example, before the students began to read aloud the story at the beginning of the Dissolving lesson cluster, the teacher made sure that the students would understand the story, and had the following exchange with the students:

Mrs. Peters:	*. . . this packet starts like most of the packets with a little story. . .Does anybody know what an "anase" is?*
Artie:	*A name?*
Mrs. Peters:	*Yes, it's a name for something, not a Nazi, but "anase" [a-nas-ee].*
Kenny:	*Spider?*
Mrs. Peters:	*Yes, it's a spider. OK, in here we have Chinua. . . and. . we have the rain god. . Norman, do you want to be the narrator?. . .Come on up front, . . please. . .*

The class continued with a reading of the story, and Kenny, Norman, Artie, and Irma taking the parts of the Chinua, narrator, rain god, and Anase. After the story was completed, the teacher reviewed and made sure the students understood.

Mrs. Peters:	*OK . . .these are some crystals that we're talking about, and what happened to the ones in the*

	story here? . . what happened in the story?. . .what happened to the crystals. . . what did he do? . . .what happened to the crystals?
Students:	*Ground them up. . .*
Mrs. Peters:	*Ground them up and made them into . . .*
Students:	*powder.*
Mrs. Peters:	*and then his other job was what?*
Students:	*Put them back as crystals.*
Mrs. Peters:	*Put them back as crystals. . .So these are some crystals that were made up, and this is what the story deals with. . .I'll give you a couple of crystals to pass back. . .Like this, these were the crystals that were ground into powder. . . And then the job was to get the powder to come back into crystals. . . Quite a problem we have. . .*

During her reviews and introductions, the teacher called on each student at one time or another, so students knew they might be called on to answer a question whether they raised their hand to answer or not. If a student had trouble answering her questions, she often rephrased the question, and coached the student until he could answer. The next day after students had read the story "Getting the Crystals Back" about the spider, Anase, the teacher reviewed the story at the beginning of the hour to remind students what the story was about. Here, she coached a student to help him remember what the class had discussed the day before.

Mrs. Peters:	*OK, let's look at the packet we're dealing with today then. . . we read about getting the crystals back. . Who can summarize the story. . .tell us in about 30 seconds what the story was about. . . remember? What was the story about. . . about the crystals. . .I had three or four people reading. . . remember what happened. . .Artie?*
Artie:	*That lady. . . that Chinua? He went to the rain god. . .and he had to do three tasks. .*

	.first he had to . . . second he had to crush the crystals. . . first he had to pick up the rock, then he had to crush the crystals, and then his third task was to put them back together again, but he couldn't.
Mrs. Peters:	*Why?. . .and when he crushed them what happened to the crystals?*
Artie:	*They turned into powder.*
Mrs. Peters:	*They turned into powder. . . and then who tried to help him out. . .remember?*

Sometimes the teacher would ask other students to finish answering a question, and asked the entire group if they agreed with the students' answer. The teacher would then go on to clarify in lecture format, alternately having a student read, or she would read, then question students to check their understanding, as she did in this segment:

Mrs. Peters:	*OK. . "Heating a Metal Ball" . . Norman, you may begin reading. . .*
Norman:	*[reads] "What do you think will happen if a metal ball is heated, but not enough to make it melt? Let's find out. Your teacher has a special ball to heat. Notice that its <u>volume</u> is exactly large enough so that it barely fits through a metal ring."*
Mrs. Peters:	*OK, let's see what Norman read about. . . here's the metal ball [shows students metal ball and ring apparatus], here's the ring, and it. . . what?*
Students:	*[simultaneously] Barely fits. . .just fits. . .*
Mrs. Peters:	*Barely. . .that means its just a little bit. . .*
Students:	*[simult] dangerously close. . .smaller. . .*
Mrs. Peters:	*Smaller, right? . . .than the hole or this ring is. So, it does fit through here. . . [to Norman] You have a question, go ahead, Norman.*
Norman:	*[reads] "What is its weight?"*

Mrs. Peters: ***OK, I'm going to weigh this for you...***

Once the story in the lesson clusters had been introduced, the lessons provided a conceptual change strategy of teaching where students were asked to write down and discuss their real-world notions of phenomena, then discuss and share their ideas in small groups. The plan for the curriculum design was to make students aware of their prior conceptions about the subject. The lessons then provided students with scientific knowledge about the phenomena, and gave students practice with applying, explaining, and predicting events using the new conceptions. For this, the lesson clusters often provided opportunities for students to experiment with substances, talk about their ideas in small groups, and write and discuss their new understandings with the larger group, led by the teacher.

Students were usually first asked to think and write about questions and examples individually, and then in small groups of four or five students to come to new consensus and understanding. Here students prepare to do a dissolving activity by thinking first about the size of the holes in the teabag, the size of sugar crystals, and how to get the crystals out of the bag.

Mrs. Peters: ***OK... let's look at page 2. We're going to start this activity with the sugar and teabag activity... Activity 1. In this activity, as we have done with many of our activities, we will first work individually, and then we'll work in our group... tomorrow we should be able to do the individual and the group.. . follow along please, second page... [reading from booklet] "We learned in the last lesson cluster that particles come in many different states"...***

Students: ***sizes...***

Mrs. Peters: ***"sizes... particles that we can see, such as grains of salt or specks of dust each contain billions or trillions of molecules,***

which are the smallest particles of a substance. Let's see if you can use these ideas to solve a problem"... remember our powers of ten chart?... two grains of salt was what?

Students:	*Ten to the negative three.*
Mrs. Peters:	*Ten to the negative what?*
Students:	*Three.*
Mrs. Peters:	*Two grains of salt... [reads from packet] "The problem is this: Your group will soon get a closed teabag with sugar in it. Can you figure out a way to get the sugar out of the bag without tearing or opening the teabag? This problem is like the separating mixtures and the spaceship problems that you did earlier in that it is a practical problem"....(Charles is not paying attention) [to Charles] Can I go on?*
Charles:	*[nods yes]*
Mrs. Peters:	*[reads] "You are trying to figure out how to get a job done. Sometimes the best way to solve a practical problem is to 'just do it'. Sometimes, though, it is important to be thoughtful about how you solve practical problems. Remember that engineers, who are people that solve practical problems all the time have found that thoughtful solutions to practical problems include a plan"... first you need a plan...[reads] "and an explanation of why you think the plan will work"...and what's an explanation?.. We've got to think about the..*
Students:	*[inaudible]*
Mrs. Peters:	*We have to think about the what?... we have a plan, then our explanation will include what?*
Students:	*molecules...and statements about substance...a statement about molecules.*
Mrs. Peters:	*[simultaneously] substance, right?*
Students:	*and statements about molecules...*

Mrs. Peters:	*and statements about the molecules. . .right, that's right. [reads] "In this activity you will work in your groups to get the sugar out of the teabag. Before actually trying to get the sugar out of the teabag, you will make plans and explain why you think your plans will work. You will need these materials: Sugar, a teabag, a magnifying glass, and a ruler." . . .*

After the group activities, the teacher debriefed students in the whole class setting by clarifying and questioning to check understanding. The day after the group worked on their plan to get the sugar crystals out of the teabag, the discussion was as follows:

Mrs. Peters:	*With your teabag, and your grains of sugar, which ones are the largest. . . the holes in the teabag, or the grains of sugar?. . .Agnes?*
Agnes:	*The grains of sugar?*
Mrs. Peters:	*OK,. . . and when you drew the two in the box up there you should have shown this. . .now grains of sugar magnified a hundred times, and the holes in the teabag magnified a hundred times looks much larger, but when you drew that on there it should be . . . you should be able to tell that your grains of sugar are indeed larger. . . then you did the bottom by yourself, and then you did it with a group. . . OK, on page 4 you had your plan, what you expected to do, your facts, your observations, what you knew, what will happen to the substance. . . what substance are we dealing with?. . . what's the substance?*
Carol:	*Sugar.*
Mrs. Peters:	*Sugar. . . and what will happen to the molecules, then you have your group plan and you did. . after discussing it, then you did the activity on page 5. On page 5, you also had filled in what happened when you tried your plan, so in your group, if you weren't here, be sure you see someone in your group to explain to you what*

	happened when you tried your plan. Then we took some water and touched the teabag with the sugar into just the surface of the water, to bring the bag over the rim of the cup, and just enough water to reach the bottom of the teabag. What happened when you touched the teabag, very shortly after the teabag with sugar in it touched the surface of the water . . . what did you see happen? . . . and that's what our picture is. . . what did you see happen, Jose?
Jose:	*It was. . um. . getting out of there. . .*
Mrs. Peters:	*What did you see?. . [waits] . what did you see?*
Jose:	*It started disappearing into the water. .*
Mrs. Peters:	*What's "it"?*
Jose:	*The sugar.*
Mrs. Peters:	*You saw the sugar disappearing? . . What did you see? What you did, you had a cup with water in it, and what did you see? Here's a teabag with sugar, what did you see? You had a teabag with sugar. . . [takes cup of water and teabag with sugar in it, goes to Jose's desk and holds it for him to look at] . . what did you see? Look, look, . . what do you see? Under the teabag? Watch. What do you see?*
Jose:	*It's coming out.*
Mrs. Peters:	*What is?*
Jose:	*The sugar.*
Mrs. Peters:	*How do you know that's sugar?. . What does it look like under the teabag? . .*
Jose:	*It's just coming into the water, and. . .*
Mrs. Peters:	*What does it look like? . . .How did you draw it?*
Jose:	*Little lines?*

Mrs. Peters: *OK! That's right. You saw little, kinda, swirly lines. . .In fact, some people I heard them say they thought it looked like oil. . .it looked like when you put oil in water. . .[shows cup with water and teabag of sugar to other students] You can still see it pretty good. . I don't know if you were here, Antoine [shows to Antoine]. . . see under the teabag? . . see something?*

Antoine: *[looks under cup] Yeah.*

Mrs. Peters: *That's what you draw in that space, under . . . that goes right in here. . .so we should have our drawing under there showing these little bit of a wavy-type lines. Is there anyone that didn't see that happening. . under the teabag? . . .Is there anyone that didn't see this?. . under the teabag? . . . OK, so all of you. . see that going on. . . [reads from booklet] "Taste the water in the cup, and what did you taste?" For those of you who did taste it, what did it taste?. . What did you taste?. . .Charles?*

Charles: *It tasted like. . sugar and water.*

Mrs. Peters: *OK. So you tasted, . . .it tasted sweet. . or it tasted sugary, or the water tasted sugary. . .so you should have an answer down there. OK, let's look at page 6. All of that should be done, up until that far. . . This is the part that you have to do before getting into your group. [reads] It says: "Try to explain what happened to the sugar in the teabag. Write your own answers to the questions below, then discuss them with your group, and write the answers that your group agrees on. . . " So, by yourself first, . . .*

At the end of a lesson cluster, students would usually take a quiz where they were asked to apply their new knowledge to problems, some familiar, and some new. The chart in Table 3.1 shows the conceptual framework for the Matter and Molecules Unit.

TABLE 3.1

Conceptual Framework for Revised Matter and Molecules

Important Ideas about Matter and Molecules

1. All solids, liquids, and gases are substances or forms of matter.
2. All matter is made of molecules; other "stuff" (such as heat and light) is not made of molecules.
3. The molecules of pure substances are all alike; mixtures contain different kinds of molecules.
4. All molecules are constantly moving:
   - -In solids they stay closely packed and vibrate in place.
   - -In liquids they stay close together, sliding and bumping past each other.
   - -In gases they are farther apart and move freely through space.
5. Heating a substance makes the molecules move faster; cooling makes the molecules move slower.
6. Air always contains water vapor (as well as nitrogen, oxygen, and carbon dioxide).

Types of Substances	Changes in substances	Molecular explanations
Pure substances -water -sugar -salt -alcohol -oxygen -nitrogen -carbon dioxide -clean sand -(add others as they come up)	1. Dissolving: solids dissolve in liquids.	1. Dissolving: molecules of the solid break away and mix with molecules of liquid.
	2. Separating mixtures: one substance is separated from another.	2. Separating mixtures: different kinds of molecules are separated.
	3. Thermal expansion: substances expand when heated.	3. Thermal expansion: molecules of hot substances move faster, so they push each other farther apart.
Mixtures -air -salt and pepper -sugar and sand -shampoo -salt water -sugar water -(add others as they come up)	4. Melting: solids change into liquids when they are heated.	4. Melting: molecules of the solid break apart and start sliding past each other.
	5. Freezing: Liquids change into solids when they are cooled.	5. Freezing: molecules of a liquid slow down and settle into a pattern.
	6. Boiling: liquids turn into gases and bubble away when they are heated.	6. Boiling: groups of fast-moving molecules break apart, make gas bubbles.
	7. Evaporation: Liquids slowly turn into gases and mix with the air.	7. Evaporation: individual molecules escape from a liquid.
	8. Condensation: gases turn into liquids when they are cooled.	8. Condensation: gas molecules clump together in drops when they move more slowly.

Design

This research was qualitative and interpretive in design. In interpretive research investigators observe participants to assess the meaning of their actions within the social context. Qualitative research has the following theoretical assumptions: "Humans create meaningful interpretations of the physical and behavioral objects that surround them in the environment, and take action toward the objects that surround us in light of our interpretations of meaningfulness" (p. 126), and individuals may have different interpretations of the meaning of what appears to be the same or similar objects or behaviors. The object of interpretive research is subjects' physical behavior and their meaning interpretations, and those of the others they are engaged with in interaction. The main questions of qualitative research have to do with the mental life of the subjects, and the sense they make from events. In this study, the mental life studied and interpreted was students' thinking about matter and molecules, and the meaning they made from instruction to restructure their knowledge about matter, physical change, and molecules. By pursuing interpretive research, my task was to discover some "concrete universals from studying a specific case in great detail to compare it with other cases studied in equally great detail" (Erickson, 1986, p. 130). The researcher studied six cases in detail—target students' proposed schema as they learned about matter and molecules, based on their writing. The researcher then compared the six target students' written and verbal statements. Then the six target students' cases were compared with schema changes of other students in the class, based on students' writing about content.

The criterion for validity in interpretive research is the meaning of actions defined from the actors' point of view (Erickson, 1986). In this study, I attempted to infer the meanings students made within the classroom context of learning science in order to change their conceptions about science. The literature review provided several means of arriving at some understanding of the meaning students made as they learned science: Writing, verbal statements, small group work, and clinical interviews provided for making meaning of students' understandings. My methods of analysis were similar to other researchers' analyses, and eventually became a combination of methods using both qualitative interpretations, and quantitative coding and analysis. Staton's (1982) methods to track students' writing about a topic over time, and Chi, Glaser, and Rees' (1982) methods to construct semantic node-link networks from students' written and verbal statements to observe their proposed schema about content were useful for following students' thinking. Vosniadou and Brewer's (1987) and Carey's (1985b) descriptions of knowledge restructuring were useful for assessing students degree of restructuring from their schema pictured in the semantic node-link networks. Students' goal conception attainments were assessed using Lee, Eichinger, Anderson, Berkheimer, and Blakeslee's (1990) pretest/posttest and clinical interview and coding scheme. Students' use of strategies for learning from instruction were assessed using Anderson and Roth's (1988) descriptions of students' processing of science texts.

According to Erickson (1986), there are five major types of "evidentiary inadequacy" in interpretive research (p. 140). I address each of these five types to build a case for the adequacy of my evidence, and thus, the validity of the results, to some logical degree.

(1) ***Inadequate amounts of evidence:*** In this study, I attempted to draw as much evidence as possible given the restraints of classroom activities. I wanted to get as much student writing evidence as possible, but not add so much writing to the lessons that it would be unrealistic to expect classroom teachers to use the methods for observing indicators of their own students' thinking. The use of videotapes and clinical interviews added more evidence. Had I been able to interview each student my evidence would have been much richer, but realistically this was not possible due to my time constraints and those of the students and teacher involved.

(2) ***Inadequate variety in kinds of evidence***: I attempted to gather as much variety of evidence as possible to help me determine students' thinking. Student writing in activity books, quizzes, freewrites, verbal statements in class that occurred on the videotapes, and statements during interviews were used as evidence.

(3) ***Faulty interpretive status of evidence***: Faulty interpretive status of the evidence is probably one of the most difficult aspects of interpretive research, and I had to be somewhat confident that I understood the key aspects within the students' perspectives and the meaning they made from their science lessons. To help with this, I enlisted other researchers' interpretations of the same data to corroborate my interpretations.

(4) ***Inadequate disconfirming evidence***: To alleviate the potential problem of inadequate disconfirming evidence it was necessary for me to make a deliberate search for disconfirming evidence of my key assertions. I attempted to identify discrepant cases, and develop possible alternatives to my interpretations. I requested help from other researchers in locating disconfirming evidence, and discrepant cases, as well.

(5) ***Inadequate discrepant case analysis***: Erickson suggested that the interpretive researcher scrutinize the disconfirming evidence and examine each discrepant case to compare it with the confirming cases, and analyze the features that are the same or different to reveal flaws in original assertions, and allow researchers to refine and adjust their major assertions. In chapter 5 of this report, the disconfirming and discrepant evidence are analyzed.

Instruments and Procedures

The instruments used to measure students' conceptual changes were students'

(1) Written answers to paper-and-pencil pretest and posttest questions;

(2) written explanations in students' science activity booklets and freewriting exercises;

(3) for six target students, verbal answers during pre-clinical and post clinical interviews about matter and molecules;

(4) target students' thoughts about writing;

(5) videotapes of classroom interactions;

(6) my summary observation notes;

(7) an interview with the teacher about her goals and plans for instruction; and

(8) the text materials used by the students during the lesson unit.

I discuss each in more detail, along with the procedures I used to collect the data, in the following section.

Student writing. Students wrote about science in four ways:

(1) Students wrote answers and explanations on a paper-and-pencil pretest about matter and molecules;

(2) They wrote ideas, plans and explanations in their activity booklets during instruction;

(3) Students wrote occasional freewrites using their new ideas about content; and

(4) Students wrote answers and explanations on a paper-and-pencil posttest following instruction.

Copies of students' written work were collected as the unit progressed—paper-and-pencil pretest and posttest answers, written notes in activity booklets, freewrites, and quizzes. The pretests and posttests, and the freewrites were collected immediately after students completed them. The activity booklets and quizzes were collected after the teacher had read them, commented, graded and returned them to the students. After each lesson cluster, and after the students had a chance to look at the teacher's responses, students passed the booklets and quizzes back to the teacher and the booklets were collected from her. The students knew I was observing their work to see what they wrote and to see how they learned science. I describe how I analyzed the conceptions in each student's writing in a later section of this chapter, Data Analysis.

Reliability. To establish the reliability of the interpretations of students' writing, I wrote criteria for my assessments of students' writing for knowledge restructuring and changes in core concepts over time. I then gave two other raters the criteria, transcripts of randomly selected target students' writing and the semantic node-link networks constructed from the writing. The two other raters interpreted students' written ideas and node-link networks using the criteria I had provided for them. After further discussing the categories and defining attributes of the examples, the other raters agreed with the interpretations. Both stressed that the categories be clearly defined and applied uniformly across all student samples to ensure reliability. We further discussed the categories, defining attributes and examples until we were able to reach agreement. One rater was a professor with many years of experience interpreting students' ideas about matter and molecules, and the other was a doctoral student with experience with students' conceptions about matter and molecules.

Pretest and Posttest. The pretests and posttests used in this study were revised tests that were developed by Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990) in their study observing students' conceptions about Matter and Molecules. The pretest and posttest are identical, administered once before instruction, and once following instruction. (See Appendix B for a copy of the test.) The pretest/posttest can be used to assess each student's belief or non-belief in different conceptions using coding procedures from open response and multiple choice items developed by Anderson and Smith (1983) and Roth, Smith, and Anderson (1983). Anderson and Smith (1983) wrote computer programs that used information from different test items assessing the same conception to produce a score reflecting the strength of whether a student's understanding of a scientific goal conception, ambivalence (somewhere between scientific and real-world or alternative), or belief in a real-world or alternative conceptions about the content. The test was designed to generate information about students' prior knowledge/alternative conceptions and how closely they reached the scientific goal concepts of the instruction, and to reveal change from pretest to posttest. The pretest/posttest was designed to help researchers diagnose students' beliefs and thinking about the nature of matter and physical change, and to disclose students' conceptions about the various concepts covered in the unit. The test included 22 questions in both multiple choice and short essay formats. Eight of the questions were short answer or multiple choice, and the other fourteen questions required students to explain or describe. Many of the questions asked students to explain physical phenomena. For instance, one question asked students to "Explain in your own words why heating makes water boil. Explain in terms of molecules, if you can" (p. 7). The questions examined students' ideas about the nature of matter at both macroscopic and microscopic levels. At the macroscopic level, students were asked to explain substances and their properties, and at the microscopic level, molecules and their properties.

I administered the paper-and-pencil pretest the day before the lesson unit began during the students' first hour science class. Students were instructed to answer the questions the best they could, that it was alright to get wrong answers, and they would not be graded. Students were told that the tests were designed to show their thinking about these science concepts. Only one student of the 27 missed the pretest. The same student, and one other student, missed the posttest. These two students did not make up the test, because there was other writing from both students that could be used for the analysis, and the students would have had to come in after school to complete the tests, which was an inconvenience for them. Because the analysis did not count scores, or take averages, it did not seem worth inconveniencing these students to get pretest and posttest writing from them. There were rich sources of data from the other 25 students, probably more than could be studied in detail. Students were able to complete the test within their 50 minute class period. The students' written explanations on the test were used to analyze their conceptions about the content, and the tests were coded the same as Lee and her colleagues (1990) to get a conception score that could be compared with the assertions from the node-link networks from students' written statements. This test is valid because the results have been replicated with other student populations before and after lessons in matter and molecules (Lee, Eichinger, Anderson, Berkheimer, and Blakeslee, 1990).

The same paper-and-pencil test was administered as a posttest on the first day of the second semester, following the semester break. This was the first day following the end of the instruction that students were in class. The instructional unit had lasted until the last day of the first semester. Neither the pretest or the posttest were graded. The same instructions were provided before the posttest that had been provided before the pretest: Students were to answer the questions the best they could, and attempt to explain the best they could. However, they were not told that the tests would not be graded, because the students might not try as hard to write complete, accurate answers if their efforts would not contribute to a good grade. I describe how I analyzed the pretest and posttest measures in the Data Analysis section of this chapter.

Reliability. The pretest and posttest were the same test administered at the beginning and the end of the unit. These tests had been used in similar form by Anderson and Palinscar (1990) the previous year in Year 1 of their study, and by Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990), in their study of sixth grade students' conceptual change in matter and molecules. These researchers had found that more than 70% of the time, when independent researchers blindly coded randomly selected pre-clinical interviews with pretests from the same student, and post clinical interviews with posttests from the same student, their coding agreed with one another.

I provided for interrater agreement by meeting with two other raters, who were working with the Anderson and Palincsar research project, and had experience coding pretest and posttest statements about matter and molecules. We practiced coding randomly selected pretests and posttests, and independently coded tests, then checked our coding for agreement with one another. We discussed our responses until we agreed on how the coding instrument would be interpreted and applied, then independently coded five more randomly selected tests. We continued this procedure once more, until we had reached more than 90% agreement. The pretests and posttests were coded by concealing the identity of the student taking the test, whether it was a pretest or posttest, and randomly shuffling the order of the tests so the identity of the student was unknown to me, or whether it was a pretest or posttest. Another rater randomly selected ten of these tests and independently coded each. We compared our coding, and had more than 90% agreement on the codes we assigned.

Interviews. I interviewed the teacher to understand the instructions that she provided for the students' writing and their lessons, to see if her plans for instruction were consistent with my purposes for observing students' thinking about the concepts they were learning in science. The protocol for the teacher interview was open-ended to the extent that I asked the teacher to inform me of her learning objectives, her philosophies about how students learn science, what she planned to attempt in her classroom instruction, and the goals of the students' activities. The questions asked of the teacher are listed in the Teacher Interview Protocol, Appendix D.

I also interviewed the six selected students before the unit began, to investigate their prior knowledge about matter and molecules, and their prior experiences and knowledge about writing to learn. I interviewed each of the same students again following the instructional unit, and following the paper-and-pencil posttest. The interview protocol followed a semi-structured "clinical" format to assess students' content understandings as thoroughly as possible, while also maintaining a more or less natural conversation with them. Clinical interviews furnish a procedure for exploring the nature and extent of knowledge. Clinical interviews have been used by many researchers as a means of probing students' alternative conceptions in science, and for attempting to ascertain students' thinking. (Posner & Gertzog, 1979). The interview was structured in such a way that the interviewer could uncover students' thinking, and get a picture of their cognitive structures. For example, at the pre-clinical interview, each of the students was asked to observe a beaker of water boiling on a hot plate. Then each was asked to explain what he or she observed. The questions went something like this: "What's happening to the water?" "Describe what you see." "If we leave the water boiling, what happens to the amount of water in the beaker?" "Why?" "Where does the water go?". If the student mentioned bubbles, the next question asked "Is there anything in the bubbles?" "What?". If the student mentioned "air", the question was "Do you think the air in the bubbles is the same as the air in the room?". If the student mentioned "steam", the next question was "What do you mean by 'steam'?". The questioning continued to probe students' understanding of molecular behavior in boiling by asking questions such as "How does the water change from liquid to gas?", and "Can you explain in terms of molecules?", and "Which has more space between the molecules, the liquid or the gas?". Students were asked to explain the differences between different states of water (ice, water, and steam), molecules in water, molecules in other solids, liquids, and gases, molecules in air, how air expands and compresses, explain dissolving, heating and cooling, and expanding and contracting, melting and solidifying, evaporation and boiling, and condensation (see clinical interview, Appendix C). Each interview lasted from 30 to 45 minutes and was conducted in private in an empty classroom. Each interview was videotaped.

The six selected students were asked to tell about their prior experiences with writing to explain their thinking, and their feelings about writing (see Appendix E). They were asked if they had some facility with the written discourse form they were using, thus allowing them to write more freely about their thinking. I wanted to know for what purpose the students saw the writing in the beginning and throughout the lesson--did they perceive the writing was only for grading purposes? Or did they see other purposes for writing about what they were learning?

The purpose of the interviews was to inform my understanding of what meaning the students were making as they involved themselves in learning new concepts and fitting them into their conceptual frameworks, and how this related to how they wrote about their thinking, and what they wrote about their conceptual understanding. The questioning was designed to find out if the writing activities the students accomplished were difficult for them, and whether or not those activities interfered with their abilities to put their ideas in writing. If the writing was difficult, it might confound the ability to "see" thinking in their writing. How much the writing act itself might have influenced or contributed to students' knowledge restructuring was an important aspect, because the literature review showed that inactivity and reflection, possibly in the act of writing, might be an important classroom event associated with knowledge restructuring. The same six target students were interviewed periodically throughout, and following the learning unit to investigate their thinking about how the writing might have shaped their thinking, and how well they were able to express content in their writing. Some of the questions asked were about the relative difficulty of the writing tasks, their awareness of using any writing strategies during their activity completion, and any particular difficulties they found in carrying out plans for writing. The students were also asked what other types of writing they were currently required to do in school, and the relative difficulty of this writing. Each was asked to evaluate his or her own ability in science and in writing, and comment on the ways those abilities had changed because of what they have learned in school the past few years.

Students were asked if their writing helped them think in any different ways, and if their writing ever changed as they wrote (see Appendix E).

Reliability. The clinical interviews or interviews about writing were not quantitatively coded. I chunked students' verbal statements by topic, and compared them to students' written statements about the same topic. Essentially, the students' verbal statements about the content were used as a reflection of students' thinking about the content to check the reliability of the interpretations of their thinking reflected in their writing. Students' verbal statements from the interviews were compared with their written statements about the same content, and interviews were used primarily as a check on the interpretations about student thinking. The students' statements in the interviews about writing were analyzed to understand how their writing might have influenced their ability to write their ideas, and how the writing tasks might have contributed to students' knowledge restructuring. The reliability of the interpretations comes from support of the other evidence of students' thinking available, such as verbal statements during class, and other written materials. I describe how the interview records were analyzed in the Data Analysis section of this chapter.

Transcribing. All of the students' written comments were transcribed into Microsoft Excel spreadsheet computer program that would allow me to move pieces of data easily from one file to another. Everything a student wrote in the pretest was transcribed into a file for that student, and statements were flagged according to different pieces of the lessons, such as statements about molecules, molecular movement, states of matter, dissolving, and thermal expansion. For each lesson cluster, a file was built for each student, into which their written statements were transcribed chronologically for the same subject matter. The same transcribing for students' statements on the posttest was placed into a posttest file similar to the pretest file. Students' pretest and posttest statements were transported into their subject matter files, for a transcribed record of what a student said about the same subject over time. Figure 3.1 shows part of one student's file for everything she said about states of matter. The verbal statements that the six target students made about the content on pre-clinical interview and post clinical interview were transcribed into separate files organized by lesson cluster subject matter, and appropriate statements were transported into their subject matter file. For example, target student Carol's file on molecules contains her statements from the pretest concerning molecules and molecule behavior, the

Student: Irma **CONCEPTIONS ABOUT STATES OF MATTER**

Pretest	States of Matter Booklet	Quizzes	Freewrite
water weighs same as ice because its the same thing only liquid heating a solid makes it melt because the heat makes it softer and it melts freezing: molecules slow down and fit in pattern bubbles=molecules heat is so hot that the molecules start to jump, and they jump so much the water starts to boil	ice melts, it turns liquid instead of staying solid water boils, bubble start to form and then gases water will rise from the cup pure ice and pure water are both pure because ice is the same as liquid water, just in the solid state if you put them together it would still be a pure substance molecules and are in bubbles; steam is water, only in a gaseous state; molecule in solid=locked in a rigid pattern close together, vibrate in place, do not move past	weight doesn't change but volume does water boils, volume decreases molecules are getting farther and farther apart; weight same, same amount of molecules; wax melts, volume increases, molecules are getting farther apart. weight stays same, same amount molecules.	the snow is melting and the molecules are moving farther apart. They are not far apart, but they are no longer stuck in a rigid pattern. So when they are in a different pattern, the snow will become in a different state.

Figure 3.1 A portion of Irma's file for her conceptions of states of matter across time.

pre-clinical interview, the activity booklet, freewrites, posttest and post clinical interview, all statements about molecules, and positioned chronologically from pretest to posttest in the file. Figure 3.2 shows a portion of Carol's file on the subject of molecules. When the time came to analyze students' writing from these files, the identity of the students was covered and the printed files were shuffled. Semantic node-link networks were constructed from these transcribed records, and interpretations made about changes in *core concepts* and knowledge structures without knowledge of which student's records were being interpreted. I described the reliability of my methods for analyzing knowledge restructuring changes in core concepts, and goal conception attainment in the above section, Student Writing.

Student: Carol — CONCEPTIONS ABOUT MOLECULES

Pretest	Pre-Clinical Interview	Nature of Molecules Booklet/ freewrite	Posttest	Post Clinical Interview
molecules are air bubbles in a liquid; air, helium steel, water, salt water made of molecules; not=smell, mud heat, light? don't know same size as dust speck move in air, not in rock; stop when air gets frozen	not sure what molecules are; maybe specks, close together much smaller than dust, not sure; not moving molecules in solids, always same, same color, shape, not moving; not moving in water; air is gas that floats around	matter is anything made of molecules non-matter is any-thing not made of molecules; pure is made of only one kind of molecule mixture is made of 2 or more kinds of molecules; might see molecules under microscope water & glass are different molecules light is not matter	molecules are what makes up the substance made of: air helium, steel water, smell mud, salt water, not=heat, light trillions times smaller than dust speck; move in air, rock, always move, never stop	molecules all are moving; small; dot is trillions times bigger; hard to see under microscope solid-in a rigid pattern; liquid-kind of in between, in a mixture too; move a little bit farther apart out of its rigid pattern, but not enough to move freely; gas-moving freely

Figure 3.2 A portion of Carol's file for her conceptions about molecules.

Videotape records of classroom events. Each lesson in the instructional unit was videotaped using two video cameras for a total of 49 days over five lesson clusters. One camera was located at the back of the room focused forward on the teacher and the overhead projector, and the other camera was positioned at the front right of the room focused on the students. During small group interactions, one camera and microphone was placed with one target group, and the other camera and microphone was placed with the second target group. I recorded the date and running time on each videotape. Both cameras were synchronized to match actual clock time, and each other, as closely as possible. I describe how the videotapes were analyzed in the Data Analysis section later in this chapter.

Text: Activity Booklets. Each lesson cluster had a separate activity booklet (text) that students used to guide their learning with questions to answer, drawings to make, text to read, and places to write their plans and explanations. The activity booklets (Anderson & Palincsar, 1990) were designed to support students' conceptual change by having students write and discuss their real-world knowledge about matter and molecules, then gain new knowledge from text and experiments, and attempt to explain phenomena and events using their new knowledge. The text was designed to help students and the teacher confront real-world or alternative conceptions about matter and molecules, and begin to see how their prior knowledge may or may not fit with their new, more scientific ideas. I describe how two of the lesson clusters were analyzed in detail in the Data Analysis section of this chapter.

Summary: Subjects, Data Collection, Design, Instruments and Procedures

My subjects were drawn from a middle school sixth grade class in an urban setting with 27 students of mixed ethnic and socioeconomic backgrounds. The sample was part of Anderson and Palincsar's (1990) three year study of teaching for self-regulation and small group problem solving in a unit about the nature of matter and physical change. The classroom was a sixth grade science classroom located in a 60-to-70 year old building. The lessons consisted of short lectures, questioning, reading, individual and group student activities, and quizzes. The text was a revised unit on Matter and Molecules (Anderson & Palincsar, 1990; Berkheimer, Anderson, Blakeslee, 1990) that included opportunities for students to confront their real-world conceptions, and use new more scientific knowledge in explanations, predictions and problem-solving both individually and in groups. This study was primarily descriptive and interpretive: I was interested in finding out the different ways that knowledge is experienced and understood by learners, and in illuminating the possible mechanisms that might be associated with students' changes in understanding of science content. All student writing, target students' verbal statements during clinical interviews, and during classroom discussions within two lesson clusters, and videotapes of classroom interactions were observed to help identify links among the various forms of data, and make assertions about the processes sixth graders go through when attempting to learn about matter and molecules.

Limitations

There were limitations to this study, the most problematic of which was my inability to directly access students' thoughts. All of the results were based on interpretations of students written statements, backed up by six target students' verbal statements. The other important limitations were as follows:

(1) The most obvious was the limitation of a student's writing ability and his or her possible inability to express ideas in writing. To help adjust for this limitation, I took care to look closely at what the six target students said verbally about the content, to see how it compared with their written concepts. What students' verbally expressed during class discussions and in small target groups was observed to see how closely their verbal statements matched their written statements.

(2) And because learning is recursive and dynamic, and conceptual change may take a long time, there may have been times when students expressed a concept in clear scientific goal conception terms, and a later time when they momentarily lost their commitment by questioning their ideas with new problems. Such questioning and going back and forth between conceptions is necessary for meaningful learning, but may confound my observation of students' learning across time, because the time line is artificial and imposed by me. Students do not learn in a linear fashion. I attempted to modify this limitation by observing all the utterances about the content that students made, written, or verbal, within the classroom context. In this way I could be more confident that what the student wrote was a close representation of what the student believed to be true.

(3) There were also limitations to the semantic node-link network method used to analyze student utterances. There were

limited concepts that could be followed, due to the time limitations of a study such as this. Thus, there could have been other concepts in students' thinking that were not tapped, due to the nature of the lessons, the writing, and the limitations of the clinical interview. Students may have known more than was asked or followed. Students may have been able to identify and recognize concepts that go together and make sense in their schema of understanding matter and molecules, but not mention those when they wrote or spoke about the concepts. So there might have been concepts missed in the analysis of their potential schema about the content. This limitation was modified to a degree by the clinical interview with the six target students, because prompts were provided, with words they might identify and use to construct their explanations that were not present during their writing exercises. Thus, there may have been some understandings they expressed verbally that did not appear in their writing. And consistency could then be checked between what students wrote about the concepts, and what they verbally said about the same concepts.

(4) Another limitation was my interpretation of the restructuring I saw in students' writing, the interpretation of the classroom events, and how those events related to students' knowledge restructuring. The interpretations were based on this researcher's prior knowledge and experience with learners, and were biased to the degree that her beliefs about how students learn influenced the interpretations. To help balance this

limitation, as much information as possible is provided about what was found and how it was interpreted so that others with different backgrounds and prior knowledge might have a go at making their own interpretations, and either add more credence to, refute, or revise the considerations with new aspects. Care was taken to check out the interpretations with other scholars experienced and competent in interpreting children's thinking about matter and molecules to help modify the inevitable limitations of the interpretations.

Other limitations of this study lay in the

(5) narrow cross-section of students studied,

(6) the limited access to students' thinking processes,

(7) the limited ability of student writing to display their thinking,

(8) my limited abilities to interpret students' writing, and

(9) how students were making some sense of what they thought and what they were learning.

Students' writing may or may not display their thinking based on how easy they find the writing task, and what they perceive the task to be. This limitation was modified by interviewing six of the target students, and comparing their verbal statements to statements they had written about the same content. When there was a match, what students wrote was likely to be close to their thinking. Interviewing the six target students about their perceptions of the writing tasks to assess whether the writing task might have limited students' ability to write their thoughts helped modify this limitation as well.

Data Analysis

Erickson (1987) asserted that reporting interpretive fieldwork research such as this has two basic tasks. The first task of data analysis is to "generate. . . assertions largely through induction. . .searching the data corpus---reviewing the full set of field notes, interview notes or audiotapes, site documents, and audiovisual recordings" (p. 146), looking for links among the various forms of data. The other task of interpretive data analysis is to establish enough evidence to support the researcher's assertions, by repeatedly searching the data corpus to test the validity of the assertions. In the analysis reported here, I have searched the data corpus available to me---all students' writings, their classroom statements, and the statements of the teacher and curriculum materials--to arrive at some assertions about the processes that sixth graders go through when attempting to learn about matter and molecules. Erickson's second suggestion was followed in an attempt to establish evidence to support the assertions with accounts from the same and different kinds of data, and establish some links among the various forms of data. In the following section, I describe how each form of data was analyzed and interrelated to arrive at the important links that form the interpretations. I have organized the presentation around the research questions.

Question 1: Do Students Show in their Writing that they are Restructuring their Knowledge?

Analyzing Student Writing

Constructing semantic node-link networks. Once I had a complete record of students' transcribed written records, and had concealed the names on each record, the records were shuffled so that the identity of the records sugar, so "heat", and "burns" were connected to "sugar". His last statement was that "sugar dissolves faster in hot water", so "dissolves" was connected to "sugar", and from there to "faster", since he mentioned that next, and then to "hot water", which was placed up near "heat" since the hot water Artie mentioned was related to the heat he had mentioned earlier.

Finding evidence for restructuring. The first research question asked whether, if students provided evidence of knowledge restructuring, how much did they seem to be restructuring their knowledge. The presence of different concepts and structures about a conception than the student originally possessed, and an increase in number and kinds of domains that the student associates within the conception were evidence of ***radical restructuring***, more of a conceptual change in thinking (see the Knowledge Restructuring chart, Figure 2.1, this document, page 21). The presence of merely more concepts and a slight change in structure about the conception, with similar domains associated within the conception were evidence of ***weak restructuring***, and likely little conceptual change, or change of their alternative conceptual frameworks. I attempted to determine: Were students restructuring their thinking at all, and if they seemed to have restructured, how much restructuring did they seem to be accomplishing?

The changes observed in the networks were analyzed for numbers of core concepts, changes in core concepts, changes in organization, number of links, and sophistication of the networks. I mapped each concept within a student's topics in similar fashion, and compared the structures of the maps for differences in the number of concepts they contained, compared the structures of the concepts to see if structure changed over time, and if ***core concepts*** changed over time. The different domains that networks attempted was concealed. Semantic node-link networks were constructed at each point in time across the continuum of a student's writing from pretest to posttest. I examined each conception for a given student for evidence of restructuring by using semantic node-link networks, where the nodes are key terms related to the conceptions mentioned by the student, with links joining the concepts that the student mentions concurrently. Figure 3.3 shows the semantic node-link network constructed from Artie's pretest statements about dissolving.

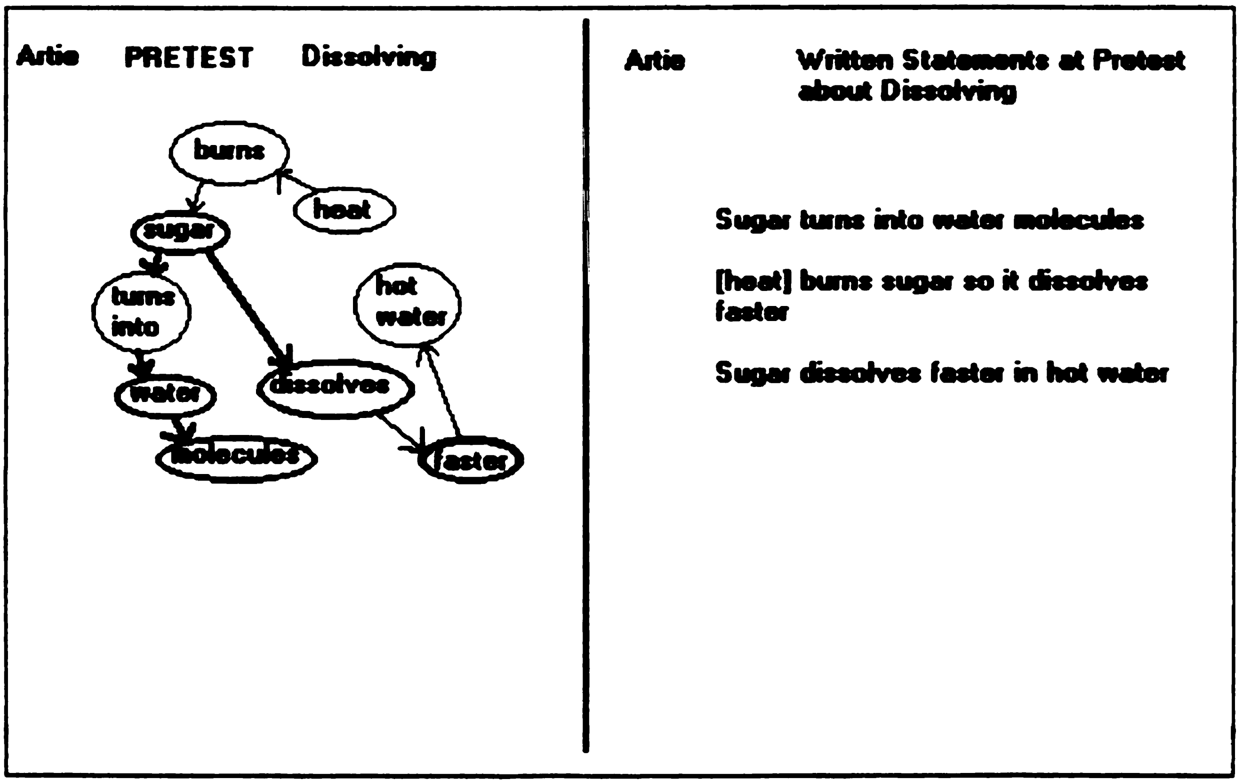

Figure 3.3. Node-link networks of Artie's pretest conceptions about dissolving.

Notice that his statements were "Sugar turns into water molecules". Thus, in the node-link network these words were placed next to one another, since Artie mentioned them contiguously. He also mentioned that heat would burn the to explain were charted, just as Kuhn (1970), Carey (1985b), and Carey and Wiser (1983) suggested as generally accepted for evidence of radical restructuring of existing schema (see also Weak and Radical Restructuring Chart, Figure 2.1, page 21). Concept development was followed to answer my question about whether students showed evidence of restructuring in their classroom writing activities. The *core concepts* of a student's semantic node-link network were the concepts that formed the "core", or the concepts that contained more links to other concepts, and formed part of the student's theories or principles by which he or she connected the concepts together. For instance, in Carol's semantic node-link network in Figure 3.4, for the pretest, the *core concepts* that seemed to hold the base of the structure were "molecules", "air bubbles", "move", "dust speck", and "tiny". In the semantic

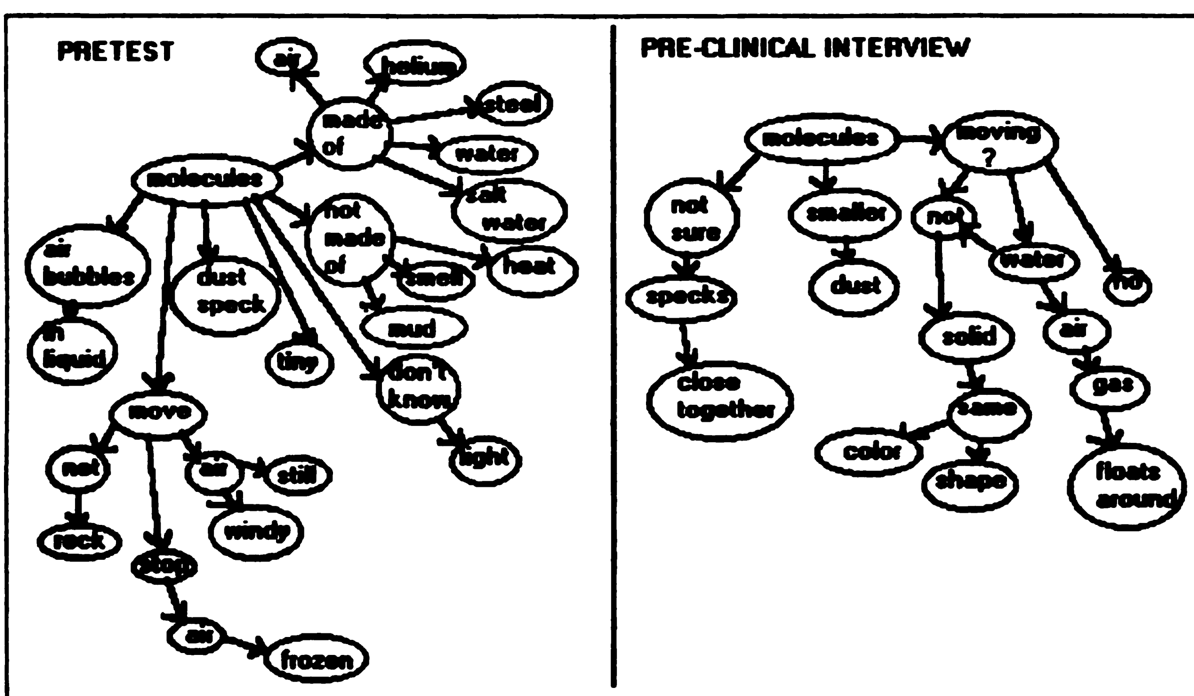

Figure 3.4 Carol's semantic node-link networks for her pretest and pre-clinical interview statements about molecules.

node-link network for her pre-clinical interview the ***core concepts*** that seemed to be the base of the structure were "molecules", "specks", "smaller", and "moving". Carol's ***core concepts*** formed the basis of any theories or principles by which she organized her schema. The organizers for her schema in the pretest semantic node-link network were the words that made up her ***core concepts***—molecules, air bubbles, move, dust speck, and tiny. Comparing students ***core concepts*** and their overall structure changes of semantic node-link networks from pretest to posttest provided evidence for how much knowledge restructuring a student accomplished during a lesson cluster.

The criteria used to determine weak or radical restructuring are listed in the chart in Figure 2.1 on page 21, Chapter 2, and I list them here, as well,

Coding Scheme for Evidence of Restructuring

WEAK	RADICAL
W1 Concepts closely related	R1 Conceptual system greater <u>numbers</u> of concepts
W2 Possibly inaccurate	R2 Different relations among concepts; new domains
W3 Addition of new strategies	R3 Knowledge related to principles and procedures
W4 Addition of new relations	R4 Involves new theories
W5 Addition of more procedural knowledge	R5 Core concepts different and more varied
W6 Reorganization of domain knowledge	R6 Difficult to accomplish
W7 Core concepts same	
W8 Learner possesses more experience in the domain	

Figure 3.5 Coding scheme for weak or radical types of knowledge restructuring.

along with the coding scheme used to help make sense of the amount of restructuring a student accomplished (see Figure 3.5). These criteria are based on Vosniadou and Brewer's review of the knowledge restructuring literature (1987). The criteria listed in Figure 3.5 were used to determine what kind of knowledge restructuring the students showed in their writing and verbal statements. The restructuring changes in all students' statements were analyzed and the kind of restructuring each student demonstrated in their writing in each lesson cluster was charted. For example, Figure 3.6 shows semantic node-link networks for Artie's pretest and posttest statements about dissolving. The differences between these two networks were analyzed as follows:

(1) First, the <u>changes</u> in the *core concepts* that Artie identified were analyzed.

> <u>Example</u>:
>
> The *core concepts* for the pretest statements were those ideas that formed the core or basis of Artie's ideas, and the principles by which he seemed to organize the concept, "sugar turns into water molecules" and "heat" or "hot water" burns the sugar to make it dissolve.
>
> The *core concepts* for the posttest statements, or ideas that formed the principles by which Artie organized the concepts were "sugar breaks down", "sugar dissolves faster in hot water", "molecules move faster", "molecules push against the sugar", "molecules push each other farther apart".

(2) Then I identified all of the kinds of changes according to the criteria in Figure 3.5 for amount of restructuring.

> <u>Example</u>:
>
> -Artie added new concepts to his "core": molecules, molecular behavior as it effects sugar, and molecular behavior in hot water (R1).

-The principle by which Artie explained and organized his schema for dissolving has changed (R3).
-He had new concepts and new relations between concepts at the posttest (R2), and
-a new theory about how dissolving occurred (R4).

Artie's semantic node-link networks showed that he had radically restructured his knowledge about dissolving between the pretest and the posttest.

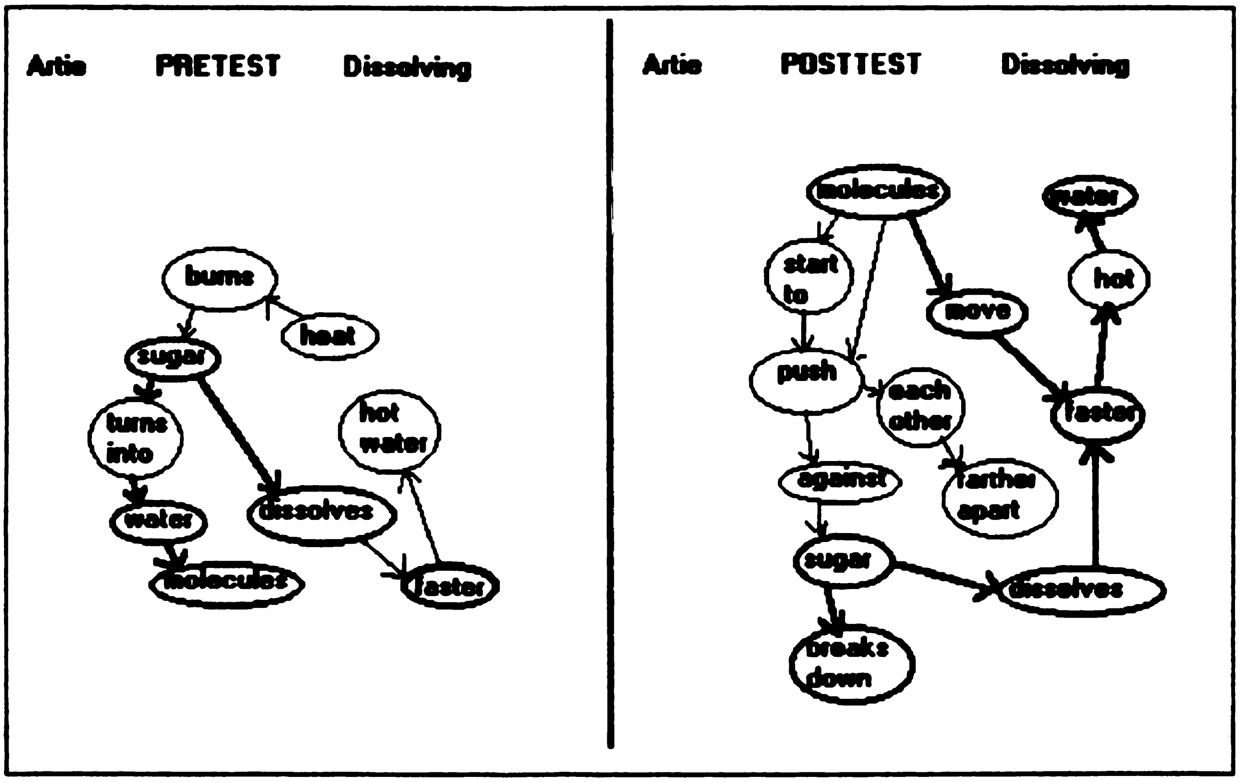

Figure 3.6 Artie's semantic node-link networks for statements about dissolving at the pretest and posttest.

Question 2: What are the Mechanisms from Classroom Events that Seem Associated with Knowledge Restructuring

Student Goal Conception Attainment and Strategy Use

To answer the second question about mechanisms within classroom events that seem associated with knowledge restructuring, I found it important to understand not only how much knowledge restructuring students were accomplishing, but whether they were attaining the conceptual learning goals for the lesson unit. It was important for this research to know whether or not students restructured their knowledge toward the correct learning goals. Knowledge restructuring may not be helpful for students, if they do not learn information correctly, or do not learn all of the information we desire them to learn as a result of instruction. I also wanted to know if when students restructured their knowledge, it indicated they had learned the scientific goal conceptions for the unit. It was important to help answer the second question that the kinds of learning strategies students might be using to make sense of the new information be observed. As reported in Chapter 2, Roth (1985), and Anderson and Roth (1988) reported that students showed different learning as a result of their use of different learning goals and strategies to learn from text. As proposed in Chapter 2, students' differential use of learning strategies might be one of the mechanisms that could be associated with students' knowledge restructuring. In the following section, I describe how students' writing was analyzed to assess their goal conception attainment and how students' learning goals and strategies were determined.

Finding evidence for students' attainment of the scientific goal conceptions. Pretests and posttests were analyzed quantitatively using the coding scheme developed by Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1990). The coding system was based on student understanding of 17 conceptions, 8 conceptions at the macroscopic level, and 9 conceptions at the microscopic level. The real-world or alternative and scientific goal conceptions for each of these 17 conceptions are located in Appendix H. Each student response was coded and tallied across the relevant questions that could yield a "conception score" indicating how well a student understood a scientific goal conception, or whether the student's understanding was more ambivalent, or more real-world or alternative. Students' scores for each of the 17 conceptions were determined by how they answered the questions on the test according to the scoring scheme in Appendix I. For instance, on her posttest, Melinda answered the following when asked why heating a solid makes it melt. She said, "The molecules push each other farther apart as the solid gets hotter. The movement sometimes causes the solid to melt." When coding this answer according to Lee and her colleagues' coding scheme, Melinda's answer was a partially correct microscopic explanation. She stated that molecules of a heated substance move farther apart, but she did not mention that the molecules move faster. This question related to three of the 17 goal conceptions, 3, 14, and 15. Melinda received 2 points for conception 3 (she had the macroscopic goal conception that substances expand when heated), 2 points for conception 15 (she understood the microscopic goal conception that increased motion moves molecules farther apart), but she received 0 points for conception 14, since she did not mention the microscopic goal conception that the effect of heat on substances is to make the molecules move faster. Each question on the pretest and posttest was designed to assess more than one of the 17 goal conceptions, as in Melinda's example above. The total student's score for one of each 17 conceptions was then compared to the total possible for each conception, and a decision made as to the student's commitment to that conception. For instance, in Melinda's case, for goal conception 3 above, there were 5 points total possible across the test. Melinda received all 5 points on her posttest. According to Lee and her colleagues' scoring scheme on this test, Melinda had achieved the macroscopic scientific goal conception that substances expand when heated. For conception 14, for which Melinda received 0 points on the melting question, there were a total of 7 points possible across the test. Melinda received 5 of the 7 points for conception 14. Lee and her colleagues would say that even though Melinda did not receive all of the points possible, she still received enough to warrant stating that she had attained the microscopic scientific goal conception that the affect of heat on a substance makes the molecules move faster. Across the test, there were 5 points possible for goal conception 15. Melinda received 2 points for 15 on her melting answer, and 5 points across the test. She demonstrated that she had attained the microscopic goal conception that increased motion moves molecules farther apart.

The conceptual content of the students' pre-clinical and post clinical interviews were analyzed much like the written pretest and posttest, to see if students had attained any of the 17 scientific goal conceptions for matter and molecules. My purpose was to understand students' conceptions from their paper-and-pencil tests, and writings, to look for consistency, and be better able to describe their alternative conceptions for each of the 17 conceptions. I did not attempt any summative formal analysis from the clinical interview results. They served merely as another source of the same data, to support, or not support, my findings from students' writing.

For each of the 17 goal conceptions, which students had attained goal thinking, and which were still real-world or alternative, or ambivalent (somewhere between the two) was determined. I compared these numerical scores with the interpretations of their restructuring, to check consistency of the numerical coding with the interpretations. I added this information to each student's chart and each lesson cluster. In addition, the number of students attaining each of the goal conceptions, the percentage of the goal conceptions each student reached, and the percentage of the goal conceptions reached by the whole class were calculated. These results were compared with the interpretations about knowledge restructuring and learning strategies students accomplished across the lesson clusters. I report the results of my analysis in Chapter 4.

Finding evidence for students' learning goals and strategies. I also analyzed each student's node link network changes to see if the kinds of learning goals and strategies students might have used to accomplish their restructuring might be determined. In Table 2.2, on page 62 of this document, the criteria used to make judgments about students' learning goals and strategies are listed. The criteria are based on Roth's (1985) and Roth and Anderson's (1988) reports of students' strategies for processing science texts. I attempted to see if the students applied similar strategies to process science classroom instruction as students had previously used to process text. I guessed that if students used different learning goals and strategies as they learned, these goals and strategies might have an effect on the amount of restructuring they accomplished.

The writing that students accomplished on their pretest, then during their activity booklet writing, and then again on their posttests, was observed to look for the following clues to help assess their possible learning strategy use. If students answered their activity booklet questions, quizzes, and freewrites with similar answers from their real-world knowledge they had used on their pretest answers, and then relied again on these ideas for answering the posttest questions, it was inferred that they had used Anderson and Roth's

(1988) Strategy 1: Overreliance on Prior Knowledge, tending to interpret text in terms of their real-world prior knowledge, and using that knowledge as a source of information, rather than the text. When using Strategy 1, students' learning goals were often to just "finish the task", and not to learn. For example, one of the target students showed that he might be using Strategy 1 in his approach to learning about Pure Substances and Mixtures. His pretest conceptions about pure were that it was air, and mixtures were something used to make a formula. During his writing in the activity booklet to answer questions and provide scientific definitions of pure and mixtures, he wrote that pure was "water", and matter was "liquid or gas", and non-matter was "liquid or gas". On his posttest, the same student answered that pure was "clear", and mixtures were something that we "could not see through". He seemed to rely primarily on his real-world knowledge and ignore the information in the text.

Sometimes students would come up with acceptable words to answer the questions in their activity booklets, but seemed to use the words in isolated ways, not connecting their meaning to each other or to the students' prior knowledge. These students would write acceptable answers in their activity booklet, but when asked questions about real-world phenomena at the posttest, rely on their real-world knowledge to answer the questions rather than the information they wrote in their activity booklets. These students' learning goals were to "finish the task". They isolated words from the text and instruction and did not make sense of them or integrate them into their prior knowledge. These students showed evidence for using Strategy 2: Overreliance on Words in the Text. One target student provided an example of this strategy. He produced acceptable answers to the questions during instruction in his activity booklet, but relied on real-world knowledge to answer real-world problems about molecules in substances on the posttest. His definition of molecules was that "a molecule is a matter of a substance." He picked up big words from the text, but did not make any sense of the words or connect their meaning to each other or to his prior knowledge. He remembered big words from the instruction like "molecule" and "matter" and "formed in a rigid array or pattern", and pasted these words into his schema without making sense of them.

Sometimes students had higher goals than to just finish the task, but merely learned a list of facts and added them to memory without integrating them with their prior knowledge. These students were often able to answer activity booklet and quiz questions with acceptable answers, but when asked to explain real-world events, they relied on their real-world prior knowledge exclusively, and separated their new instructional knowledge from their real-world knowledge, as if each belonged in separate domains. These students used Strategy 3: Overreliance on Unrelated Facts, and Separation of Disciplinary Knowledge and Real-World Knowledge. An example of a student using this strategy was when the student learned details from the instruction that "water weighs the same as ice" but did not make sense of what that meant in terms of his real-world knowledge. He answered questions in the activity booklet and on quizzes that were acceptable that he understood that the weight of a substance stays the same when its state changes, but he did not make sense of what that meant or integrate it into his schema. The evidence that he did not was in his posttest explanation of why the weight of ice stays the same when it melts into water. He said, "because the same ice is being melted and the same water gonna turn into water". This student seemed to separate his disciplinary knowledge from his real-world knowledge, and used disciplinary knowledge to answer questions in his activity booklet, but did not make enough sense of the ideas to make them useful in his schema. He relied primarily on his real-world and separate schema to answer the real-world problems on the posttest.

Another strategy students could be seen using was ability to make sense of new information, and integrate it into their real-world knowledge, but they would ignore or distort some of the information to make it fit with their incorrect pre-existing notions. Rather than abandoning conflicting information from their prior knowledge, these students would add new information from the instruction, and retain conflicting prior knowledge, sometimes distorting the new information to fit within their schema. For instance, one of the target students possessed some schema for understanding molecules, their size, and their relationship to matter before beginning the unit. At the posttest, he retained a notion that molecular arrangement moves from "close" in solids, to "in the middle" between close and far apart in liquids, and "far apart" in gases. He ignored or forgot the instruction that stated that molecules are still close together in liquids, but just move freely, rather than being locked in a rigid pattern. He remembered new information and integrated it into his existing schema, but he distorted or ignored some of the information to make it fit his real-world knowledge that molecular arrangement is close in solids, farther apart in liquids, and farther apart yet in gases, using Anderson and Roth's (1988) Strategy 4: Overreliance on Prior Knowledge to Make Sense of Disciplinary Knowledge.

The last strategy that students could use to learn new information is the most effective, and when students used this strategy, they were able to recognize inconsistencies in their real-world knowledge and the new scientific information, and abandon their alternative and conflicting ideas to integrate the new knowledge into their schema. These students were actively involved in making sense of new information, and integrating it with their prior knowledge, abandoning old knowledge that no longer fit. These students used their new knowledge to effectively explain real-world phenomena. They used Strategy 5: Conceptual Change Strategy Using Text Knowledge to Change Real-World Ideas. An example of a student using this strategy was one target student, who began the lesson unit with little schema for understanding the dissolving process. By the end of the unit, the student had added molecules, and molecular behavior to her schema, abandoned her real-world conception about sugar becoming "part of the water", and used her new understanding of molecules to explain dissolving.

By charting students' apparent amount of restructuring, and comparing it with their goal conception attainment, and possible use of different learning strategies, a picture was obtained of how students' knowledge restructuring changes related to their effective learning and how that learning related to instructional events.

Students' Perceptions of the Writing Tasks

Tracking thoughts about writing. Target students were interviewed about their writing experiences periodically throughout the lessons, their strategic knowledge of the writing process and how they used writing was tracked in a chart like the one in Figure 3.7. I was interested in observing any changes students perceived in purposes for writing, their perceived facility with writing, and their feelings about writing as they progressed through the learning unit.

Name: Melinda **IDEAS ABOUT WRITING**

	Oct 23	Nov 11	Jan 11	Jan 28
Facility Activity Booklets hard easy Freewriting hard easy Quizzes hard easy	writes a lot finds writing in between hard & easy tends to ramble when writing stories	in between; want to think of stuff but it won't come up; it's in there but I can't pull it out I wanted to think of an idea that was original	in between hard & easy; you had to think about it; but it wasn't like you had to have a genius brain to figure it out!	hard part, getting the words down; to find the right words to do it; like I know whats happening, but I don't know the right words to say it;
Enjoyment Activity Booklets Freewriting	I'm not much for sharing my ideas	not hard, once I had ideas	in between; I like writing stories and all that stuff; but I'll do this if it will give me a grade;	I found I could think about it pretty well, and I could concentrate, and then I just wrote it down.
Purpose	so we don't forget our ideas; easier to remember if we write it down; helps her learn	to learn		
Strategies				to see what's going on in my mind

Figure 3.7. Melinda's chart of her ideas about writing across time.

Each interview was recorded on audiotape and the audiotape transcribed. What each student said over time about his or her writing was followed by looking back at the interview transcripts. I took what students had said about their writing and tracked their statements about the same questions about their writing across time. I attempted to relate these thoughts about writing to knowledge changes, and get more insight into how well students were able to express their knowledge in their writing. The more students were able to express their ideas without the writing task getting in the way, the more their writing might have displayed evidence of their conceptual structures. I was also hoping to find out more about how this related to their understanding of the purposes of writing, whether <u>their</u> purposes for writing changed, and if writing influenced their knowledge restructuring at all. I report what I found in students' perceptions of the writing tasks in Chapter 4.

Analysis of classroom events related to conceptual change learning

Finding evidence of conceptual change mechanisms. Once there was evidence for the existence of weak and/or radical restructuring, students' goal conception attainment, and their possible learning goals and strategies, I attempted to answer the second question posed: What mechanisms from classroom events seem to be associated with science knowledge restructuring, and what seems to make the difference for students who restructure their knowledge, and those who have difficulty?

By analyzing the occurrences of classroom events and their relationship to instances and non-instances of knowledge restructuring, I attempted to illustrate some instructional events that helped students make difficult conceptual changes, and the conditions under which such events seemed most helpful for learners. My attention was focused on the classroom events for just two lesson clusters---the dissolving lesson, which seemed to encourage conceptual change thinking, and the pure substances and mixtures lesson cluster, with which students had more difficulty. My question was: What seems to make the difference for the majority of these students who could perform so well learning one lesson, and not so well on another? Observation summary notes and videotaped sessions in the classroom were carefully reviewed for these lessons to look for reasons why one lesson might have been more fruitful than the other.

Analyzing the lesson presentations. The conceptions presented by the teacher, and classroom dialogue gained from observation, audiotapes, and field notes about teacher-student discourse in the behavior setting of the science classroom were analyzed according to day and time. The videotape records of the classroom events were analyzed using the observation form, task descriptions, and lesson summaries as a guide for making sense of the classroom instructional events and what might be occurring there to influence knowledge restructuring. I viewed all videotapes of the two lessons several times to get an overall feeling for the movement of the lessons, the speaker, and the classroom events that the teacher might be using during her presentations. All instances of questioning, use of analogy and metaphor, coaching, cognitive conflict, and surprise were recorded. Also noted were instances of reflection on the part of students and notes made of concepts the teacher particularly emphasized for each lesson cluster. I listed activities the target students performed, and noted conversations about content the target students had around these activities in the whole class discussions, and in their target groups. Each time a target student spoke out in class, and what

Statements during Class and Small Group Interactions
Student: Kenny Lesson Cluster: Pure Substances and Mixtures <u>Day 3</u> Whole Class: None Small group: "mixture" "Is carbon dioxide and oxygen?" "I think it's gravel" "It's gravel" "Mine had this rock inside it" "Then how come the one I had had rocks in it?" "You can't break gravel. . . it's like sand, and rocks, and dirt. ." "Then put all three. . . rocks, dirt, and salt!" "Yeah, it's matter. . "

Figure 3.8 Target student Kenny's spoken statements during class on Day 3 of Pure Substances and Mixtures lesson cluster.

he or she said about content was also noted. A separate chart was made for each student, and what he or she said in class on any given day. These charts were similar to the charts made for students' written comments across time. Figure 3.8 is part of the chart used for one target student Kenny's statements in the classroom. This information was cross-referenced with the identification and elaboration of conceptions identified in the student writing to identify the events that occurred within successful and unsuccessful lesson clusters.

The students' statements were observed to see if they showed any dissatisfaction with their existing conceptions and any of their new conceptions were according to the conditions that Posner, Strike, Hewson, and Gertzog (1982; see page 62 this document) proposed were necessary to influence knowledge restructuring. The teacher's dialogue was analyzed to find instances where she asked questions eliciting students' alternative conceptions, focusing on the "whys" and responding to incomplete or incorrect "why" statements on the part of students. Roth, Anderson, and Smith (1986; see pages 67-68 this document) suggested that these were necessary verbal behaviors of teachers to influence students to change their conceptions from real-world or alternative and common sense to more scientific. The text materials and teacher presentations were analyzed for each of the two lesson clusters for the presence of Minstrell's six instructional principles for teaching for conceptual change (1984; see p. 69 this document). See Figure 3.9 for one of the charts used for the beginning Dissolving lesson cluster. I report my results in the next chapter.

DISSOLVING
Day 2

Questioning 8 instances
Analogy/Metaphor 0
Coaching - individual, Candice : about story, Artie
Cognitive Conflict 0
Surprise 0
Reflection 0
Teacher Emphasis 0
Activity-measuring grain of sugar, holes in teabag, making plans
Explaining individual plans (writing)

▷ Topics: Story, powers of ten, talking about substances, molecular behavior

Target students who speak:	What they say:
Artie	explains story "molecule arrangement and the way they move" "statements about substances, statements about molecules"
Kenny	"statements about substances, statements about molecules"
Carol	"statements about substances, statements about molecules"

Figure 3.9 Chart analyzing classroom events in Day 2 of Dissolving lesson cluster.

Summary

In this chapter, I presented the data collection and analysis methods used to answer two research questions:

(1) Do students show in their writing that they are restructuring their science knowledge, and how much restructuring seems to occur for students during a science lesson unit?

(2) What mechanisms from classroom events seem to be associated with such science knowledge restructuring, and what seems to make the difference for students who restructure their science knowledge, and those students who have difficulty?

To answer the questions, I observed the interactions that occurred in students' actual writing as they thought about content, and the classroom interactions students had with the teacher, other students, and the text, to attempt some meaningful connections between what students seemed to understand about content, and the surrounding instructional events.

This chapter began with an overview that explained the purposes of the research, and described why student writing about content, interviews from target students about the content and their writing, and videotape records of classroom events were part of the data collected. How each piece related to the questions and was necessary to interpret students' possible knowledge restructuring and conceptual change was explained. The subject sample was part of another ongoing study participating in collaborative problem solving and teaching for conceptual change in a Matter and Molecules Unit. The sample had been selected previously by the principal investigators of the larger study. The data for this study was collected as part of their study and more data was added in the form of student freewriting, student interviews about writing, and teacher interview to answer the research questions. The classroom was a middle school class located in an urban setting of low to middle socioeconomic families with a cross-section of student abilities and ethnicity. The lesson materials and how the teacher usually presented the lessons were described. The design of this research was descriptive and interpretive, and reliability and validity factors were outlined and limitations discussed. I described each element of the data collected, and discussed the procedures for collecting the data.

In the last section of the chapter, Data Analysis, I described that the writing students accomplished was analyzed by transcribing their writing into a computer spreadsheet program, creating files for each student about each lesson cluster. Semantic node-link networks were constructed to view students' proposed schema changes over time, and the changes students made in their knowledge structures were analyzed. Students' writing and verbal statements were analyzed for evidence of how closely each came to reaching the scientific goal conceptions of the instruction, and the learning goals and strategies each might have used. The chapter discussed how this information was used to locate two lesson clusters for further analysis about how classroom events might influence conceptual change, by identifying a lesson cluster during which most students used conceptual change thinking, and one during which many students had difficulty learning and remembering the information, or how to use it. Each lesson cluster was carefully analyzed, observing instances of questioning, cognitive dissonance, surprise, opportunities for reflection, teacher use of analogy, or metaphor, and other classroom events that might have influenced students to restructure their knowledge. The text differences and student activities between each lesson cluster were compared to observe the differences and the effects on student learning.

In the next chapter, Chapter 4, I outline the results obtained from my analysis of students' conceptions from their writing, and clinical interviews, and how those results related to classroom events during two lesson clusters that had different outcomes for student success with conceptual change learning.

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A WINDOW INTO THINKING: USING STUDENT WRITING TO UNDERSTAND KNOWLEDGE RESTRUCTURING AND CONCEPTUAL CHANGE

VOLUME II

By

Nancy Jane Fellows

A DISSERTATION

Submitted to
Michigan State University
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for the degree of

DOCTOR OF PHILOSOPHY

Department of Counseling, Educational Psychology, and Special Education

1991

Chapter 4

RESULTS

Introduction

The Context: Teaching and learning in science. The subject of this study was the learning and use of new science concepts, and the writing students do as they learn. When individuals learn new information in a domain, they either incorporate the new knowledge within their existing prior knowledge, or modify their prior knowledge to fit new information (Bransford, 1979; Rumelhart & Norman, 1981). The knowledge changes that individuals make to learn in a new domain, such as the Matter and Molecules Unit in this study, is known as ***domain-specific restructuring*** (Carey, 1985a; Glaser, 1984; Vosniadou & Brewer, 1987). Restructuring can take either a weak or radical form, depending on the amount of modification learners must make in their existing prior knowledge schema: The more change learners must make in their existing schema, the more radical and difficult the conceptual change. In science especially, even if lessons are well taught, the restructuring that learners must do is often difficult.

One reason that knowledge restructuring in science might be so difficult is that students begin learning a new domain of science with alternative conceptions based on their real-world knowledge, and resist the difficult knowledge changes that are required to understand and use new information. Sixth-grade students attempting to learn about the nature of matter and physical change in previous studies showed common alternative conceptions when beginning the unit of study at both the macroscopic and microscopic levels (Lee, Eichinger, Anderson, Berkheimer, and Blakeslee, 1990.) For instance, before learning about molecular behavior in substances, when asked to explain why a deflated balloon placed over the top of a cool bottle inflated when the bottle was warmed, students often say that heat makes air in the bottle "rise", or that when air is warmed it will move to the top of the bottle and into a balloon placed over the bottle. Sixth grade students, before they have heard of molecules, will refer to them as if they possessed the same properties as the substance, and say that the molecules "get warm and rise to the top", because they know that heat rises. But they do not know that molecules do not themselves get warm, but only change their behavior when heat is applied. Even when instruction accounts for student alternative conceptions and real-world ideas, and helps students confront these conceptions most students retain many of their original real-world conceptions about air and the behavior of the molecules when air is heated or cooled (Lee, et al., 1990).

The problem: Understanding students' conceptual change processes, and their mechanisms. Because students' changes in conceptions about science are often difficult for them to accomplish, the focus of research in science learning needs to be placed on understanding and assisting students to make the conceptual changes to more scientific thinking (Glaser, 1982). Science teachers and researchers need to carefully identify the student understandings that reflect competent performance, the initial states of learner, and the prior knowledge that might facilitate or interfere with their learning. We also need to carefully identify the learning transition processes that students pass through on their way to competent performance, the kinds of instruction that facilitates learning, the diagnostic measures that can help assess students' understandings, and to realize the structures and strategies that lead to incorrect performance (Glaser, 1982). With better understanding of learners' pri

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of learners' prior knowledge, their learning transitions and difficulties, teachers and researchers can design instruction that assists students with these difficult knowledge changes in science courses.

Researchers have described knowledge restructuring changes, but few have attempted to explain the mechanisms that might be associated with the changes that occur as knowledge develops. In this study, I attempted to identify some of the mechanisms that are associated with students' knowledge restructuring in science.

A solution: Student writing as a "window" into their restructuring changes and the classroom mechanisms associated with conceptual change. The purpose of this research was to carefully observe students' thinking processes as they attempted to learn about the nature of matter and physical change in a sixth grade science class. I attempted to describe students' transition processes from possessing little scientific understanding about matter and molecules to a more well-developed scientific conception of how the world works. This study sought to reveal the events of instruction that might have facilitated students' learning. Students' writing was used to assess students' understandings and for revealing the strategies they might be using for correct and incorrect performance. In this study, I attempted to answer the following questions:

(1) Do students show in their writing that they are restructuring their science knowledge, and how much restructuring seems to occur for students during a science lesson unit?, and

(2) What mechanisms from classroom events seem to be associated with students' science knowledge restructuring,

and what seems to make the difference for students who restructure their science knowledge, and those who have difficulty?

Students' thought processes are difficult to study because we cannot view thinking directly. Other researchers have inferred learners' knowledge structures by documenting common student misconceptions (McDermott, 1984; Viennot, 1979), analyzing the elements that students perceive to be similar conceptually (Chi, Glaser, & Rees, 1982), analyzing students' problem-solving processes (Larkin, McDermott, Simon & Simon, 1980), and analyzing students' knowledge with "concept maps" (Carey, 1986; Chi, Glaser, & Rees, 1982). In this study, I attempted to analyze students' knowledge by constructing concept maps of the ideas they identified when writing about content. Students' written ideas about a concept may indicate their current thinking, and provide a window for researchers to observe students' changes in thinking as they progress in a learning unit and attempt to understand new ideas. One purpose of this study was to observe how student writing might help teachers better understand what students are thinking, and how students use instruction to restructure their knowledge. Another purpose of the study was to understand the relationship between classroom events and knowledge restructuring, especially the role of writing as a possible influence on knowledge restructuring.

In this study I observed sixth grade students' writing to make inferences about their knowledge structures and related changes, over a learning unit on the nature of matter and physical change. In this study, the students wrote daily in activity booklets and weekly in freewrites about their understanding of new information.

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new information, as part of the lesson. All of the writing that students completed was collected and analyzed to observe the changes students made in their conceptions about the subject matter over time. I charted the concepts that students identified, and constructed semantic node-link networks to observe students' conceptual structure changes. Instructional events, the teacher's talk, students' interactions within their small discussion groups and all teacher written feedback in activity books and on quizzes were also observed. I attempted to connect students' knowledge restructuring changes evidenced in their writing with classroom events by charting their restructuring changes and comparing them with classroom events. This data was used to make grounded inferences about the following occurrences: Given the constraints of the classroom, can student writing inform teachers about how much students are thinking and restructuring their knowledge? And, given that I can identify thinking changes in student writing, what classroom events seem to encourage students to change their thinking to more scientifically correct conceptions, and what seems to be present for students who do not restructure their knowledge?

This chapter presents the evidence for knowledge restructuring found in students' writing, and the extent of restructuring students showed in their writing to answer the first research question. The chapter begins with a presentation of the evidence interpreted from one target student's case. Artie showed different kinds of restructuring and responses to the instruction across all of the lesson clusters, so his case is explained first in detail to illustrate the various kinds of changes found. Artie's case shows the varied forms that restructuring can take, and examples of the criteria used for the interpretations. A review of the findings for each of the other five target students, and the students in general across the class is presented following the analysis of Artie's knowledge changes.

Artie: From Weak to Radical Restructuring and Conceptual Change

Students demonstrated in their writing various forms of restructuring along a continuum from weak to more radical. There were two students who demonstrated radical restructuring across all of the lesson clusters, but all of the other students demonstrated either weak or radical restructuring, or somewhere in between, for each lesson cluster. For instance, one target student, Artie, demonstrated weak restructuring for the information in the first two lessons clusters, Pure Substances and Mixtures, and Introduction to Molecules. He showed more radical restructuring for the information contained in the other three lesson clusters, States of Matter, Dissolving, and Thermal Expansion. The following section traces what I found in Artie's writing. These findings serve as a framework to summarize the findings in the other students' writing. I begin by showing that the ideas that Artie expressed in writing were similar to those he expressed verbally, to confirm that his writing might have matched his oral expression. I then show how the difficulty of the writing tasks might have interfered with Artie's ability to express his thinking, to confirm that the writing tasks Artie did were not difficult, and did not interfere with his idea expression. Understanding that the writing tasks were not difficult for Artie helped confirm that Artie's writing showed his thinking and might be a valid indication of his knowledge. After I present evidence that Artie's written ideas were similar to his verbal expressions, and that the writing tasks did not interfere with his ability to write ideas, I show how

Artie's writing indicated his understanding about content and the kinds of knowledge restructuring he accomplished.

Artie's Conceptions for the Pure Substances and Mixtures Lesson Cluster

Before the learning unit began, at the paper-and-pencil pretest, Artie wrote the following for what he understood about Pure Substances and Mixtures (see Figure 4.1). The semantic node-like network constructed from Artie's statements, using the concepts he identified in his explanation, is represented in Figure 4.2. The node-link network reads much like Artie's statement: The words "pure" and "don't have" and "two or more substances" were said contiguously, so were placed together in the network. "Mixed does"

Student: Artie — **CONCEPTIONS ABOUT PURE SUBSTANCES & MIXTURES**

Pretest	Pre-Clinical Interview	Pure Subs & Mixtures Activity Booklet & Quiz
Mixtures: heat, air steel, mud salt water	Pure is like a solid, they're both hard, aggressive Probably air and water are pure; Pure is the main thing, not anything else made of it, the main thing.	Matter is made up of a solid, liquid or gas Non-matter is anything that is not made up of a solid, liquid or gas Pure is made from one kind of matter Mixture is made from two or more kinds of matter
Pure: light, water, helium		Pure is made from solid, gas or liquid
Smell is something else (not pure or mixture)	A mixture is a pollution, and pollution is a mixture of different things, polluted together; some pure substances are pollution.	Pure substances are made of one kind of molecule Mixtures are made of two or more different kinds of molecules
Pure don't have two or more substances put together; mixed does		

Figure 4.1 Artie's written and verbal statements about Pure Substances and Mixtures, Part 1.

was said following this and refers to "two or more substances" so were connected to those statements, and to "mixtures", to which Artie was referring networks, when he men

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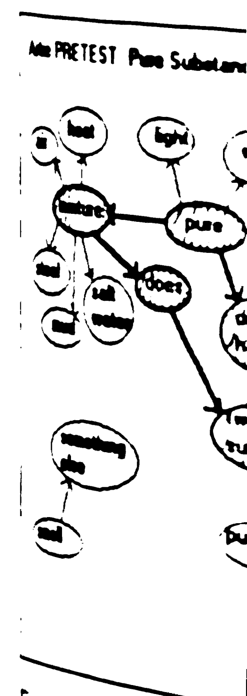

Figure 4.2 Proposed sch
with semantic node-link

When asked at the

substances and mixture

networks, when he mentioned "mixed". I shaded the *core concepts* in Artie's node-link so that these concepts stand out from the others. I refer to the *core concepts* when comparing one network with another. The *core concepts* in a students' node-link network are those concepts that form the <u>core</u> or base of the structure, those concepts from which the branches extend and link to, most often. For instance, in the semantic node-link network in Figure 4.2, the concepts carrying the most links are "pure", "mixture", and having or not having "two or more substances". These concepts form the <u>core</u> of this conception for Artie.

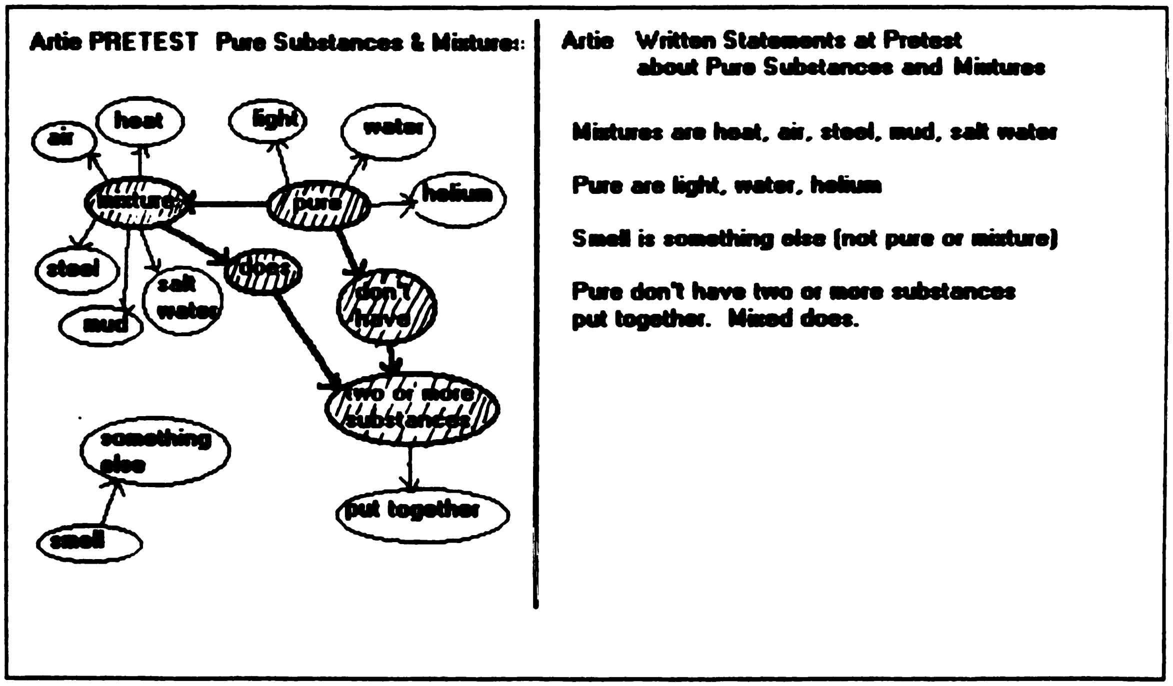

Figure 4.2 Proposed schema for Artie's written pretest statements, constructed with semantic node-link network.

When asked at the pre-clinical interview about his understanding of pure substances and mixtures, Artie stated what is shown in the second column of

Figure 4.1. The semant c

s in Figure 4.3. The writin

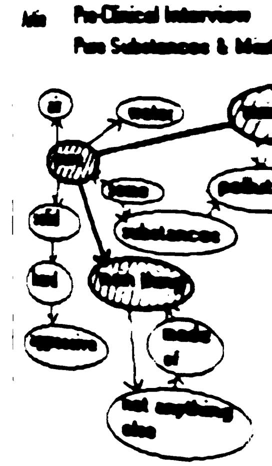

Figure 4.3 Artie's verbal
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Figure 4.1. The semantic node-link network constructed from these concepts is in Figure 4.3. The writing Artie completed during the unit on Pure

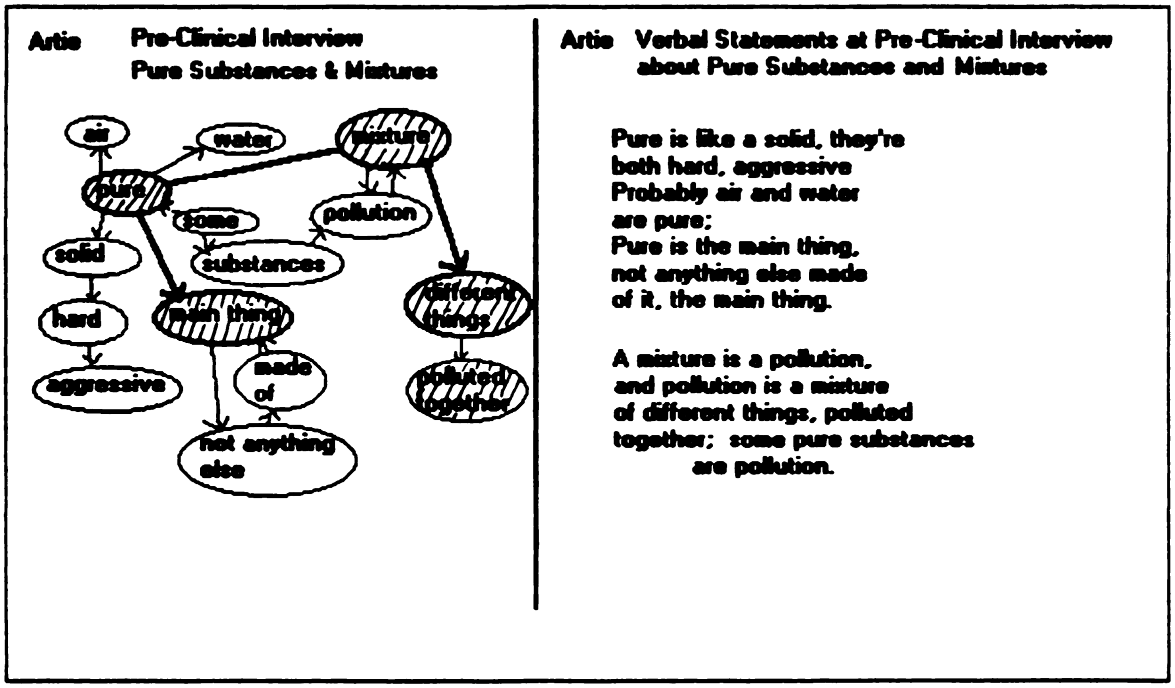

Figure 4.3 Artie's verbal statements at Pre-Clinical Interview, and the semantic node-link network representing his concepts.

Substances and Mixtures is shown in the third column from the left in Figure 4.1, and the semantic node-link network constructed from this writing is shown in Figure 4.4. Figures 4.5 and 4.6 show Artie's statements about Pure Substances and Mixtures at the paper-and-pencil posttest and post-clinical interview, along with the node-link networks constructed for each writing. The constructed node-link networks were placed side-by-side for the pretest and pre-clinical interview, and posttest and post clinical interview, as in Figures 4.7 and 4.8. By observing the differences in core concepts that Artie identified in these various statements, I was able to picture the form of knowledge restructuring that Artie's

verbal displays.

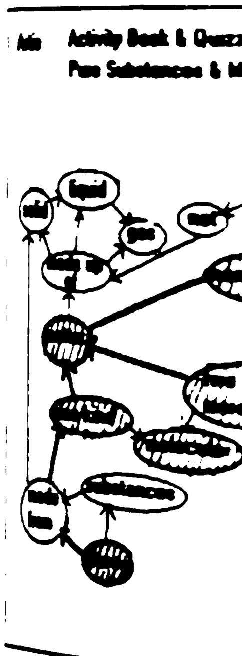

Figure 4.4 Artie's written
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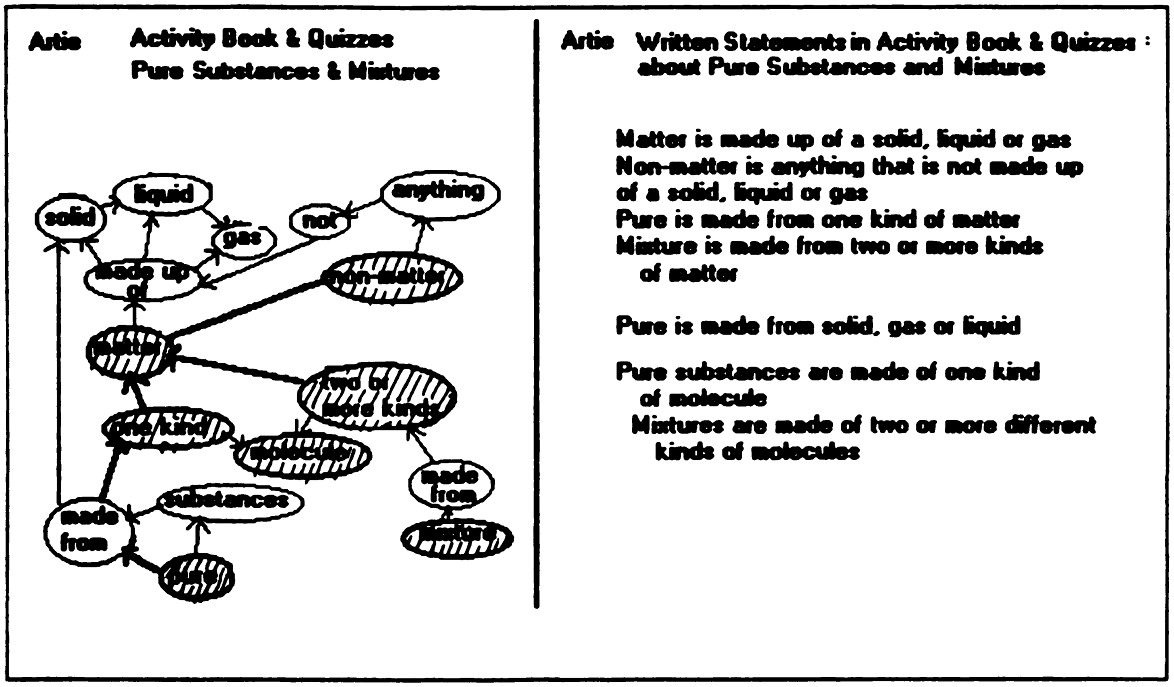

Figure 4.4 Artie's written statements in his activity book and quiz, and the semantic node-link network that illustrates his concepts.

<u>How Well Did Artie's Writing Display his Thinking?</u>

<u>Pretest and pre-clinical interview conceptions</u>. Figure 4.7 shows the semantic node-link networks constructed for Artie's <u>written</u> statements on his paper-and-pencil pretest, and his <u>verbal</u> statements during the pre-clinical interview. Notice that the ***core concepts*** were similar in both networks. Only the way Artie <u>stated</u> the ideas was different: On the written pretest, pure [substances] "don't have two or more substances put together", while mixtures

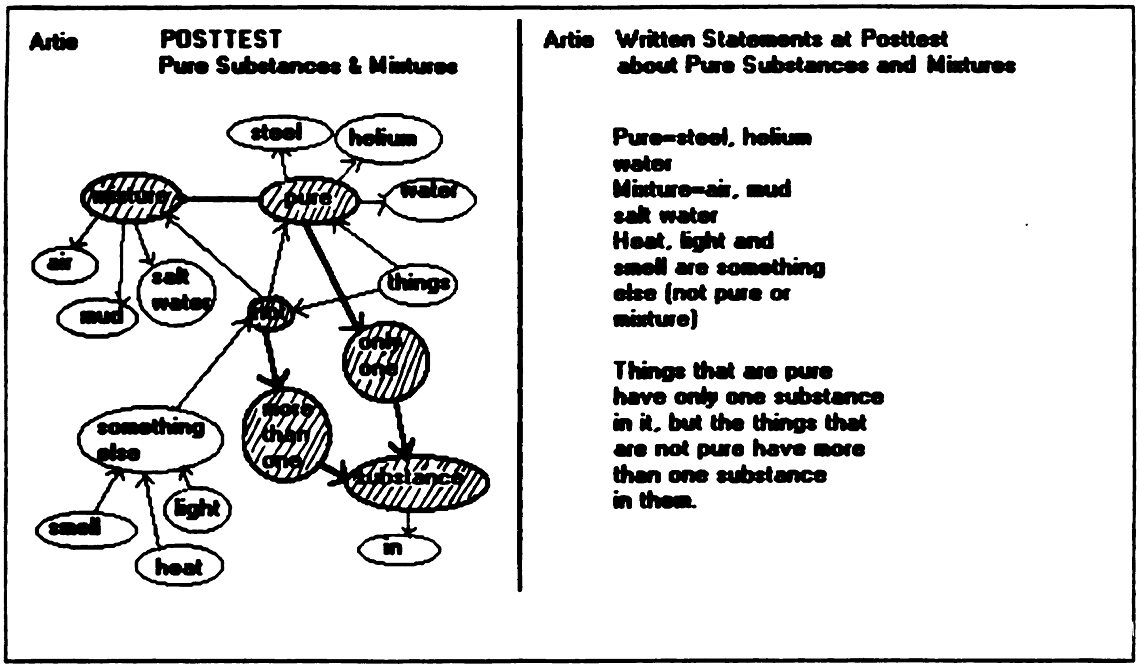

Figure 4.5 Artie's written statements on posttest, and the semantic node-link network constructed from his statements.

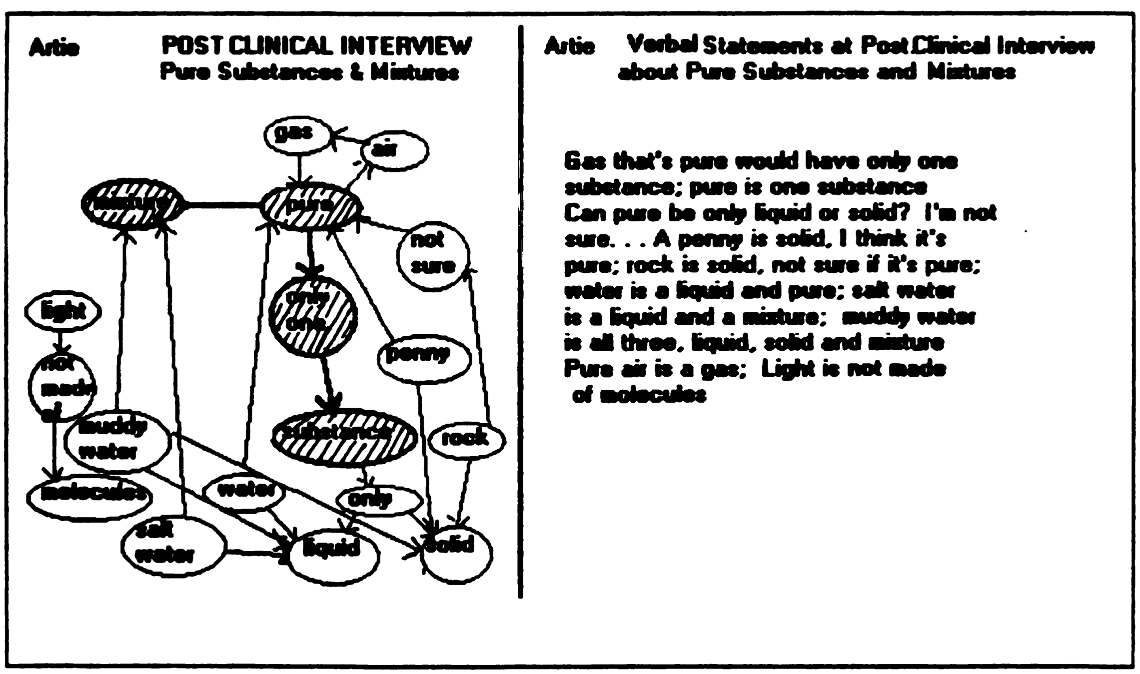

Figure 4.6 Artie's verbal statements during the post clinical interview about pure substances and mixtures, and the node-link network constructed from his statements.

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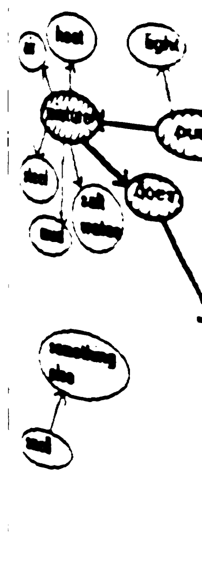

Figure 4.7 Semantic n
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do; and at the verbal pre-clinical interview, "pure is the main thing", not made of anything else, while mixtures are made of different things. There were some differences in Artie's written statements and verbal statements as well. The content of the clinical interview seemed different from content of the pretest in its tone and the kinds of ideas emphasized due to the nature of the questions asked. In the written pretest, Artie was asked to tell what the difference is between things that are pure and things that are not. He was asked to classify common substances such as air, light, heat, water and salt water. For the

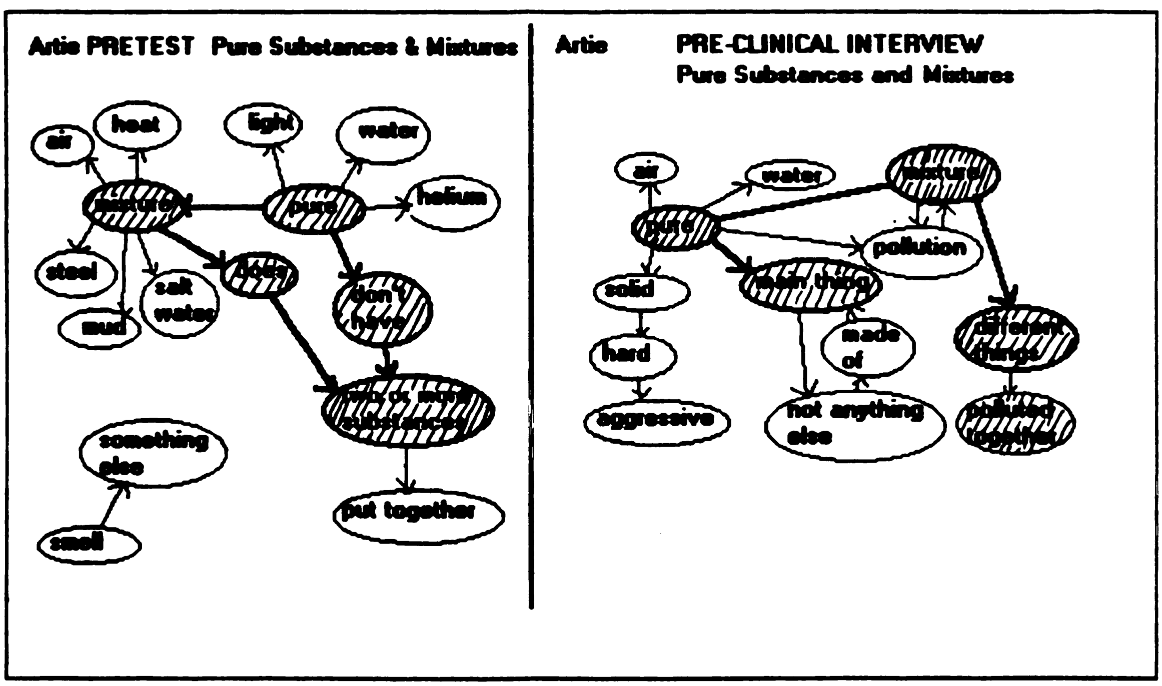

Figure 4.7 Semantic node-link networks for Artie's written pretest statements, and his verbal pre-clinical interview statements.

clinical interview, Artie was given a card sort task with the words pure, mixture, matter, solid, liquid, and gas and asked to arrange the cards in a logical order and explain why he put certain cards together. The differences in the contexts and the ideas emphas ze

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and the ideas emphasized for the pretest and clinical interview were somewhat different, so that made Artie's statements sound different. By looking at the ***core concepts*** within Artie's semantic node-link networks, it looked as though his schema for understanding pure substances and mixtures before instruction was that pure things have only one ingredient, and mixtures have more than one. Artie's written ideas about pure substances and mixtures at the paper-and-pencil pretest were similar to his verbal statements about the same content at the pre-clinical interview. The ideas were dissimilar only in how he chose to express the concepts, based on the kinds of tasks and questions he was asked on both tests. On the pretest he approached his definition by telling what pure does not have---two or more substances put together. Verbally, during the pre-clinical interview, his ideas were similar, but stated differently---pure is the main thing, not made of anything else. Because in this instance, Artie's written statements were consistent with his verbal statements, it is likely that his written statements about "pure" was what he believed to be true about pure. The ***core concepts*** were similar in both instances: Pure [substances] consist of only one substance, while mixtures consist of more than one substance. Again there was evidence that Artie's written statements show his thinking, because he verbally expressed similar ideas to his written ideas.

Posttest and post clinical interview conceptions. Artie's written ideas about pure substances and mixtures at the paper-and-pencil posttest were similar to his verbal statements about the same content at the post clinical interview. Figure 4.8 shows the semantic node-link networks constructed from Artie's written statements on the paper-and-pencil posttest about pure substances and mixtures, and his verbal statements from the post clinical interview. The core

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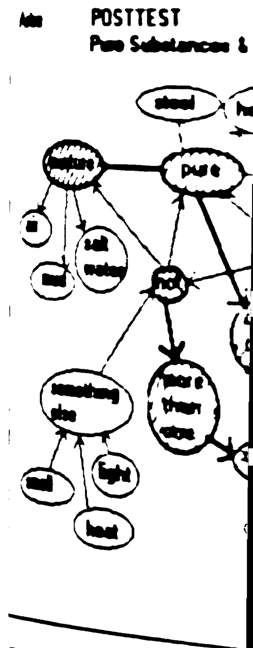

Figure 4.8 Semantic noc
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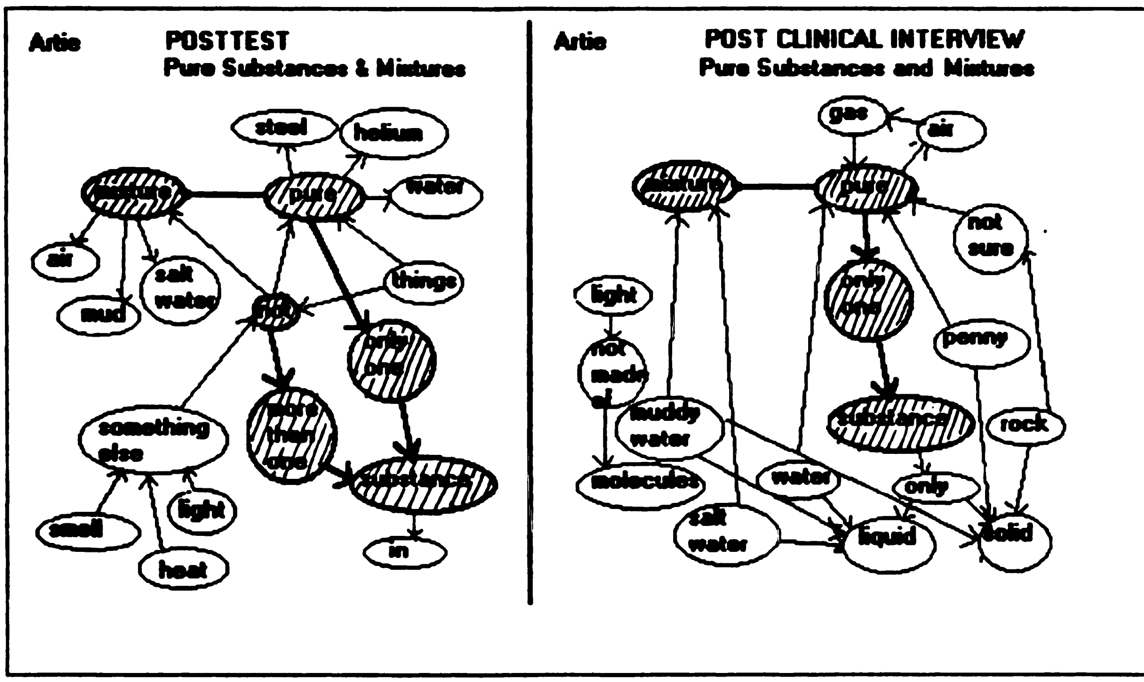

Figure 4.8 Semantic node-link networks for Artie's written posttest statements, and his verbal post clinical interview statements.

thinking, his written and verbal statements did so consistently. There are some differences in Artie's written statements and verbal statements as well. The content of the post clinical interview seemed different from content of the posttest in its tone and the kinds of ideas emphasized due to the nature of the questions asked. In the written posttest, Artie was asked to tell what the difference is between things that are pure and things that are not. He was asked to classify common substances such as air, light, heat, water and salt water. On the posttest, Artie was given a card sort task with the words pure, mixture, matter, solid, liquid, and gas and asked to arrange the cards in a ogical order and explain

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logical order and explain why he put certain cards together. He seemed unsure of whether some substances were pure or mixtures, and the relationship of pure to solids and liquids at the post clinical interview, and the posttest did not capture these uncertainties. Because the two tasks, posttest written explanations, and post clinical interview card sort, were different, Artie's explanations were somewhat different. The part of his explanation that was most important for my analysis, however, the ***core concepts***, were similar, regardless of the difference in the other ideas that Artie happened to mention at the same time, due to the nature of the tasks. The question still remained to be answered whether the difficulty of the writing tasks might have interfered with Artie's ability to express his ideas in writing.

Artie's perceptions of classroom writing. Artie said that he had written before in other classes---writing stories and book reports. He said that in fifth grade he did a lot of writing and got an award for one of his stories. He felt that the kind of writing he was required to do in his science activity books and freewrites during the Matter and Molecules unit was not difficult. Sometimes thinking about the ideas was difficult though. During an interview in the eighth week about writing, the following conversation transpired:

I: Did you find writing in your science booklet hard or easy?

Artie: Sometimes easy, sometimes hard.

I: Why was it hard sometimes?

Artie: I forgot sometimes what the words meant. . . it was easy when I knew more about it.

I: How about the freewrites. . . were they hard or easy?

Artie: That was easy. . . because I knew what I was going to write. . . I liked it.

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For the activity booklet writing and freewrites, Artie expressed that he usually felt comfortable about the writing task, and his ability to put his ideas in writing. There was only one time that he expressed that the writing task was difficult, and that was on a States of Matter quiz about weight and volume changes when water changes state. This is what he said:

> ***I:*** ***Did you ever find it difficult to carry those [writing] plans out?***
>
> ***Artie: Yes.***
>
> ***I:*** ***Can you see in one of these where it was more difficult for you?***
>
> ***Artie: That one . . . [Weight and Volume Quiz]. . .***
>
> ***I:*** ***Why do you think that one was more difficult?***
>
> ***Artie: I didn't understand these very well so I couldn't figure out what we were supposed to . . . and it wasn't clear in my head.***

Artie thought he did not perform very well on this quiz, and said that he was unclear about the ideas and couldn't explain his thinking very well. He stated that it was easier the second time, when the teacher had him go back and write his explanations again, after she coached the students about what they should write. In general, however, for the writing he did in his activity booklets, and on freewrites, Artie stated that the tasks were easy and he enjoyed them. He stated that he liked writing and challenges to think. Artie had little difficulty with the writing tasks, except on the two weight and volume quizzes, and thus, the writing was not a main interference with Artie's ability to express his ideas.

Evidence for Weak Rest

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Evidence for Weak Restructuring in Artie's Writing

Now I was reasonably confident that the ideas Artie expressed in writing in his activity booklets and freewrites were indicators of his thinking, because his written ideas from the pretest were similar to those he expressed verbally at the pre-clinical interview, his written ideas from the posttest were similar to those he expressed verbally at the post clinical interview, and he stated that the writing tasks in the activity booklets and freewrites were not difficult, and he enjoyed them. In the following section, I present evidence from Artie's writing that he accomplished a weak form of restructuring as a result of the Pure Substances and Mixtures lesson cluster. I will show that his *core concepts* remained similar from pretest to posttest, even though he began to change some of his ideas during the instruction. Artie refined and reorganized his schema, demonstrating a weak, rather than radical, form of knowledge restructuring.

Pretest conceptions compared with conceptions during instruction. Figure 4.9 shows the semantic node-link network constructed from Artie's paper-and-pencil pretest about pure substances and mixtures, and the network constructed from his writing in the Pure Substances and Mixtures Activity Book, and on his quizzes. The *core concepts* that Artie identified were similar but showed some differences: His core concepts at the pretest were that pure things don't have two or more substances in them, but mixtures do; during the lesson cluster, he identified "matter" and "molecules" within his core concepts, and correctly retained the notion from his prior knowledge that pure things contain one kind of matter or molecule, and do not have two or more [substances] kinds of matter, or kinds of molecules. The Coding Scheme for Evidence of Restructuring, Chapter 3, page 120, is also presented here in

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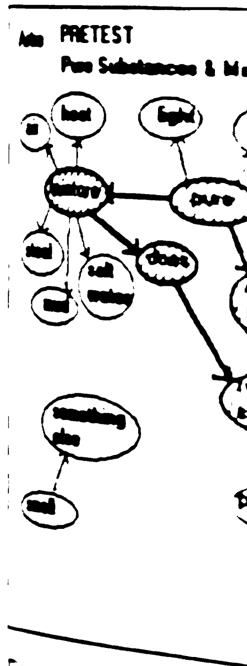

Figure 4.9 Semantic noc
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Figure 4.10. The semantic node-link networks from Artie's writing showed the same core concepts (W1), with the addition of new relations (to matter and molecules) (W4), and some reorganization of his domain knowledge (W7). He appeared to have a greater number of concepts in his schema during the

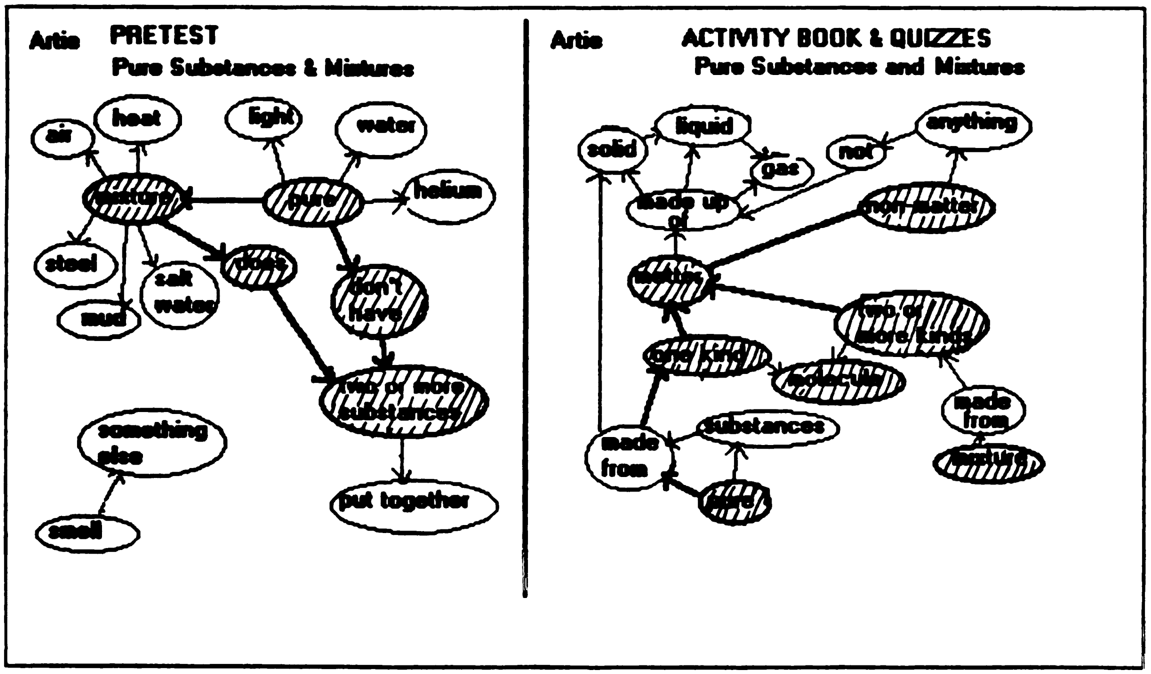

Figure 4.9 Semantic node-link networks of Artie's pretest and activity book/quiz conceptions about pure substances and mixtures.

lessons (R1), but the relations among the concepts (R2), and the variation of core concepts (R5) were similar on both the pretest writing and the writing during instruction. I also included W8, the learner possessed more experience in the domain, since Artie's statements at the pretest and pre-clinical interviewwere close to the scientific goal conceptions about pure substances and mixtures---that pure substances consist of only one kind of substance, or kind of molecule, and mixtures contain more than one kind of substance, or kinds of molecules. When assessing the kinds of restructuring Artie demonstrated above a

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W2 Possibly inaccurate
W3 Addition of new strateg
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W5 Addition of more proce knowledge
W6 Reorganization of dom knowledge
W7 Core concepts same
W8 Learner possesses m in the domain

Figure 4.10 Coding restructuring.

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demonstrated above according to the Coding Scheme for Evidence of Restructuring his changes were more weak in form than they were radical. Notice that the kinds of restructuring he showed were W4, W6, W7, W8, with only one from the radical criteria, R1, demonstrating knowledge restructuring that was more weak. The restructuring that Artie accomplished so far in the

Coding Scheme for Evidence of Restructuring

WEAK		RADICAL	
W1	Concepts closely related	R1	Conceptual system greater <u>numbers</u> of concepts
W2	Possibly inaccurate	R2	Different relations among concepts; new domains
W3	Addition of new strategies	R3	Knowledge related to principles and procedures
W4	Addition of new relations	R4	Involves new theories
W5	Addition of more procedural knowledge	R5	Core concepts different and more varied
W6	Reorganization of domain knowledge	R6	Difficult to accomplish
W7	Core concepts same		
W8	Learner possesses more experience in the domain		

Figure 4.10 Coding scheme for weak or radical types of knowledge restructuring.

Pure Substances and Mixtures lesson cluster was closer to a weak form than a radical one based on the criteria that distinguishes weak from radical restructuring presented in Figure 4.10.

<u>Conceptions during instruction compared with posttest conceptions</u>. Figure 4.11 shows the semantic node-link networks constructed from Artie's writing about Pure Substances and Mixtures in his activity book and on quizzes, and the network constructed from his writing at the posttest. The

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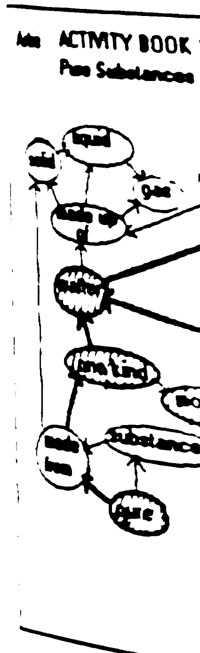

Figure 4.11 Sem
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core concepts that Artie identified were similar, but showed differences much like those between his pretest and activity book writing: His core concepts at the posttest were that pure [substances] contain only one substance, while mixtures contain more than one substance; during the lesson cluster in his activity book, and on quizzes, Artie identified "matter" and "molecules" within his core concepts. He expressed that pure things are one kind of matter or molecule, and do not have two or more [substances] kinds of

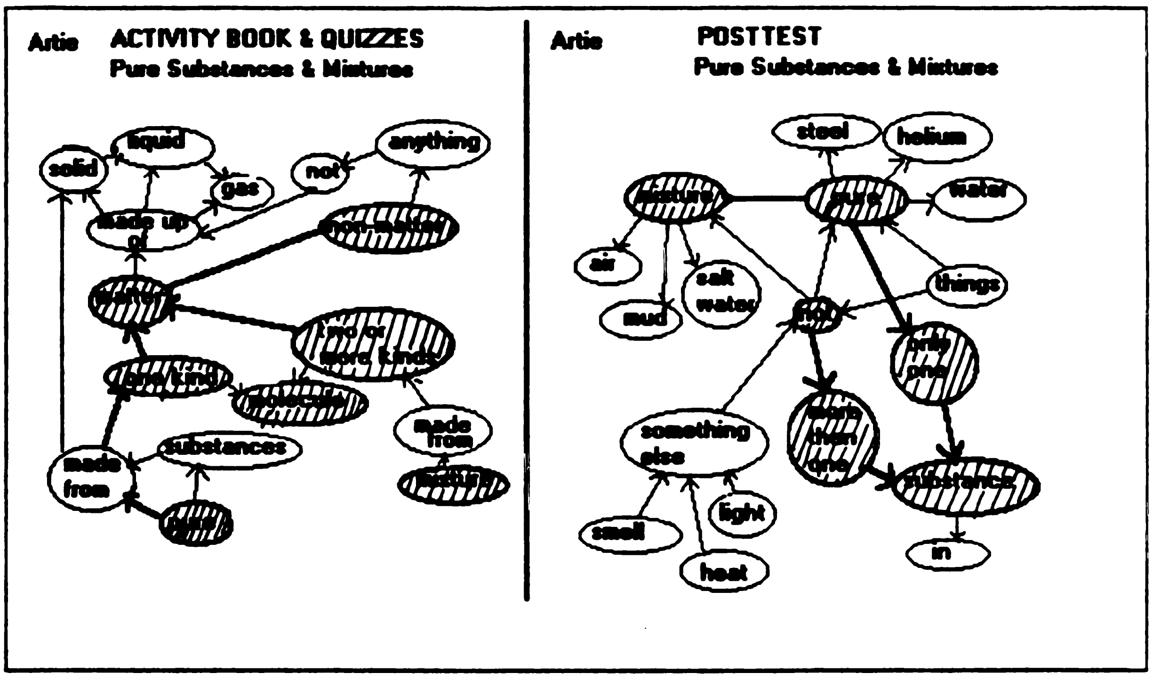

Figure 4.11 Semantic node-link networks of Artie's activity book/quiz and posttest conceptions about pure substances and mixtures.

matter, or kinds of molecules contained in them. As Artie moved from the writing during instruction to the posttest writing he showed some reorganization of his domain knowledge (W6), because he changed his definition of pure to having only one substance it, but the number of concepts (W7) and the variation of the concepts that he identified at the posttest is less

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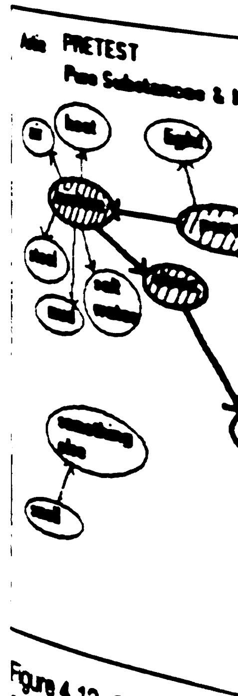

Figure 4.12 Semantic
and his written posttes

than he identified during the instruction (not R5). During instruction he identified molecule, matter and non-matter, he did not identify these terms or any other new ones at the posttest. The criteria for assessing how much restructuring Artie accomplished between instruction and the posttest contained only W's, and showed a more weak than radical form of restructuring as a result of the instruction in this lesson cluster.

Pretest compared with posttest conceptions. To confirm the findings about Artie's thinking across the lesson, I compared his pretest and posttest writing to see if his expressed ideas from pretest to posttest also demonstrated weak restructuring. Figure 4.12 shows the semantic node-link networks constructed from Artie's writing on the paper-and-pencil pretest and those from the paper-and-pencil posttest. The *core concepts* that Artie identified were similar: At the pretest, pure [substances] do not have two or

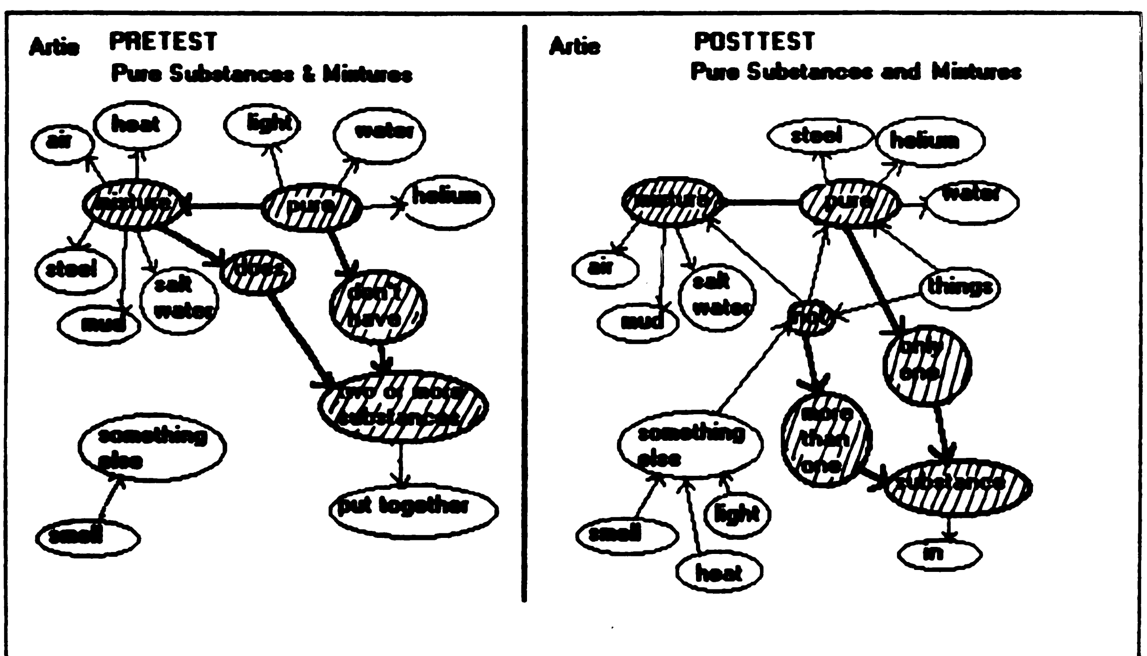

Figure 4.12 Semantic node-link networks for Artie's written pretest statements, and his written posttest statements.

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Looking for Learning

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more substances, while mixture does; at the posttest, pure [substances] contain only one substance, while things that are not pure have more than one substance in them. The networks constructed from Artie's writing about these concepts showed they contained the same core concepts with some reorganization of the knowledge (he moved steel to pure, and light and heat to something else), and he used more scientific expression by describing pure as made of only one substance, rather than not having two or more substances put together. According the criteria for weak or radical restructuring located in Figure 4.10, Artie's thinking showed the concepts to be closely related (W1), with some reorganization of his domain knowledge (W6), but with core concepts the same (W7), and likely some prior experience with the domain (W8). Based on the semantic node-link networks constructed from Artie's writing, his restructuring changes as a result of the instruction in the Pure Substances and Mixtures lesson cluster fit the criteria for weak rather than radical restructuring, and his writing showed evidence that he was restructuring his knowledge.

Looking for Learning Mechanisms

To help direct my search for the mechanisms in classroom events that might be associated with knowledge restructuring, I desired more information from Artie's writing than just how much knowledge restructuring he accomplished as a result of the lesson. It also made sense to understand whether he had attained the scientific goal conceptions of the instruction. If students restructure their knowledge, but do not learn the desired information, looking at students' writing for only knowledge restructuring will not help teachers assess students' progress. Artie's writing provided a "window" into his thinking about the go

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his thinking about the goal conceptions, as well. I present these findings in the next section, and used the findings about knowledge restructuring and goal conception attainment to direct my search for mechanisms in the instructional events.

Another piece of evidence from Artie's writing that helped direct my search for knowledge restructuring mechanisms was the evidence he provided in his writing that he was using a particular learning strategy (Anderson & Roth, 1988). I observed this evidence to see if differences in students' uses of strategies across the different lesson clusters might help me detect lessons that were more influential for supporting students' uses of effective learning strategies to accomplish conceptual change, and thus provide evidence for the mechanisms that might be associated with knowledge restructuring and conceptual change.

Artie's attainment of goal conceptions for pure substances and mixtures. The scientific goal conceptions that the teacher desired students to attain as a result of the instruction in the Pure Substances and Mixtures lesson cluster consisted of mainly three: Goal conceptions at the macroscopic level, 1, which stated that pure substances are made up of only one kind of substance, and mixtures are made up more than one substance, and 1a, which stated that solids, liquids and gases are matter, and other things (like heat and light) are not; and one goal conception at the microscopic level, 9, which stated that all matter is made of molecules, non-matter is not (see Appendix I for a complete list of the seventeen Goal Conceptions for Matter and Molecules). Based on his statements at the posttest, Artie attained goal conception 1 and 1a at the macroscopic level. He stated during the posttest that pure substances are made of only one substance, and mixtures are not, and that liquids, solids, and

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gases are matter. For conception 9 (microscopic), he was more uncertain in his statements. In his written posttest statements, he did not mention molecules in relationship to pure or mixtures. His post clinical interview statements back up his written statements. He stated during the post clinical interview that light is not made of molecules, but he did not mention molecules with regard to pure or mixtures, or to matter. Even when he classified penny, rock, water, salt water, and gas as solids, liquids or gases, he did not mention their relationship to molecules, or the relationship of molecules to pure substances or mixtures, so he may not have understood the last goal conception.

Evidence for Artie's learning goals and strategies. During the Pure Substances and Mixtures lesson cluster, based on the concepts Artie identified in his writing, Artie used a learning strategy to make sense of the new information. I used Anderson and Roth's (1988) descriptions of students' learning goals and strategies while attempting to understand science text as the basis for assessing Artie's goals and strategies (see page 62, this document). Artie demonstrated in his conceptions written during the instruction that he was able to draw on new information to answer the activity booklet questions. He responded to questions about pure substances and mixtures that pure is made from one kind of matter, and one kind of molecule, and mixtures are made of two or more kinds of matter, or kinds of molecules. When answering questions about the real-world at the posttest, however, Artie relied on his real-world schema. He used the same statements at the posttest about pure being made of only one substance and mixture of more than one. He said, "Things that are pure have only one substance in it, but the things that are not pure have more than one substance in them"—very similar to his statement about pure an

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-Strategy 3.

statement about pure and mixtures at the pretest, "pure don't have two or more substances mixed together. Mixed does". Artie's post clinical interview statements were similar. He did not mention at either time the role of matter or molecules in his conceptions of pure and mixture. Because Artie returned to his real-world conceptions about pure and mixture at the posttest and post clinical interview, he fit Strategy 3 within Anderson and Roth's (1988) framework (see page 62, this document), possessing a goal to learn, but tending to add facts to his memory without integrating them with his prior real-world knowledge, using instructional schema to answer instructional questions, and real-world schema to answer questions about the real-world. There was more evidence for Artie using Strategy 3 than for any other strategy. He did not isolate the words matter and molecule, but integrated them into his answers during instruction, and made them part of his explanation about pure substances and mixtures. When asked during instruction to explain the difference between pure and mixture, he used the terms "matter" and "molecules". He said, "Pure substances are made of one kind of molecule. Mixtures are made of two or more different kinds of molecules". However, when asked to use his new knowledge to explain real-world substances at the posttest and post clinical interview, he did not refer to his new knowledge, but used words and ideas similar to the real-world conceptions he identified at the pretest and pre-clinical interview---"pure have only one substance in it". Artie showed evidence here that he drew on textbook ideas to answer textbook questions, and real-world schema to answer questions about real phenomena---Strategy 3.

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Summary of Artie's conceptions for the pure substances and mixtures lesson cluster. Before instruction in Pure Substances and Mixtures, Artie identified similar conceptions in his written statements from his paper-and-pencil pretest and his verbal statements in the pre-clinical interview. His *core concepts* were similar for both: Pure things don't have two or more substances put together, while mixtures do; and pure is the main thing, not made of anything else, and mixtures are made of different things.

After instruction in Pure Substances and Mixtures, Artie identified similar conceptions in his written statements from his paper-and-pencil posttest and his verbal statements in the post clinical interview. His *core concepts* were similar for both: Pure things are made of only one substance, while mixtures are made of more than one substance.

When I compared Artie's pre-instruction conceptions with his ideas written during instruction, there were some differences in the conceptual structure. The *core concepts* were similar. Pure things are of one kind, and mixtures consist of more than one kind of something. But during instruction, Artie added new relations to his schema with the concepts "matter" and "molecules". He reorganized his domain knowledge to assimilate these two concepts, but retained the same core concepts as in his pretest, thus demonstrating a weak form of restructuring.

Artie demonstrated in his writing that he was certain about at least two of the goal conceptions for Pure Substances and Mixtures. He consistently mentioned that pure substances were made of one kind of substance, and mixtures were made of more than one substance, and mentioned solids, liquids, and gases as matter. He was more uncertain and not consistent about the other goal conception for the lesson cluster. He did not refer to "matter" or "molecules" in relation t

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"molecules" in relation to pure and mixtures, or liquids, solids, and gases at the posttest or post clinical interview. The findings about Artie's thinking evidenced in his writing across all lesson clusters is summarized in Table 4.1 on page 181.

Artie showed evidence in his writing across the Pure Substances and Mixtures lesson cluster that he might be using Anderson and Roth's (1988) Learning Strategy 3, because he demonstrated ability to draw on new ideas to answer the questions in his activity book correctly, but when answering questions about the real-world at the posttest and post clinical interview, he seemed to rely on the same real-world schema that he possessed prior to instruction. He refined his ability to state his ideas about the substances, but he did not mention molecules or matter, or use them to explain the difference between pure substances and mixtures.

Artie's Conceptions for the Dissolving Lesson Cluster

Before the Matter and Molecules lesson unit began Artie wrote the following on his paper-and-pencil pretest about dissolving (see Figure 4.13). The semantic node-link network constructed from Artie's written statements is located in the same figure (4.13). Notice that the node-link network resembles Artie's statements by the words he mentioned contiguously placed together and connected in the network. For instance, he said "sugar turns into water molecules", so sugar was placed next to water and molecule. "Sugar" was also mentioned with "burn" and "dissolve", so was connected to those concepts as well. Artie's response answered a question in the pretest that stated "John stirred some sugar into a glass of water. After a while the sugar had all dissolved--the water was clear and John could not see any sugar. What

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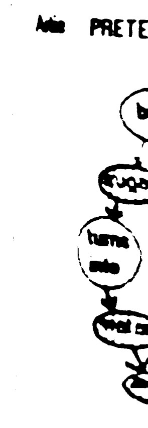

Figure 4.13
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happens to the sugar when it dissolves in water?" The test then asked Artie to answer a multiple choice question about whether sugar dissolves faster in hot or cold water, or the same, and explain his answer. The *core concepts* within Artie's node-link networks were shaded so that these concepts stand out and

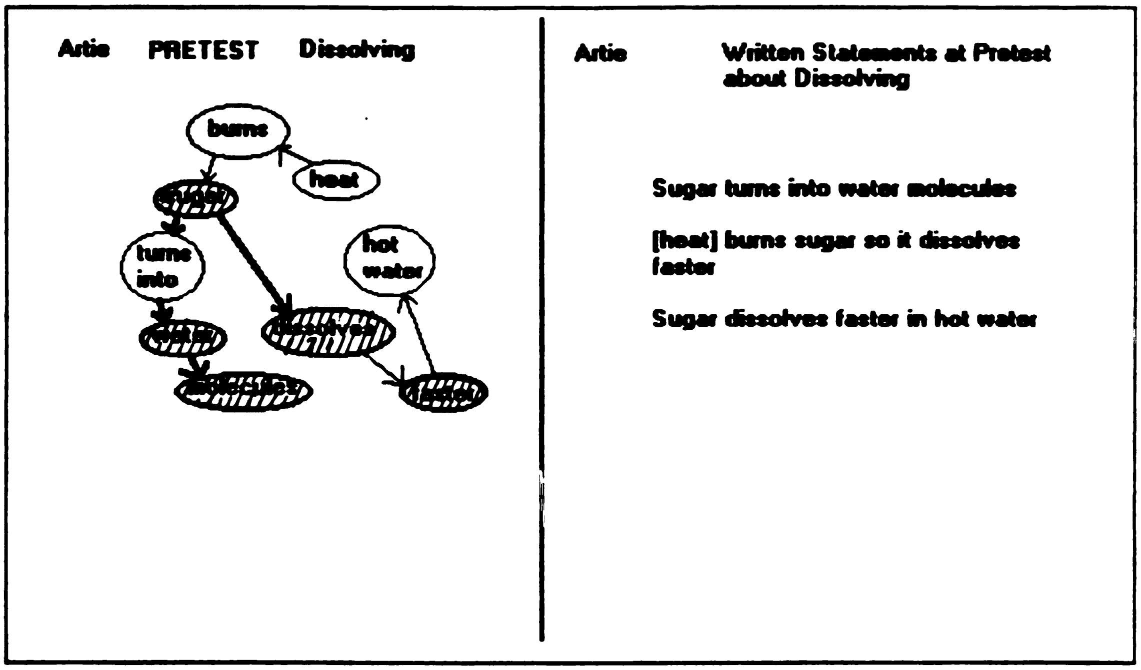

Figure 4.13 Artie's written statements about dissolving on the pretest, and the semantic node-link network constructed from the statements.

could be compared between one network and another.

When Artie described sugar dissolving at the pre-clinical interview, he made the statements transcribed in Figure 4.14. Here Artie was responding to a question posed during the interview that he describe and explain what he observed when a teabag of sugar was placed in a cup of water. The semantic node-link constructed from Artie's verbal statements is located in the same figure. Figure 4.15 shows some of Artie's statements during the dissolving

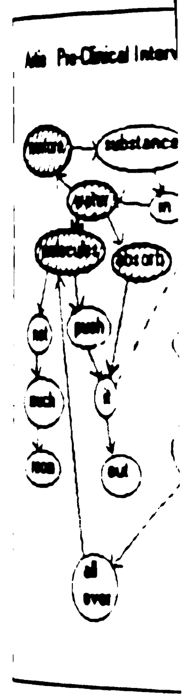

Figure 4.14 Artie's
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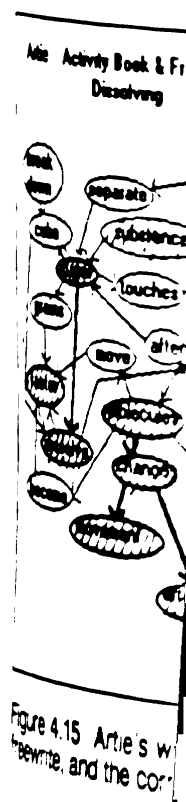

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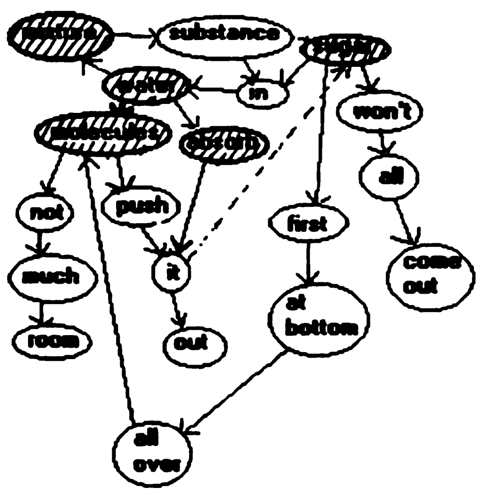
Artie Pre-Clinical Interview Dissolving



Artie Verbal Statements at Pre-Clinical Interview about Dissolving

Water molecules don't have much room so they push it out
The water is going to absorb it

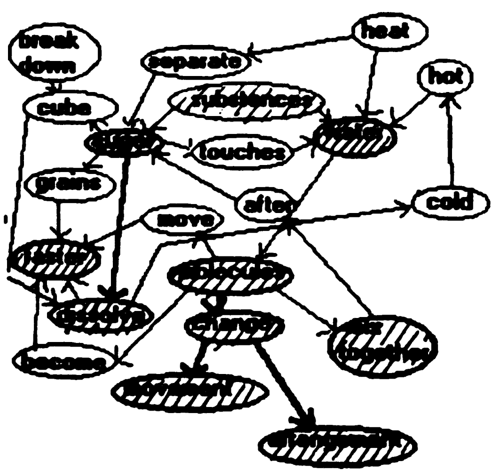
The sugar will be in the water
It won't all come out

Sugar will be first at the bottom, then all over because water molecules will push it around

It is a mixture because you put a substance in the water to make it a mixture

Figure 4.14 Artie's verbal statements about dissolving at the pre-clinical interview and the corresponding node-link network.

Artie Activity Book & Freewrite Dissolving



Artie Written Statements in Activity Book and Freewrite

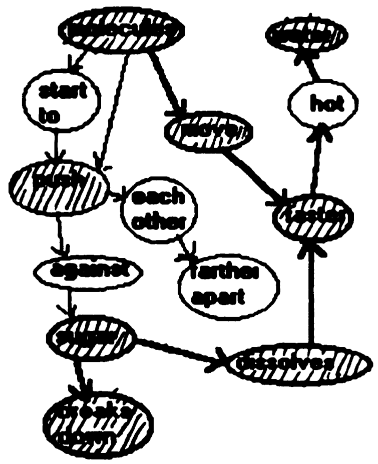
Sugar will dissolve; molecules will change movement and arrangement; the sugar cube can dissolve.. . . the substances sugar and water molecules will mix together after the sugar cube touches the water; heat of the water will separate the sugar grains faster.

The hot water helps dissolve the sugar cube faster. The molecules move faster which helps break the cube down.

Sugar can dissolve in both cold and hot water. The hot water will dissolve the sugar faster. In hot water the behavior of the molecules change. The molecules become faster. . .

Figure 4.15 Artie's written statements in the Dissolving Activity Book and on freewrite, and the corresponding node-link network.

Artie POSTTEST Dissolving



Artie Written Statements at Posttest about Dissolving

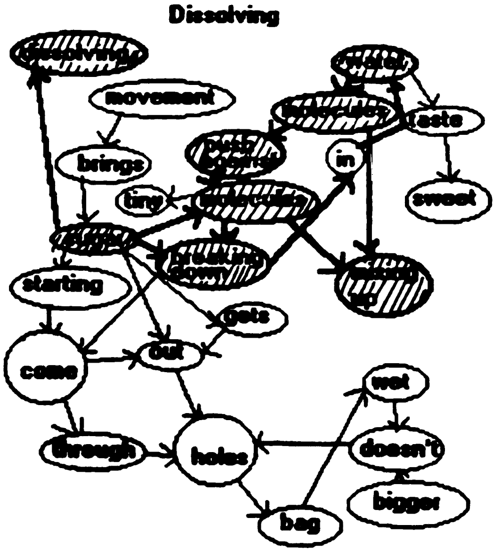
The molecules start to push against the sugar which breaks it down.

Sugar dissolves faster in hot water.

The molecules move faster. The sugar can dissolve. The molecules push each other farther apart. Molecules move faster in hot water.

Figure 4.16 Artie's written statements about dissolving at the posttest, and the corresponding node-link network.

Artie POST CLINICAL INTERVIEW Dissolving



Artie Verbal Statements at Post Clinical Interview about Dissolving

The movement brings the sugar out.
The sugar is starting to come out.
The water would taste sweet.
Sugar gets out of the holes because the bag is wet; it doesn't make the holes bigger.

I forgot this one; they started mixing up, the sugar molecules and water molecules started mixing up.

The water molecules started pushing against the molecules [sugar] so they started breaking down and could come through the holes.
The molecules went through the holes because they're so darn tiny.
Sugar is breaking down in the water, its dissolving.

Figure 4.17 Artie's verbal statements about dissolving at the post clinical interview, and the corresponding node-link network.

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Figures 4.16 and 4.17 show Artie's statements about dissolving at the paper-and-pencil posttest and post clinical interview, along with the node-link networks constructed for each statement.

As with the results for the Pure Substances and Mixtures lesson cluster, the node-link networks for Artie's concepts were placed side-by-side to better compare the differences in core concepts and organization of the various schema. The findings of changes in Artie's conceptions about dissolving, and his knowledge restructuring are discussed in the following sections.

How Well Did Artie's Writing Display his Thinking?

Pretest and pre-clinical interview conceptions. Figure 4.18 shows the semantic node-link networks constructed for Artie's written statements about dissolving on his paper-and-pencil pretest, and his verbal statements during the pre-clinical interview. Notice that the *core concepts* were similar in that Artie attempted to state that the sugar somehow goes into the water. He mentioned water molecules in both cases. At the pretest he mentioned that the sugar "turns into water" and verbally he said the water "is going to absorb it". The concepts were also different. In his interview, Artie stated that the water molecules push the sugar around, and there is a mixture from the two substances. He did not mention these concepts in his written explanation. Considering both conceptions, Artie's ideas about dissolving were that dissolving has something to do with water molecules, and sugar somehow going in the water. Just how he thought that happens was unclear. Artie's thinking showed confusion about the dissolving process. His explanations were inconsistent in hi

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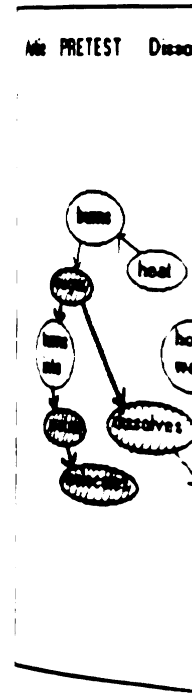

Figure 4.18 Semantic
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were inconsistent in his writing: Does heat burn the sugar to make it dissolve? Or does sugar turn into water molecules? In the interview, dissolving was

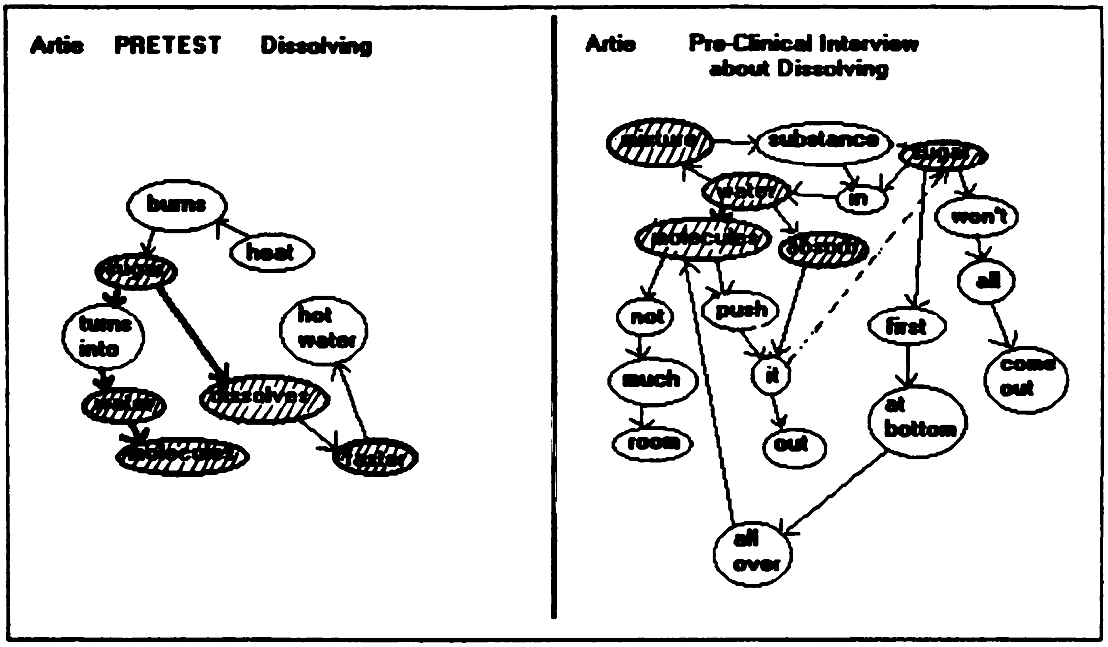

Figure 4.18 Semantic node-link networks for Artie's written pretest statements, and his verbal pre-clinical interview statements about dissolving.

something that occurred when water molecules pushed sugar molecules around, or dissolving occurred when water absorbed sugar. Another conception Artie held was that sugar goes all around in the water, first at the bottom. Artie showed evidence that his written statements reflected his thinking, because he seemed unclear about what happened during dissolving, and his writing showed unclear thinking. The written ideas may not be as elaborate, but the evidence used to detect knowledge restructuring, the ***core concepts***, both showed Artie's confusion and misunderstanding of the dissolving process. Artie's written statements were reliable for measuring his core concepts, the

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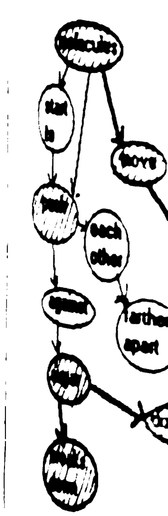

Figure 4.19 Seman
statements, and his ve

core concepts, the ideas he held as central to understanding the nature of dissolving and molecular behavior in dissolving.

Posttest and post clinical interview conceptions. Figure 4.19 shows the semantic node-link networks constructed from Artie's written statements about dissolving on the paper-and-pencil posttest, and his verbal statements at the post clinical interview. Artie's core concepts identified during the written posttest were that molecules break down sugar, and accomplish the break down faster in hot water because the molecules move faster and push each other farther apart. His core concepts verbally identified at the post clinical

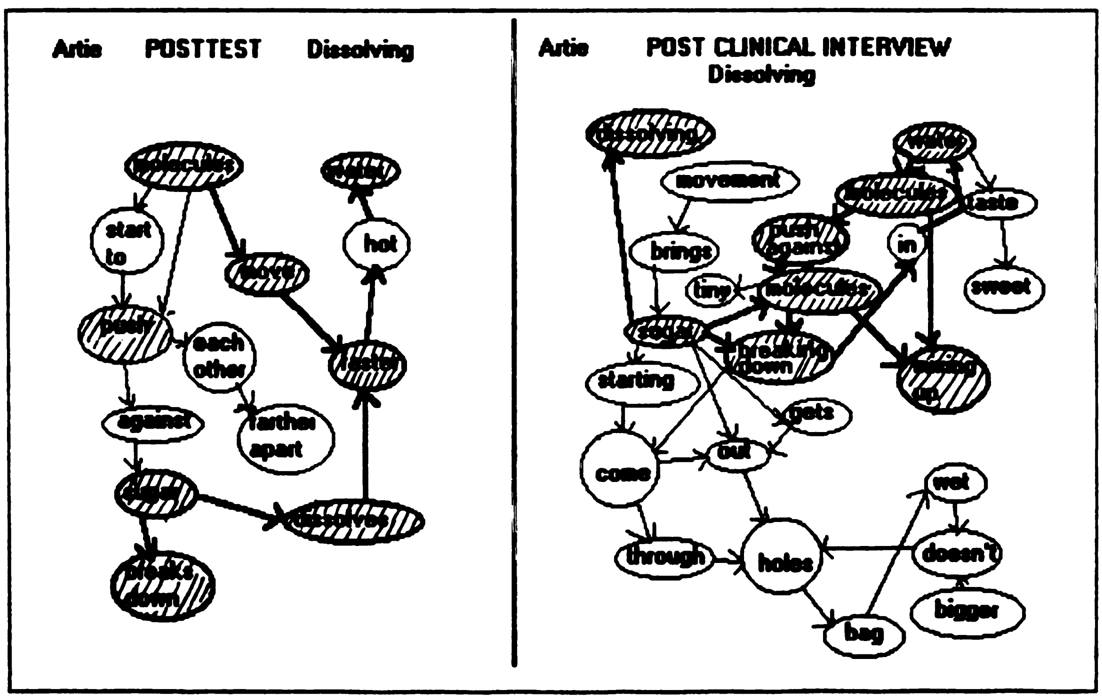

Figure 4.19 Semantic node-link networks for Artie's written posttest statements, and his verbal post clinical interview statements about dissolving.

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interview were that water molecules start mixing up with the sugar and break it down, but he did not mention how heat affects the water molecules. Essentially, his core concepts were similar in that he identified that water molecules break down sugar when sugar dissolves in water.

Artie's perceptions of classroom writing. In the previous section, it was reported that Artie said the writing tasks in the activity booklets and freewrites were not difficult, and he enjoyed them. There was only one instance where he felt the writing was difficult, the States of Matter weight and volume quiz, and that was due to his fuzziness about the ideas, and what he was expected to write. In general, he reported that the writing tasks were easy to accomplish. Artie's statements about writing helped me conclude that the writing task difficulty did not interfere with his ability to write his ideas.

Evidence for Radical Restructuring in Artie's Writing

Once I observed that the ideas Artie expressed in writing about dissolving concepts was similar to the ideas he expressed verbally about concepts, and that the difficulty of the writing task did not interfere with his ability to express his ideas in writing, I was more confident that the ideas he expressed in writing in the pretest and posttest about dissolving, and in the dissolving activity book and freewrites were reasonable indicators of what Artie was thinking about dissolving concepts. The following section presents evidence from Artie's writing that he accomplished a radical form of knowledge restructuring as a result of the Dissolving lesson cluster. I will show that his *core concepts* changed from pretest to posttest, and that he used his new theories about molecules to explain and understand how dissolving occurs.

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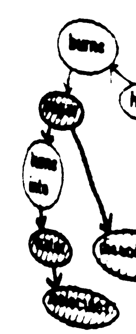

Figure 4.20 Semantic
and his written statem

Pretest conceptions compared with conceptions during instruction. Figure 4.20 shows the semantic node-link network constructed from Artie's written pretest explanations about dissolving, and the network constructed from his writing during the lesson cluster instruction. Artie's *core concepts* at the pretest were that sugar put into water turns into water molecules, that hot water might burn the sugar to make it dissolve faster. His *core concepts* during the lesson changed: Now Artie talked about molecular movement and arrangement changing as the sugar dissolves in the water, and that hot water dissolves sugar faster because the molecules become faster and put more pressure on the sugar to break it down. He added new concepts about molecular behavior and how that affects dissolving to his *core concepts*. When I analyzed Artie's changes for the kind of restructuring he accomplished,

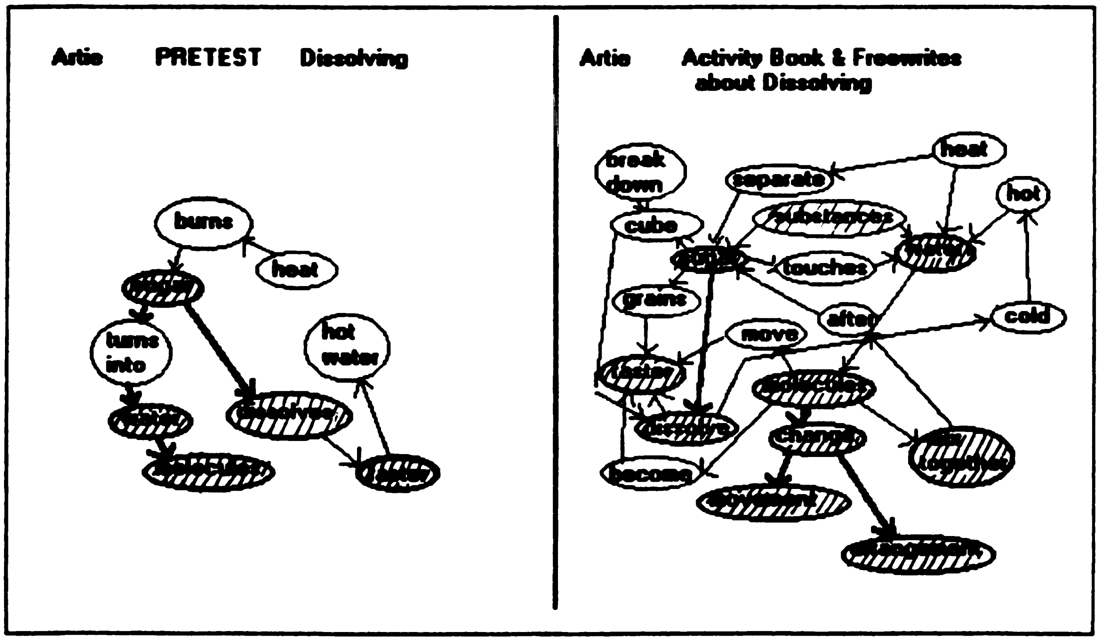

Figure 4.20 Semantic node-link networks for Artie's written pretest statements, and his written statements during instruction about dissolving.

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I found evidence that he incorporated greater numbers of concepts within his conceptual system (R1). He added molecular behavior and used it to explain the dissolving process. He had different relations among the concepts (R2). Rather than sugar turning into water molecules, or water absorbing the sugar, the sugar breaks down in water due to the molecular behavior of the water. And his system involved new theories (R4). Rather than using his confused theories that sugar goes into water and gets pushed around or "burned" or changed into water, he explained the dissolving of sugar in water based on what he knew about the movement and arrangement of molecules. Artie retained his correct prior instruction notion that sugar going into water somehow mixes with it, and that it has something to do with the water molecules, and he had a more complex schema for his conception about dissolving that added concepts about molecular behavior. Artie demonstrated in his writing during lessons a radical form of restructuring, conceptual change. How well did Artie retain these new conceptions at the posttest?

Conceptions during instruction compared with posttest conceptions. Figure 4.21 shows the semantic node-link networks constructed from Artie's writing about dissolving in his activity book and freewrites, and the network constructed from his writing on the posttest. The *core concepts* that Artie identified were similar: During instruction Artie's core concepts were that the molecular behavior of water molecules breaks down sugar grains into sugar molecules which mix with the water, and that hot water makes this process go faster; at the posttest, he identified similar concepts, that water molecules push against and break down sugar, because in hot water the molecules move faster and farther apart. Artie retained the same new core

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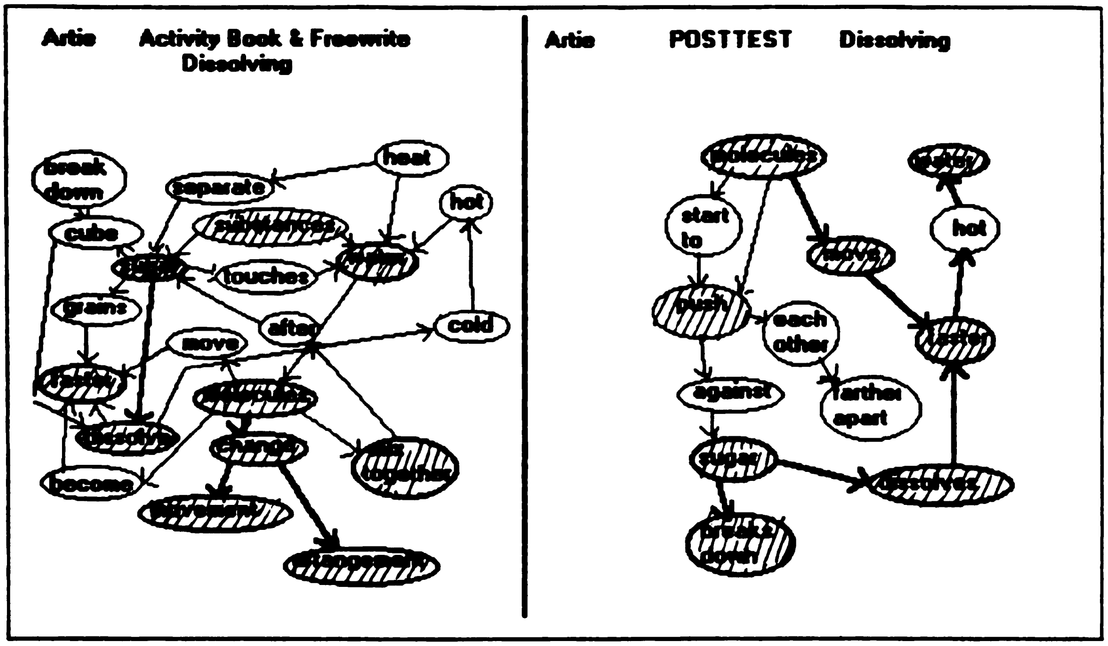

Figure 4.21 Semantic node-link networks of Artie's written statements during instruction, and his written statements on the posttest about dissolving.

concepts he began to use during his instruction about dissolving. He demonstrated conceptual change, a change in his core concepts and theories about dissolving, as a result of the instruction.

<u>Pretest compared with posttest conceptions</u>. Figure 4.22 shows the semantic node-link networks constructed from Artie's writing on the paper-and-pencil pretest with those from the posttest. The ***core concepts*** that Artie identified at the posttest contained greater numbers of concepts (R1), different relations among the concepts (R2), and new theories for explaining dissolving (R4). At the posttest, Artie added conceptions about the behavior of water molecules and their effect on sugar when it is placed into water. He used his theories about molecular behavior, and the effect of heat on molecules to explain how dissolving occurs. Artie showed a conceptual change kind of radical restructuring at the posttest.

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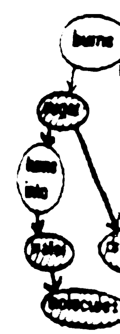

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<u>Looking for Learning Mechanisms</u>

Artie's writing provided evidence of radical restructuring and conceptual change in his thinking about dissolving. To better understand how he attained the scientific goal conceptions of the instruction, and how well the instruction supported his thinking, I looked for evidence in his writing. I intended to further the knowledge gained about the <u>kinds</u> of restructuring Artie

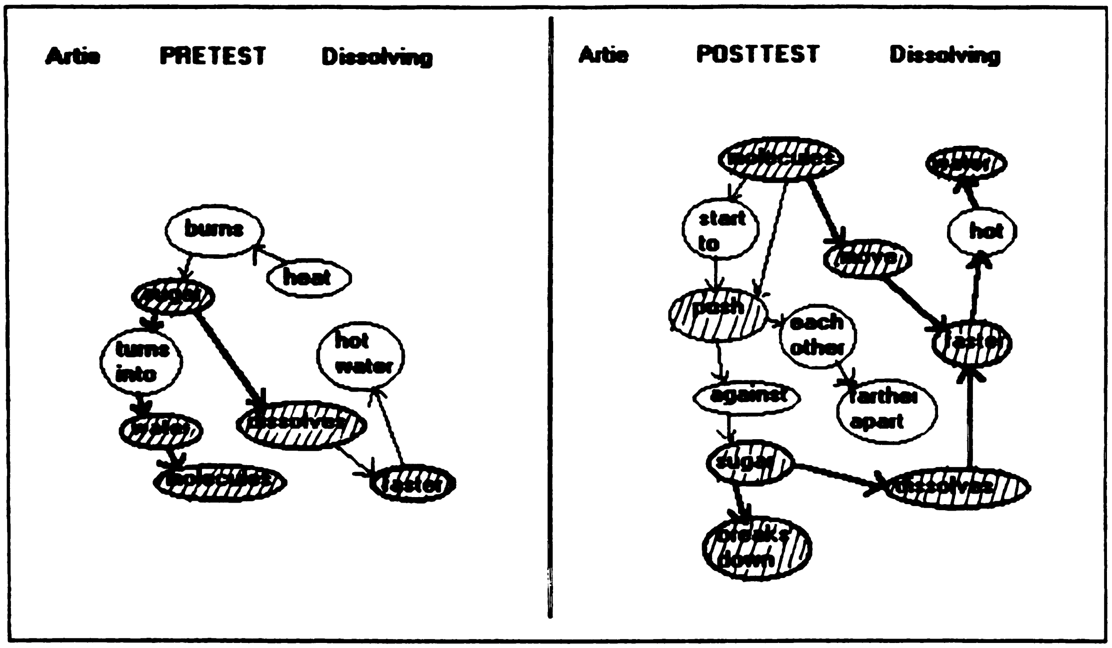

Figure 4.22 Semantic node-link networks for Artie's written pretest and posttest statements about dissolving.

accomplished to understand first, what goal conceptions Artie learned, and the relationship of his restructuring to his learning. And second, if he used any particular learning strategy and how that wasrelated to restructuring and goal conception attainment. Understanding the relationships between Artie's knowledge restructuring, the goal conceptions he learned, and his learning strategies would

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strategies would direct my search for the mechanisms in the classroom instruction that influenced Artie's learning.

Artie's attainment of goal conceptions for dissolving. The scientific goal conceptions that the teacher desired students to attain as a result of the instruction in the Dissolving lesson cluster consisted of four: All were goal conceptions at the microscopic level; goal conception 13, molecules of a solute break away and mix with molecules of a solvent; goal conception 14, the only effect of heat on substances is to make its molecules move faster; goal conception 15, increased motion moves molecules farther apart; and goal conception 17, states of matter are due to different arrangements and motions of molecules (see Appendix H for a complete list of the Goal Conceptions for Matter and Molecules). Based on his statements at the posttest, Artie attained three of the four goal conceptions. He stated that the molecules of water break down the sugar (goal conception 13). He also stated at the posttest that sugar dissolves faster in hot water because the molecules move faster (goal conception 14), and that the molecules push each other farther apart (goal conception 15). His acquisition of conception 17 was more uncertain, since there was no evidence for this in his writing except during his freewrite that "in hot water the behavior of the molecules changes". He did not mention the motion or arrangement of molecules during dissolving at the posttest, except to say that the molecules get farther apart, so it is difficult to conclude that he was committed to the last goal conception that the state of sugar or water might be due to the arrangement and motion of the molecules. His verbal post clinical interview statements supported what I found in his writing. He stated that the sugar molecules and water molecules started mixing up, and that water molecules push against the sugar to break it down.

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Evidence for Artie's learning goals and strategies. During the Dissolving lesson cluster, based on the concepts Artie identified in his writing, I was able to detect the kinds of learning goals and strategies Artie used to make sense of the new information. I used Anderson and Roth's (1988) descriptions of students' learning goals and strategies while attempting to understand science text as my basis for assessing Artie's goals and strategies (see page 58, this document). Artie demonstrated in his conceptions during the instruction that he was able draw on the instruction to answer the activity book questions, and make explanations. When asked to explain what happens when sugar goes in to water, he responded that sugar will dissolve because the water molecules will mix with the sugar molecules, and that in warm water the grains of sugar separate faster because the water molecules move faster and break it down faster. Artie demonstrated the same conceptions during his posttest. According to Anderson and Roth's criteria, Artie used a conceptual change learning goal and strategy (Strategy 5) to learn about dissolving. He was able to abandon his alternative conceptions about sugar turning into water, or being absorbed by water, and replaced them with more scientific thinking about the effect of molecular behavior of water to influence dissolving. He used his new knowledge about molecules to change his schema and integrated the new knowledge with his real-world prior knowledge about sugar mixing with water. He attempted to use his new knowledge by applying it to the real situation of what happens when sugar is placed in water, explaining, and predicting. At the posttest he was able to modify and integrate his prior knowledge ideas about how sugar goes into water or is absorbed by it, with his new conceptions about water molecules pushing against sugar and breaking sugar down in the water, and sugar dissolving.

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Summary of Artie's conceptions for the dissolving lesson cluster. Before instruction in the Matter and Molecules unit, Artie identified similar confusions in his written statements from the paper-and-pencil pretest and his verbal statements about dissolving. His *core concepts* were that dissolving has something to do with the water molecules moving the sugar around, and that hot water might burn the sugar, or make the sugar turn into water molecules or be absorbed by the water.

Artie's pre-instruction conceptions were different in conceptual structure from his ideas written during and after instruction. His *core concepts* changed. He added molecular behavior and its effect on sugar to explain dissolving. He added greater numbers of concepts to his schema, and his schema involved a new theory about why sugar dissolves in water. Artie's thinking that is evidenced in his writing shows a more radical form of restructuring. Because he also reached three of the four scientific goal conceptions, he accomplished conceptual change in his understanding of dissolving.

Artie showed evidence in his writing across the Dissolving lesson cluster that he might be using Anderson and Roth's (1988) Learning Strategy 5, a conceptual change strategy, because he was able to abandon his alternative conceptions about dissolving that he held at the pretest, and replace them with more scientific thinking. He used his new knowledge to change his schema and integrate the new knowledge with his real-world prior knowledge. The findings for Artie's thinking evidenced in his writing across all lesson clusters is summarized below in Table 4.1.

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Artie's Knowledge Restructuring Across the Lesson Clusters

Artie's writing showed that he restructured his knowledge to some degree across all of the lesson clusters. For the Pure Substances and Mixtures and the Introduction to Molecules lessons, his restructuring exhibited weaker restructuring characteristics. As shown above, in the Pure Substances and Mixtures lesson, Artie already possessed some schema and prior knowledge for understanding the difference between pure substances and mixtures. And even though he added "matter" and "molecules" to his schema during activity

TABLE 4.1

Knowledge Restructuring, Goal Conception Attainment, and Strategy Use for Artie

Student	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Artie	Pure & Mixt	W4 W6 W8 Weak	refines schema, prior knowledge	3	Goal-1,1a No-9
	Intro to Mol	W2 W6 W7 W8 Weak	refines schema, adds to struct retains misconceptions	4	Goal-10,11,12 No-9
	St of Matter	R2 R3 R4 (R)	schema more complex, interrelationships, uses to expl	5	Goal-2,3,14 No-9,17,18
	Dissolving	R2 R3 R4 (R)	began with little schema for mol behavior, uses new k to explain	5	Goal-13,14,15 No-17
	Thermal Exp	R2 R3 R4 (R)	some prior knowledge schema; uses new to explain	5	Goal-3, 14, 15 No-17

book writing, he abandoned those concepts to answer the questions on the posttests and post clinical interview. He essentially reorganized and refined his prior domain knowledge, but did not add to his core concepts, relations among concepts, or the theories he used to explain pure substances and mixtures.

The conceptions that Artie expressed in writing before, during, and after the lesson on Introduction to Molecules showed similar weak restructuring (see semantic node-link networks for Artie's pretest and posttest conceptions in Appendix G). Artie already possessed some schema for understanding molecules, their size, and their relationship to matter before beginning the unit. He reorganized his domain knowledge, but retained the same core concepts after instruction, and retained one or two alternative conceptions that were contradictory to the scientific goal conceptions. For instance, at posttest, Artie persisted in his conception that molecules are "in" things like solids, liquids, and gases, rather than stating that molecules "make up" solids, liquids, and gases. He retained a notion that molecular arrangement moves from close in solids, to "in the middle" between close and far apart in liquids, and far apart in gases. He ignored or forgot the instruction that stated that molecules are still close together in liquids, but just move freely, rather than being locked in a rigid pattern. He remembered new information and integrated it into his existing schema, but he distorted or ignored some of the information to make it fit his real-world knowledge, apparently using Anderson and Roth's (1988) Strategy 4, overreliance on prior knowledge to make sense of disciplinary knowledge. He demonstrated understanding for three of the four goal conceptions for this lesson cluster, 10, 11, and 12: Molecules are too small to see, even with a microscope; all molecules are constantly moving; and molecular motion continues independently of observable movement. He was more uncertain for 9—his statements sometimes showed his certainty of 9, and sometimes contradicted the conceptions in 9, that all matter is made of molecules, and non-matter is not.

For the lesson clusters on States of Matter, Dissolving, and Thermal Expansion, Artie demonstrated radical restructuring and conceptual change. He showed evidence of using his new knowledge to change his schema, and integrated the new knowledge with his prior knowledge (see semantic node-link networks of Artie's pretest and posttest conceptions, Appendix G). He showed attempts to use his new knowledge to explain phenomena, and make sense of the instruction, thus using a conceptual change strategy for learning, Strategy 5 (Anderson & Roth, 1988). He attained all of the scientific goal conceptions for these lesson clusters, except 9 again, for which he showed uncertainty about matter being made up of molecules and non-matter not being made up of molecules. He also remained uncertain on one other goal conception, 17, that states of matter are due to different arrangements and motions of molecules; sometimes he used this information to explain events, and sometimes he failed to use it. Table 4.1 on page 181 summarizes Artie's restructuring, strategy use, and goal conception attainment for each lesson cluster. The semantic node-link networks used as evidence for the interpretations are located in Appendix G.

Results: Knowledge Restructuring, Learning Strategy Use, and Goal Conception Attainment Across Lesson Clusters and Students

All students showed some degree of knowledge restructuring in their writing, from weak to radical. I was able to identify changes in *core concepts*, organization, and different relations among concepts from the ideas students identified in their writing about the content when I constructed semantic node-link networks from the concepts students mentioned. The following section summarizes the kinds of knowledge restructuring found for each of the other five target students, based on their writing. The results for each target student's goal conception attainment are based on what they wrote at the posttest, supported by what each said verbally at post clinical interviews. The researcher was able to look at what each student said about the 17 goal conceptions, and assess their understanding of each conception, based on their written and verbal explanations. The findings for each target students' learning goals and strategies are also presented. Findings are based on what was observed in their writing, from pretest through activity booklets and freewrites, to the posttest. For all of the other students in the class the researcher assessed the kinds of learning goals and strategies they used for each lesson cluster based on the statements in their writing, and how they used their new knowledge. Decisions were based on Anderson and Roth's (1988) explanations about the strategies students' used when they attempted to learn from science texts. Unlike the Anderson and Roth (1988) studies, students' strategy use was not analyzed by asking them about their strategies. Students' strategies were inferred from their strategy as evidenced in their writing alone. For the six target students, their clinical interview statements were used to support the interpretations of students' strategy use. I was interested in observing whether students might use similar strategies for making sense of classroom instruction, and whether their choice of strategy might influence their restructuring. For the following results, the same analysis procedures and criteria were used that were used in the analysis of target student Artie's strategies above. The findings in Artie's case were described in more in detail to provide a framework for understanding the results found in the other target students' writing. In the next section, the findings for the other target students' written and verbal statements are presented in brief. The findings for restructuring across the lesson clusters are summarized in chart form for each target student in Table 4.7 on page 230.

Kenny

The semantic node-link networks constructed for Kenny's writing during each lesson cluster on his pretest and posttest are located in Appendix G. Kenny's written explanations at the pretest were similar to his verbal explanations at the pre-clinical interview. For instance, on the pretest Kenny wrote that molecules "are small things we can only see with a microscope. . . two times smaller than a dust speck", and they move in air and rock. At his pre-clinical interview, Kenny said that molecules "are smaller than a speck of dust. . quite a little. . . maybe see under a microscope", and "they move around". Kenny's written explanations on his posttest were similar to his verbal expressions at the post clinical interview. His spoken statements at the post clinical interview were sometimes more organized and elaborate than his written posttest statements, but the important part for my analysis, his *core concepts*, were similar in all instances. For example, on his posttest Kenny wrote that molecules "are tiny particles in air, water and other things", and are "trillions times smaller than a speck of dust". At his post clinical interview, Kenny said that molecules are "trillions of times smaller" than the dot on the table, and move in substances, like "moving slower in water", and "move fast" in air. He added more information about molecular movement verbally, but portrayed the same core concepts understanding of molecular movement in his verbal explanations as he did in his posttest writing.

Kenny's perceptions of the writing tasks. Kenny's perceptions of the writing tasks was that freewrites were easy, but activity booklet writing was sometimes hard because coming up with reasons was sometimes difficult, but most often it was easy. When asked if he used any kind of strategies to put his ideas down, he said, "I just put them down." Kenny found the hardest part of the writing was on activity book questions where he had to give reasons. When asked when his writing in science booklets was easy, he said, "I knew some of the answers and drawings". When asked why it was sometimes hard, he said, "It wasn't easy to think about it. . . to get it right", and "it's hard to write about my thinking. . . giving the reason". He thought that the freewrites were all easy, and he said he sometimes enjoyed the writing he did in science. When asked if he liked any of the writing, he said, "Yeah. . .kind of. . .yeah. . .I don't know." The following section summarizes what was found in Kenny's writing for knowledge restructuring, goal conception attainment, and use of learning strategies in the following sections.

Pure Substances and Mixtures. As a result of the instruction in the Pure Substances and Mixtures lesson cluster, Kenny demonstrated radical restructuring. He had different relationships among concepts on his posttest schema (R2), his schema involved new theories (R4), and consisted of more varied and different *core concepts* (R5). For example, at the pretest, Kenny said that pure is "normal things that you will see or feel. Helium, steel, mud and salt water aren't normal regular things that you see everyday". His core concepts for pure seemed to be that pure things are normal and regular. By the posttest, Kenny had new core concepts: He said "pure things have only one substance, and things that are not pure are made of two or more substances". The core concepts of Kenny's schema at the posttest are totally different. For the Pure Substances and Mixtures lesson, Kenny attained goal conceptions 1 and 1a: Solids, liquids and gases are matter, and other things are not; and pure substances contain only one kind of molecule or substance, and mixtures contain more than one. He did not attain goal conception 9, that all matter is made of molecules. He did not mention the relationship of molecules to pure substances and mixtures, even during instruction in his activity booklet. Kenny completed the lesson cluster about pure substances and mixtures with new schema about the meaning of pure at the macroscopic level, and used his new knowledge to classify real-world substances, thus demonstrating use of a conceptual change thinking strategy (Strategy 5, Anderson & Roth, 1988). At the posttest he attempted to classify real-world substances according to his new definition, but was not very successful. Many of his classifications are similar to his pretest conceptions. But one thing that he had classified as "pure" on the pretest he now classified according to his new definition as a mixture instead (i.e., smell). One substance he had classified as "something else" on the pretest, he now seemed to realize was made of molecules, and therefore either pure or a mixture, even though he classified it incorrectly (i.e., steel; he may not have known that steel contains more than one substance).

Introduction to Molecules. After instruction in powers of ten and the basics of molecules in the Introduction to Molecule lesson cluster, Kenny demonstrated a weaker form of restructuring. He refined his knowledge of molecules, but his schema for understanding molecules was not essentially different in structure at the posttest than it was at the pretest. His *core concepts* for understanding molecules at the pretest were that "molecules are small things. . . can only see with microscope", they "move", and may never

stop moving, but he did not know. His *core concepts* at the posttest were similar: Molecules "are tiny particles in air, water and other things", they move n air and rock, and never stop moving. He did change some of the concepts within the structure (he understood now that molecules never stop moving, and that they are found in air, water, for instance), but his *core concepts* emained the same: Molecules are small pieces in things, and they move round. Kenny understood Introduction to Molecules goal conceptions 9, 11, nd 12: Molecules are too small to see, even with a microscope; all molecules re constantly moving; and molecular motion continues independently of bservable movement. He did not express that he understood goal onception 10: All matter is made of molecules (he states that molecules are ound "in" matter, not that they "make up" matter). Kenny may have nderstood these conceptions, but he did not mention them in his posttest vriting, or his post clinical interview. Kenny demonstrated using Strategy 3 uring his attempts to make sense of the Introduction to Molecules lesson. He ended to draw on textbook schema and "big words" such as the movement nd arrangement of molecules in substances, but he did not use this formation to explain real-world phenomena. He stated that molecules are ny particles in air and water, and then classified helium, steel, smell, mud and alt water as substances not made of molecules. He retained a real-world efinition that molecules are small and "in" things, much like his conceptions at e pretest.

States of Matter. Kenny demonstrated radical restructuring during the tates of Matter lesson cluster. He used a similar schema to explain states of atter on the posttest as he used for the pretest, but he added new *core oncepts* about what happens to molecules when substances freeze, and new ncepts about weight conservation in changes of state (R2 and R5). Kenny's re concepts at the pretest were that water weighs less than ice when ice elts. He had little schema for the relationship of molecules to the weight of a bstance, or what happens during melting, freezing, or boiling. His core ncepts at the posttest contained new concepts about molecular patterns in eezing, and the effect of heat to make solids melt, at least at a macroscopic vel. By the posttest Kenny understood States of Matter goal conceptions 3 d 14: Substances expand when heated; and the only effect of heat on bstances is to make the molecules move faster. He showed no evidence of derstanding the other goal conceptions for the States of Matter lesson, 9, , and 18: Matter is made of molecules (rather than molecules are in matter); tes of matter are due to different arrangement and motions of molecules; d heating and cooling cause changes of state by making molecules move ter or slower. Kenny demonstrated that he might have used a learning ategy that added facts to his memory, since he used the concepts during truction, but did not call upon them to explain real-world events at the sttest and post clinical interview, Strategy 3. For example, during truction, in his States of Matter activity booklet, Kenny wrote that when ice lts "molecules in ice are breaking out of their pattern", but on his posttest he y wrote about melting, "solid is made out of frozen liquid so if you heat it will lt". He seemed to rely on his real-world experiences to answer the posttest estions about melting and boiling.

Dissolving. As a result of instruction in the Dissolving lesson cluster, nny demonstrated radical restructuring. His schema at the posttest was re complex, possessed more and different *core concepts*, and more eamlined organization (R1, R2, R3, R4, R5). At the pretest Kenny possessed ttle schema for understanding dissolving, he said, "in water sugar disappears r melts sort of". By the posttest he added conceptions about molecular ehavior, and used this new theory to explain dissolving. He said, "The iolecules of the water are hitting against the sugar and breaking it down to ugar molecules. . . the water molecules move faster in hot water so they hit ie sugar harder and breaks it down faster." Kenny attained the Dissolving oal conceptions 13, 14, and 15: Molecules of a solute break away and mix ith molecules of a solvent; the only effect of heat on substances is to make ie molecules move faster; and increased motion moves molecules farther part. He did not attain goal conception 17: States of matter are due to ifferent arrangements and motions of molecules. He did not use this onception for any of his written or verbal explanations after instruction. enny completed the dissolving lesson cluster with a new schema about how issolving occurs, and used his knowledge of molecular behavior to explain ie process, demonstrating a conceptual change learning strategy, Strategy 5.

Thermal Expansion. After instruction in Thermal Expansion, Kenny gain showed radical restructuring in his writing. He possessed little schema r molecules and their role in expansion and contraction at the pretest. He aid "the heated ball stays the same size" and did not explain his thinking, but nswered that maybe the number of molecules increase when metal is heated. y the posttest he added concepts for molecular behavior when substances, oth solids and gases, are heated, and why that causes expansion. At the retest, he said the heated iron ball would get larger because "the molecules in ie ball move faster and push each other farther apart." His conceptual system ad greater numbers of concepts (molecules and molecular behavior, R1), his nowledge was related to principles about molecular behavior and expansion

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(R3), and involved new *core concepts* about when and why substances expand (R5). Kenny attained Thermal Expansion goal conceptions 3, 14, and 15: Substances expand when heated; the effect of heat on substances is to make the molecules move faster; and increased motion moves molecules farther apart. He did not use goal conception 17 about different molecular arrangement and motion in different states for any of his explanations after instruction. Because Kenny used his new knowledge about molecular behavior n heated substances to explain thermal expansion, and incorporated these deas into his conceptual structure for thermal expansion, he demonstrated a conceptual change learning strategy, using new knowledge to change his schema and integrate it into his real-world knowledge, Strategy 5. In Table 4.2

TABLE 4.2

Kenny - Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

tudent	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Kenny	Pure & Mixt	R2 R4 R5 Ⓡ	new defs pure & mixt, used	5	Goal-1, 1a No-9
	Intro to Mol	W2 W6 W7 Weak	refines k of mol, but doesn't use to explain	3	Goal-11,12 No-9, 10
	St of Matter	R2 R5 Ⓡ	adds mols to schema, uses to explain	5	Goal-3, 14 No-9, 17,18
	Dissolving	R1 R2 R3 R4 R5 Ⓡ	uses knowl of mols to explain dissolving	5	Goal-13, 14, 15 No-17
	Thermal Exp	W4 R1 R3 R4 Ⓡ	little schema for mols at pret; used k of mol to explain	5	Goal-3,14,15 No-17

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(enny's knowledge restructuring, goal conception attainment, and learning ;trategy use demonstrated in his writing across the lesson clusters are ;ummarized.

Carol

The semantic node-link networks constructed from Carol's writing about ier ideas across the lesson clusters pretest and posttest are located in ppendix G. Carol's written explanations at the pretest were similar to her erbal expressions at the pre-clinical interview. For instance, she wrote the ollowing about pure and mixtures on the pretest: "Pure is clean or something iat is only one thing. Mixture has a lot of things put together to make it." 'erbally, during the pre-clinical interview she said the following about pure and iixtures: "Pure. . .I'm not sure. . .but pollution is a mixture of garbage and gas nd stuff. . . something in the air." In both cases she seemed not sure what ure is, and showed that she thought mixtures contained things mixed ogether. On her posttest, Carol said the following about pure and mixtures: 'ure things are clean and 'sometimes' safe. Mixtures are dirty and 'mostly' nsafe." Even though at her post clinical interview, she added more details, er ***core concepts*** seemed to be similar. She said, "Pure. . . I'm not sure what is. . . it's the opposite of mixture, and pollution is a mixture of matter". lixtures are "pollution" or possibly dirty and unsafe. Pure is the opposite. Her poken statements at the post clinical interview were sometimes more rganized than her written posttest statements, but not usually, and her ***core oncepts***, were similar in all instances.

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efore the sixth grade. Carol stated that it was hard for her to write about her deas. She wrote letters to friends, she said, "If I don't have to write I don't vrite. I write letters to friends because I have to respond back." Carol found one of the writing she did in science very easy. And she did not enjoy the vriting. She stated that once she had the ideas she could write them down. nd once she had the ideas, she had no trouble writing them down. When sked if having to write interfered with her ideas, she said "No". Her difficulty vas getting the ideas in the first place, and feeling like "I wasn't really thinking hat day or something". Once she had thought of ideas, she just puts "my deas down". On another occasion she stated that the freewrites were easy nd sometimes she liked them. She felt the same for some of the quizzes vhen she already knew the information. Carol had done some freewriting in ne past, but no journal writing. She thought that explaining in science, in eneral, was not difficult. When asked which freewrite seemed harder, she aid, "That one was harder [the snowball melting]". When asked why, she said, knew a lot more about this [molecule writing]". She said it was easier to think f ideas to explain what molecules were to her dad than to explain why a nowball melts, because she knew more about molecules than she knew about olecules in the melting process. She thought of herself as good at science, nd good at writing, even though writing was not one of her favorite activities. summarize the evidence for Carol's knowledge restructuring, goal conception ttainment, and use of learning strategies in the following sections.

Pure Substances and Mixtures. As a result of the instruction in the Pure ubstances and Mixtures lesson cluster, Carol demonstrated weak estructuring. She showed little change of schema from the pretest at the osttest: Pure things are clean and safe, other things are not (W2, W6). In fact, at the posttes

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fact, at the posttest she abandoned the parts of her pretest conceptions that were correct, such as her statement at the pretest that mixtures were "a lot of things put together." At the posttest she said things that are not pure are "dirty and mostly unsafe". Carol used the new information presented in the instruction about matter, pure and mixtures to correctly answer the activity booklet questions, but did not use this knowledge to answer questions about real-world substances on the posttest, or the post clinical interview. Carol attained goal conception 9: All matter is made of molecules, and non-matter is not. But she did not attain goal conceptions 1 and 1a, that solids, liquids, and gases are matter, and other things are not; and pure means made of one substance, and mixture means made of more than one substance: She etained the notions that heat and light are matter at the posttest, even though uring instruction she stated that light was not matter, and she retained her al-world conception of pure as "clean". Carol completed the lesson cluster out pure substances and mixtures with similar schema about the meaning of re, and did not use new knowledge to classify real-world substances. She reorganize her domain knowledge (W6), and she demonstrated that she ht have used Strategy 3 (Anderson & Roth, 1988), separating instructional wledge from real-world knowledge, using instructional knowledge to ver activity book questions, and real-world knowledge to answer questions t real-world phenomena.

Introduction to Molecules. After instruction in powers of ten and the s of molecules in the Introduction to Molecule lesson cluster, Carol nstrated radical restructuring. She changed her *core concepts* from ules being tiny and moving in air and liquid, but not solids, to stating that ules make up substances, and matter (R5). She correctly related their size, and movem

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size, and movement, and used her new knowledge to reclassify real-world substances correctly (R1, R2). Carol attained goal conceptions 9, 10, 11, and 12: All matter is made of molecules, and non-matter is not; molecules are too small to see, even with a microscope; all molecules are constantly moving; and molecular motion continues independently of observable movement. Carol demonstrated using Strategy 5 during her attempts to make sense of the Introduction to Molecules lesson. She added new ideas about matter being made of molecules to her schema, and used this information to explain real-world phenomena. For example, at the posttest Carol said, "Molecules are what makes up the substance, like water molecules and salt molecules", and she proceeded to classify all of the substances correctly (i.e., air, helium, steel, water, smell, mud, and salt water are made of molecules; heat and light are not).

States of Matter. Carol demonstrated radical restructuring during the States of Matter lesson cluster. She changed her ***core concepts*** about change of weight in state changes (R5), and the role of molecular behavior when substances change state (R2, R4). At the pretest she said that when ice melts, the water would weigh less than the ice because "liquid has more weight than a solid. . . when a solid is melted it would weigh more because there are more molecules because it is hot air pushing the molecules to make the solid spread into tiny pieces". Her ***core concepts*** at the pretest were that solids that melt have more molecules, and therefore, would weigh more. By the posttest, Carol's ***core concepts*** were that when solids melt, the liquid weighs the same, because there is "still the same amount of molecules." She added conceptions about matter being conserved when a substance changes state. She also added molecular movement to her schema, "molecules in hot water move faster". But

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move faster". But Carol seemed to mention molecular movement and "attach" it to her prior knowledge about changes of state. In some instances, she seemed unable to go beyond talking about molecular behavior to how molecular behavior applies to changes of state. For instance, she said when explaining melting that enough heat [on a substance] causes melting [because] the molecules in a solid are moving farther apart and working faster because there is enough heat to make it melt." She could state the correct terminology, that heating causes molecules to move faster and move apart, but she did not seem to apply this information to explain why the substance changed state. On the same subject during the post clinical interview, Carol talked about ice melting, and said it melts "as a result of heat", and that "molecules come out of their rigid pattern". She used the terms from instruction to explain the phenomenon, but did not relate heat's effect on molecular movement to the changes in substance. Her ideas seemed static. She stated that there is "more space between the molecules in ice", but she did not know why, that when ice is heated the "molecules come out of their rigid pattern", and in water the "molecules are bumping and sliding past each other", but she seemed unable to explain how the molecular changes effected the changes of state of substances---somehow heat influenced it, and molecular arrangement changed, but she did not connect the two occurrences very well. Carol learned the words that fit the questions acceptably, but did not make more complete connections to accomplish conceptual change that was useful to her understanding. Carol seemed unable to apply her new knowledge to understanding change of state. Carol understood goal conceptions 2, 3, 9, 14, and 18: Matter is conserved in all physical changes; substances expand when heated; all matter is made of molecules, non-matter is not; the only effect of heat on substances is to make the molecules move faster; and heating and cooling cause changes of state by making molecules move faster or slower. She showed no evidence of understanding the other goal conception for the States of Matter lesson, 17: States of matter are due to different arrangement and motions of molecules. Carol demonstrated that she might have used a learning strategy that added facts to her memory, since she used the concepts during instruction, and stated them at the posttest, but did not use the facts effectively to explain real-world events at the posttest and post clinical interview, Strategy 3.

Dissolving. As a result of instruction in the Dissolving lesson cluster, Carol demonstrated radical restructuring. Carol began the Matter and Molecules unit with little schema for understanding dissolving, except that the "sugar goes into the bottom of the glass". By the posttest, Carol added more and different ***core concepts***, molecules and molecular behavior, and more streamlined organization to her understanding of dissolving (R2, R4, R5). For instance, on her posttest, she described dissolving as such, "the molecules of water breaks the sugar up into tiny molecules. The sugar mixes with the water. Sugar dissolves faster in hot water because the molecules of the hot water are moving faster, hitting bumping and sliding breaking the sugar up." Carol understood the dissolving goal conceptions 13, 14, and 15: Molecules of a solute break away and mix with molecules of a solvent; the only effect of heat on substances is to make the molecules move faster; and increased motion moves molecules farther apart. She did not understand goal conception 17, that states of matter are due to different arrangements and motions of molecules. She did not use this conception for any of her written or verbal explanations after instruction. Carol completed the dissolving lesson cluster with a new schema about how dissolving occurs, and used her knowledge of molecular behavior to explain the process, demonstrating a conceptual change learning strategy, Strategy 5, using her new knowledge to change her schema, and integrating new knowledge with her real-world prior knowledge.

Thermal Expansion. After instruction in Thermal Expansion, Carol again showed radical restructuring in her writing. She possessed little schema for molecules and their role in expansion and contraction at the pretest. She said that a heated metal ball would stay the same size, because "if it didn't melt, how could it get smaller? It would not get larger, so it would have to stay the same size". By the posttest she added concepts for molecular behavior when substances, both solids and gases, are heated, and why that causes expansion. She was able to explain that when a metal ball is heated it would get larger, because "the molecules of the metal ball are moving faster and farther apart. The solid metal ball then gets larger". She now possessed different relations between concepts, and new domains (R2), her knowledge was related to theories about molecular behavior and expansion (R4), and involved new ***core concepts*** about when and why substances expand (R5). Carol understood thermal expansion goal conceptions 3, 14, and 15: Substances expand when heated; the effect of heat on substances is to make the molecules move faster; and increased motion moves molecules farther apart. She did not use goal conception 17 about different states of matter

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TABLE 4.3

Carol - Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

Student	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Carol	Pure & Mixt	W2 W6 Weak	text q corr; real-w q with real w schema	3	Goal-1a,9 No-1
	Intro to Mol	R1 R2 R5 Ⓡ	restr k for matter/ non, mols uses to expl real-world	5	Goal-9,10,11,12
	St of Matter	R2 R4 R5 Ⓡ	main ideas, static; talks mols but doesn't use to expl proc	3	Goal-2,3,9,14,18 No-17
	Dissolving	R2 R4 R5 Ⓡ	new concepts about sugar in water; uses to explain	5	Goal - 13,14,15 No-17
	Thermal Exp	R1 R2 R4 R5 Ⓡ	no schema for exp; gets; uses k of mol to explain	5	Goal-3,14,15 No-17

being due to molecular arrangement and motion for any of her explanations after instruction. Because Carol used her new knowledge about molecular behavior in heated substances to explain thermal expansion, and incorporated these ideas into her conceptual structure for thermal expansion, she demonstrated a conceptual change learning strategy, using new knowledge to change her schema and integrate it into her real-world knowledge, Strategy 5. Table 4.3 is a chart summary of Carol's knowledge restructuring, goal conception attainment, and learning strategy use demonstrated in her writing across the lesson clusters.

Melinda

The semantic node-link networks for Melinda's writing about her ideas across the lesson unit on pretest and posttest are located in Appendix G.

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Melinda's written explanations at the pretest matched her verbal explanations before instruction, and her written explanations on the posttest were similar to her verbal expressions at the post clinical interview. Before instruction Melinda wrote the following about changes of state: "Solid water weighs more" than ice because "molecules of water slow down from cooling to become ice", and the bubbles in boiling water are "hot air". During the pre-clinical interview, she said, "molecules in water are free, and move more", and the bubbles in boiling water are "hot air." Her spoken statements at the post clinical interview were sometimes more elaborate and contained more side comments than her written explanations, but her *core concepts*, were similar in all instances. At the posttest she wrote the following about changes of state. She wrote that when solids are heated "the molecules push each other farther apart as the solid gets hotter." At the post clinical interview she said about melting ice:

> *ice is melting, changing state. . .changing from a solid to a liquid. It's colder than the air around us and just that little bit of temperature change makes it warm up a little bit, and that makes the molecules move faster and farther apart, and finally they just are moving so fast that they kind of push each other farther enough apart that it's a liquid now.*

In both cases, her *core concepts* seemed to be that solids melt from the effect of heat, causing the molecules to move farther apart (and faster, since she wrote this in other areas of her posttest, and said it verbally in her post clinical interview).

Melinda's perceptions of writing. Melinda perceived that the writing tasks were between easy and hard. "You had to think about it. . ." Melinda stated that she had written a lot in previous schooling, and felt comfortable with writing her ideas. She liked to write stories, but said "sometimes I tend to ramble!" Melinda particularly thought that her inability to "think of an idea that

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was original, that was hard. Once I had ideas, they were not hard to put down". Sometimes she found the writing tasks difficult because "I wanted to think of something but it won't come up!. . It's in there. . .I can't pull it out". When asked what was the hardest part of the writing tasks, Melinda answered, "Getting the words down. To find the right words to do it. . . like I know what is happening, but I don't know how to say it". When asked how she liked the writing activities, Melinda said she found the freewrites pretty easy, because "I found I could think about it pretty well, and I could concentrate, and then I just wrote it down". About the activity booklets she said, "I especially like it when they ask you to explain something that happened, like at the end of one of those thermometer things that we did. . .why did this happen?. . .why did this happen? . . because I'm better with explanations than I am with ideas!". To Melinda it seemed difficult to come up with guesses about what something was, or her own thoughts about scientific phenomena before instruction. Once she had experienced the instruction, writing her ideas was not difficult after she got her ideas straight. Melinda's knowledge restructuring, conceptual goal attainment, and learning strategies are presented in the following sections.

Pure Substances and Mixtures. As a result of the instruction in the Pure Substances and Mixtures lesson cluster, Melinda demonstrated weak restructuring. She showed little change of schema from the pretest at the posttest: At the pretest she said pure things are made of one thing, and mixture is a "bunch of stuff all mixed together"; and at the posttest, she said that pure have only one kind of molecules, and mixtures have two or more kinds of molecules. She did refine her schema (W6), but her *core concepts* were the same (W7), and she possessed some prior knowledge schema for

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understanding at the pretest (W8). She already seemed to understand that pure things consist of one substance, and mixtures contain more than one. She added molecules to her understanding of what pure substances and mixtures are, which gave her greater numbers of concepts (R1), but her structure was essentially the same. Melinda used her new knowledge about molecules, and incorporated them into her existing schema. Melinda attained goal conceptions 1, 1a, and 9: Solids, liquids and gases are matter, other things are not; pure substances contain only one kind of substance or molecule, and mixtures contain more than one; and all matter is made of molecules, non-matter is not. Melinda completed the lesson cluster about pure substances and mixtures with similar schema about the meaning of pure, but added new knowledge about molecules to help her understand and explain the differences between the two. She demonstrated that she might have used Strategy 5, using new knowledge to change her schema, and integrate new knowledge with real-world prior knowledge. She attempted to use her new knowledge by applying it to new situations, and was able to re-classify substances correctly at the posttest (i.e., at the pretest she classified all things as "pure", but by the posttest, she used her new schema to classify only helium and water as pure; air, mud, and salt water as mixtures, and heat and light as "something else").

Introduction to Molecules. After instruction in powers of ten and the basics of molecules in the Introduction to Molecule lesson cluster, Melinda demonstrated weak restructuring. She did not change her ***core concepts*** that molecules are everywhere and never stop moving, that they are very small. She refined her schema to show just how small molecules are (W6), and was better able to explain their relationship to matter (W4). Melinda seemed to

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possess some prior knowledge schema of what molecules are (W8)---they are small, everywhere, and never stop moving. So adding ideas about correct size, and their relationship to matter did not require her to radically restructure her schema. Melinda understood goal conceptions 9, 10, 11, and 12: All matter is made of molecules, and non-matter is not; molecules are too small to see, even with a microscope; all molecules are constantly moving; and molecular motion continues independently of observable movement. Melinda demonstrated using Strategy 5 during her attempts to make sense of the Introduction to Molecules lesson. She added new ideas about matter being made of molecules to her schema, and used this information to classify real-world phenomena on the posttest.

States of Matter. Melinda demonstrated radical restructuring as a result of the States of Matter lesson cluster. She changed her *core concepts* about changes of weight in state changes (R5), and the role of molecular behavior when substances change state (R2, R4). At the pretest Melinda's conceptions were that ice weighs more than water because the molecules slow down, and when heated, air rises, and in hot water, hot air rises. By the posttest, she added greater numbers of concepts to her conceptual system (R1), and new domains (molecular movement) (R2). She now believed that solids weigh the same when they change to liquid, that molecular movement as a result of heat causes substances to melt, and heating water causes molecules to move faster and causes the water to change state. Melinda understood States of Matter goal conceptions 2, 3, 9, 14, 17, and 18: Matter is conserved in all physical changes; substances expand when heated; all matter is made of molecules, non-matter is not; the only effect of heat on substances is to make the molecules move faster; states of matter are due to different arrangements and motions of molecules; and heating and cooling cause changes of state by making molecules move faster or slower. Melinda demonstrated that she used a conceptual change learning strategy, because she integrated new knowledge into her schema, and attempted to use it to explain real-world phenomena, applying it to real situations at the posttest, Strategy 5.

Dissolving. As a result of instruction in the Dissolving lesson cluster, Melinda demonstrated radical restructuring. Melinda began the unit with little schema for understanding molecular behavior in dissolving, except that the sugar becomes part of the water. By the posttest, Melinda added more and different ***core concepts***, molecules and molecular behavior, and more streamlined organization to her understanding of dissolving (R2, R4, R5). At the posttest she said the following about dissolving:

> ***Sugar was put into the water and it dissolved. The water molecules were bumping the sugar, so the sugar broke down. Sugar dissolves faster in hot water because the water molecules are moving faster and hitting the sugar more frequently.***

Melinda attained all of the Dissolving goal conceptions 13, 14, 15 and 17: Molecules of a solute break away and mix with molecules of a solvent; the only effect of heat on substances is to make the molecules move faster; increased motion moves molecules farther apart; and states of matter are due to different arrangements and motions of molecules. Melinda completed the dissolving lesson cluster with a new schema about how dissolving occurs, and used her knowledge of molecular behavior to explain the process, demonstrating a conceptual change learning strategy, Strategy 5.

Thermal Expansion. After instruction in Thermal Expansion, Melinda showed radical restructuring in her writing. She possessed some prior knowledge schema for molecules and their role in expansion and contraction

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at the pretest. She seemed to know that molecules will move farther apart or "push outwards" (pre-clinical interview) when a substance is heated. On the pretest she wrote that she did not know if a heated metal ball would get larger or smaller, but the molecules would stay the same size and move farther apart. By the posttest, she refined her understanding of molecular behavior (W6), added new concepts about the substance getting hotter, but not the molecules themselves (R1), and retained her basic schema that heat expands substances. She added concepts for molecular behavior when substances, both solids and gases, are heated, and why that causes expansion. She now possessed different relations between concepts, and new domains (R2), her knowledge was related to theories about molecular behavior and expansion (R4), and involved new *core concepts* about when and why substances expand (R5). Melinda attained all of the Thermal Expansion goal conceptions 3, 14, 15 and 17: Substances expand when heated; the effect of heat on substances is to make the molecules move faster; increased motion moves molecules farther apart; and different states of matter are due to molecular arrangement and motion. Because Melinda used her new knowledge about molecular behavior in heated substances to explain thermal expansion, and incorporated these ideas into her conceptual structure for thermal expansion, she demonstrated a conceptual change learning strategy, using new knowledge to change her schema and integrate it into her real-world knowledge, Strategy 5. Table 4.4 summarizes Melinda's knowledge restructuring, goal conception attainment, and learning strategy use demonstrated in her writing across the lesson clusters.

TABLE 4.4

Melinda - Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

Student	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Melinda	Pure & Mixt	W6 W7 W8 Weak	refines schema, prior knowledge	5	Goal-1, 1a, 9
	Intro to Mol	W6 W7 W8 Weak	refines schema, adds to structure	5	Goal-9,10,11,12
	St of Matter	R1 W6 R2 R3 (R)	More complex schema, inter-relationships, uses	5	Goal-2,3,9,14,17 18
	Dissolving	R1 R2 R4 (R)	little schema for mol beh at pretest	5	Goal-13,14,15,17
	Thermal Exp	W4 W6 R1 R2 R4 (R)	some prior knowledge, adds mol beh to schema	5	Goal-3,14,15,17

Antoine

The semantic node-link networks for Antoine's writing about his ideas for each lesson cluster on pretest and posttest are located in Appendix G. Antoine's written explanations at the pretest and clinical interview both showed his confusion about what pure is. For instance, when talking about pure substances and mixtures before instruction, his *core concepts* expressed in writing were that pure had something to do with air, and mixture had something to do with making things; in his verbal statements he said pure is clear and doesn't have anything in it (invisible like air), and "mixture have lots of things in it". His written statements on the posttest showed that he still believed pure things to be clear, "can see through". His spoken statements at the post clinical interview about pure was that pure water is pure, and he did not apply pure to any of the real-world substances he spoke about. He usually mentioned more concepts at the clinical interviews, but his ideas did not seem

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well organized or related to one another. For instance, when talking about molecules at the post clinical interview he said, "a molecule is a matter of a substance", and in solids molecules are "arranged in a rigid pattern, not moving, more space between than in liquid". He continued to talk about molecules in liquids being "still in a rigid pattern, moving slowly". In gases, he said, "I think they are farther apart and are moving faster in air." His ***core concepts*** from these statements compared with his written posttest statements were similar: matter is solid, liquid or gas, he is not sure of molecular size, and not sure of molecular movement, but he seemed to like the "rigid array or pattern" phrase, and used it out of context. On his posttest he wrote to explain molecules, "molecules are sometimes formed in a rigid array or pattern".

Antoine's perceptions of writing. Antoine had done little writing before coming into sixth grade, mostly writing just in English. He liked writing stories, but most of his writing was done at school. He expressed that he thought the freewriting tasks were easy and "kind of fun", but the activity book writing was sometimes hard because he "can't come up with some of the questions". When asked how he got ready to write ideas down, he said "I just write down what I remember". He expressed that he liked to write and felt "I'm pretty good at it". He said that he had never done the kind of writing he was asked to do in his activity booklets, and that sometimes he had trouble getting his ideas on paper, but that he just wrote what he remembered. When asked if he knew why he had trouble sometimes putting his ideas on paper, he said he did not know. At the post clinical interview, however, Antoine said that he thought the writing in his activity booklets was easy and that he liked it, there wasn't any part of it that he remembered not liking. In the following section, I summarize what

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what Antoine wrote about content for evidence of restructuring changes, goal conception attainment, and use of learning strategies.

Pure Substances and Mixtures. As a result of the instruction in the Pure Substances and Mixtures lesson cluster, Antoine demonstrated weak restructuring. He changed his schema slightly from pure being air, and mixtures being used to make a formula, to pure being clear, and mixtures being something we cannot see through, but his conceptions were inaccurate (W2), he added a new domains to his schema, clear, (R2) but mostly just reorganized his knowledge to fit his new "clear" definition (W6). Even though Antoine seemed to use a new principle about "clear" to organize his knowledge, it was incorrect, and was not part of the instruction in pure substances and mixtures; it likely resulted from his real-world knowledge. Antoine did not attain any of the Pure Substances and Mixtures goal conceptions, 1, 1a, or 9: Solids, liquids and gases are matter, and other things are not; pure substances contain only one kind of molecule or substance, and mixtures contain more than one; and all matter is made of molecules. Even in his activity booklet writing he did not write the correct definitions of pure, matter and non-matter: matter was "liquid or gas", non-matter was "liquid or gas", and pure was "water". He did not mention the relationship of molecules to pure substances and mixtures, even during instruction in his activity booklet. Antoine completed the lesson cluster about pure substances and mixtures with schema about the meaning of pure, that it is "clear", and used his new knowledge to classify real-world substances, but because his schema relied primarily on his real-world knowledge, he demonstrated using Strategy 1, overreliance on prior knowledge, interpreting the instruction in terms of his real-world prior knowledge, and because during

instruction he did not write answers that made sense, he demonstrated having a goal to finish the task, rather than to learn.

Introduction to Molecules. After instruction in powers of ten and the basics of molecules in the Introduction to Molecule lesson cluster, Antoine demonstrated both weak and radical restructuring. He began the instruction by guessing about molecules, but after instruction, he knew more about molecules. He seemed to believe that molecules were "in" solids, liquids and gases, and that their movement and arrangement is different in each state, and that molecules move in substances. He used his new knowledge about molecules to classify real-world substances. Antoine changed his *core concepts* (R1), and added more relations among the concepts (R2), but did not show use of any new principles, or theories involving his knowledge of molecules (W4). At the posttest when explaining molecules, he said, "molecules are sometimes formed in a rigid array or pattern", and he did not know if molecules move in still air or a rock, but he thought they never stop moving. His understanding of the scientific goal conceptions was still incomplete for molecules. He attained goal conceptions 11 and 12: All molecules are constantly moving; and molecular motion continues independently of observable movement. He did not express that he understood goal conception 10: All matter is made of molecules (he stated that molecules are found "in" matter, not that they "make up" matter). Antoine seemed to demonstrate using learning Strategy 2 for the Introduction to Molecules information. He produced acceptable answers to questions during instruction in his Introduction to Molecules activity booklet, but totally relied on real-world knowledge to answer real-world problems about molecules in substances—"a molecule is a matter of a substance." Antoine remembered isolated words from the instruction, like

"molecule" and "matter, and "formed in a rigid array or pattern", and then pasted these words into his schema apparently without making sense of them. He tended to draw on textbook schema and "big words" such as the movement and arrangement of molecules in substances, but he did not use this information to explain real-world phenomena.

States of Matter. Antoine demonstrated radical restructuring as a result of the States of Matter lesson cluster. He began the unit with little prior knowledge for understanding molecules and their behavior in different states of matter. He had some schema at the macroscopic level, such as heat causes water to boil, but little else. Antoine showed different relations among his concepts at the posttest (R2), and involved new theories (R4), that ice will weigh the same as water when it melts, and the bubbles in boiling water are gas, and has something to do with water vapor. However, Antoine's new schema was not yet complete. He was still fuzzy about why solids melt when heated, and had difficulty explaining why weight stays the same when ice melts. He said about freezing, "water molecules change into ice molecules". Antoine attained goal conception 3: Substances expand when heated. He showed no evidence of understanding the other goal conceptions for the States of Matter lesson, 2, 9, 14, 17, and 18: Matter is conserved in all physical changes; matter is made of molecules (rather than molecules are in matter); the only effect of heat on substances is to make the molecules move faster; states of matter are due to different arrangement and motions of molecules; and heating and cooling cause changes of state by making molecules move faster or slower. Antoine demonstrated that he might have used a learning strategy that focused on details in the instruction without making sense of their meaning. He used isolated words without relating them to what they mean, or understanding how to explain them. For instance, on the posttest Antoine said that water weighs the same as ice "because the ice was water and it had a weight and it will turn to ice it will still weigh the same". Part of the instruction emphasized that weight stays the same when substances change state, so Antoine picked that up. He did not seem to assimilate what that meant in terms of molecules, and change of state. Antoine added facts to his memory, and isolated words from the instruction without any meaningful relationship to one another, Strategy 2.

Dissolving. As a result of instruction in the Dissolving lesson cluster, Antoine demonstrated radical restructuring. His schema at the posttest was more complex, and possessed more and different *core concepts* (R1, R2, R3, R4). At the pretest Antoine possessed little schema for understanding dissolving, but by the posttest he added conceptions about molecular behavior, and used this new theory to explain dissolving. He said about dissolving, "The sugar will mix with the water and they will be a sugar molecules and a water molecules. . . When sugar gets into the hot water it will cause molecules to move farther apart and they will break down". Antoine had a new schema for understanding dissolving, and molecular behavior during dissolving. Antoine attained dissolving goal conception 13: Molecules of a solute break away and mix with molecules of a solvent. He did not attain the other two goal conceptions, 14 and 15: The only effect of heat on substances is to make the molecules move faster, and increased motion moves molecules farther apart. He talked about how molecules move farther apart, but he left out the step that heat causes the molecules to move faster and that is why dissolving goes faster. And he did not attain goal conception 17, states of matter are due to different arrangements and motions of molecules. He did not use this conception for any of his written or verbal explanations after instruction. Antoine completed the dissolving lesson cluster with a new schema about how dissolving occurs, and used his knowledge of molecular behavior to explain the process, demonstrating a conceptual change learning strategy, Strategy 5.

Thermal Expansion. During instruction in Thermal Expansion, Antoine demonstrated both weak and radical restructuring in his writing. He possessed little schema for molecules and their role in expansion and contraction at the pretest. By the posttest he had added concepts for molecule behavior when air and metal get heated, and why that causes expansion. He said the following about heating a metal ball, "the heated ball will be larger, . . metal can't melt so the molecules move farther apart causing the ball to expand". His conceptual system had greater numbers of concepts (R1), his knowledge was related to principles about molecular behavior and expansion (R3), and involved new *core concepts* about when and why substances expand (R5). Because Antoine retained some alternative conceptions about molecules (the molecules themselves get larger)(W2), and added new relations rather than principles (W4), he demonstrated some weaker forms of restructuring for concepts. Antoine understood thermal expansion goal conception 3: Substances expand when heated. He did not use goal conceptions 14, 15, and 17—the effect of heat on substances is to make the molecules move faster; increased motion moves molecules farther apart; and different molecular arrangement and motion in different states. Antoine consistently stated that heat makes molecules move farther apart, but he missed the step in between that what makes the molecules move farther

apart is their faster motion when heated. Because Antoine used his new knowledge about molecular behavior in heated substances to explain thermal

TABLE 4.5

Antoine - Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

Student	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Antoine	Pure & Mixt	W2 W4 R1 Weak	little change, changes relate to real-world ideas	1	Goal-0
	Intro to Mol	W2 W6 R1 R5 Weak/(R)	little schema for mol at pret; begins new; "adds" text k	2	Goal-11,12 No-9,10
	St of Matter	R2 R4 (R)	little prior k schema; underst macro, not micro, "adds" text k	2	Goal-3 No-2,9,14,17,18
	Dissolving	R1 R2 R3 R4 (R)	creates new schema for diss, uses to explain	5	Goal-13 No-14,15,17
	Thermal Exp	R1 R3 R5 W2 W4 (R)	adds mol beh to schema, uses to explain	5	Goal-3 No-14,15,17

expansion, and incorporated these ideas into his conceptual structure for thermal expansion, even though he missed some of the important steps, and retained some real-world conceptions inconsistent with the new conceptions, he demonstrated using learning strategy, Strategy 4. Table 4.5 summarizes Antoine's knowledge restructuring, goal conception attainment, and learning strategy use demonstrated in his writing across the lesson clusters.

Jose

The semantic node-link networks for Jose's writing about his ideas across the lesson cluster content on pretest and posttest are located in Appendix G. I found that Jose's written and verbal explanations before

instruction were similar for all the lesson clusters, and his written and verbal expressions after the instruction were similar for Pure Substances and Mixtures and Dissolving. However, for Introduction to Molecules, States of Matter, and Thermal Expansion, Jose's verbal statements at the post clinical interview were more explicit about molecular behavior. He wrote about changes of substances at the macroscopic level on his posttest, but did not write about molecules. For instance, when talking about states of matter before instruction, his ***core concepts*** expressed in writing were water and ice have nothing to do with molecules, and heat makes water bubble up. His ***core concepts*** expressed verbally were bubbles come up from the bottom when water boils, heat makes things want to melt, and steam comes from air and water---similar conceptions in writing and speaking about states of matter. On the posttest, Jose wrote that melting causes molecules to "slow down and get more and more slowing down", and that heating water makes water boil, and molecules are in the bubbles. When he spoke about melting and boiling during his post clinical interview, Jose said that in ice "molecules are stuck in a rigid pattern" and when ice melts, molecules "move around freely, it's not a solid anymore, they're just moving around freely". He elaborated more on what the molecular behavior consists of in ice and water and how the molecular behavior changes when ice melts. He did not write in this detail on his posttest. Some verbal statements he made at the post clinical interview did match his written posttest statements. When he talked about boiling water at the post clinical interview, he thought there might be molecules or air or steam in the bubbles, which is similar to what he wrote on the posttest. On his written posttest he did not explain why heating water makes it boil, but during his post clinical interview, he stated that when water boils molecules go up in the a

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the air in the form of steam, and "water vapor comes to the glass around the side and turns into water". He retained some real-world conceptions, that when water boils the water level will go up, and if you freeze it, it will go back down, but the important feature of Jose's writing versus his verbal expression was that Jose expressed himself better in oral language about molecules and molecular behavior than he did in writing. There are several possible reasons why this might be the case:

(1) Jose may not have understood that he should talk about molecules on his written posttest, even though the test instructions specifically asked about molecules. This is not as likely, since Jose did mention molecules in some of his written answers, but he seemed to "add" molecules to his explanations rather than use them to explain phenomena. For instance, when asked what was in the bubbles in boiling water, Jose answered "molecules", but then he did not use molecules to explain why water boils when it is heated.

(2) Jose may have had difficulty explaining molecules in writing because he was still unsure of his understandings in this area, so did not attempt to explain, much like Ammon and Ammon (1987) found when their students' scientific understandings were limited, it inhibited the writing they could do. The molecule content may have still been difficult for Jose to understand so that he skipped steps in his reporting in writing. Rather than explaining, Jose focused more on background description, just as Ammon and Ammon suggested students will do when they are unsure of content.

(3) Jose may have had difficulty putting his ideas into writing, and so even though he understood more about molecular behavior than he wrote, he was unable to put his thoughts into writing. There was evidence that this may not be the case, however, because Jose reported that he liked to write and considered himself a good writer. The only times he stated he had trouble with the writing tasks was when he did not understand the content, or understand what he was supposed to write.

Jose's writing might not tell about his knowledge restructuring because of this evidence that he said more about molecules verbally than he did in writing. Based on Jose's written posttest, he understood scientific goal conceptions 2, 3, 9, and 11. However, based on his verbal statements at the post clinical interview, Jose also understood 10 and 12: All molecules are constantly moving; and molecular motion continues independently of observable movement. He seemed close to understanding 13 (molecules of a solute break away and mix with the molecules of a solvent), but he just said water mixes with the sugar and he was not clear about what happens to the molecules.

Jose's perceptions of writing. Jose claimed to do a lot of writing, and liked to write. He stated that he always got good grades on his writing. He did not feel it was difficult to put his ideas in writing during the science writing tasks. He stated that is why he liked science. He thought writing in the science booklets was easy, and stated that he did a lot of writing at home, writing letters to his cousin in Florida, his friends, and his brothers. He thought some of the quizzes were "kinda easy and kinda hard", because "some of it I knew.

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knew, and some of it I didn't. . . the parts that I didn't understand some of the meanings. . . matter, I didn't understand too good". Jose stated that he did not use any writing strategies to put his ideas in writing, he just "put my ideas down". Sometimes he had difficulty getting ideas in his head and putting them on paper. He said,

> *I really didn't understand about this because then it said to explain and it didn't say, you know, write your observation, and so I just started looking, and then everybody said 'you've got to write your observation', and everything, and so I started writing it.*

Jose often liked the writing he did in science even though it was sometimes difficult for him to understand what he was supposed to write, or the content he needed to know. He said, "This one I kinda liked too. . .except that you had to write the observation. I really don't understand that, about the observation, assumptions. . . but I really liked this one, and these two. . " (freewrites about the snowball melting and explaining molecules to his dad). Jose expressed that he had trouble with the weight and volume quiz, it was difficult for him. He said, "I don't understand weight and volume. . . I never did". Jose expressed that the freewrites were easy, and most of them he enjoyed writing. The following sections summarize Jose's writing content that showed his knowledge restructuring changes, goal conception attainment, and use of learning strategies.

Pure Substances and Mixtures. As a result of the instruction in the Pure Substances and Mixtures lesson cluster, Jose demonstrated radical restructuring. He changed his schema slightly from pure being "actually pure", to pure being a substance without any other substance added, and mixture a combination of substances—new principles, and new concepts in his schema (R1, R3, R5). He did not use his new definition to effectively classify real-world

substances. For example, at the posttest, Jose was able to use his new definition of pure and mixtures to correctly classify water, smell, mud, helium, salt water, and light, whereas at the pretest he was unable to correctly classify light. He was still incorrect about whether steel, air, helium, and heat were pure or mixtures at the posttest. Jose understood goal conceptions 1a and 9: Pure substances contain only one kind of molecule or substance, mixtures contain more than one; and all matter is made of molecules. He was not clear about 1: Solids, liquids and gases are matter, and other things are not. Jose did not state these principles consistently or use them effectively. In his activity booklet writing he wrote the correct definitions of pure, matter and non-matter, but on his posttest, he did not express the definitions very well, "things that are pure are a substance without any other substance". Verbally, at his post clinical interview, he said that a "pure substance is only made with that and nothing else". He seemed to understand the concept, but had difficulty expressing the ideas correctly. Jose completed the lesson cluster about pure substances and mixtures with schema about the meaning of pure, that it is one substance alone, and used his new knowledge to classify real-world substances, but because he answered his activity book questions using scientific explanations, and answered real-world questions using his new schema of real-world expressions, he demonstrated using Strategy 3, learning a list of facts, but not integrating them into his prior real-world knowledge, nor using them to explain real-world events.

Introduction to Molecules. After instruction in powers of ten and the basics of molecules in the Introduction to Molecule lesson cluster, Jose demonstrated both weak and radical restructuring. He began the instruction by guessing about molecules, and thought they had something to do with

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helping us breathe, so were found in only air and gases. By the posttest he stated that molecules build things, and they are small. They still seem to exist to help us breathe, and make air. He made a slight change in his schema based on what he encountered in the instruction, but did not seem to understand the role of molecules in matter. He did not use his new knowledge about molecules to classify real-world substances correctly. At the pretest, Jose said air, helium and water are made of molecules, and smell is not. Heat and light are not made of molecules. He did not know about mud or salt water. At the posttest, he classified air, helium, and water the same as he did at the pretest, he moved salt water to matter, but not steel, smell and mud, which he said were not made of molecules. He said heat was made of molecules, even though he had thought heat was not made of molecules at the pretest, and the instruction was explicit about heat not being made of molecules. Jose changed his *core concepts* (R1), and added more relations among the concepts (R2), but did not show use of any new principles, or theories involving his knowledge of molecules (W4). His understanding of the scientific goal conceptions was still incomplete for molecules. Jose understood Introduction to Molecules goal conceptions 9 and 11: All matter is made of molecules, non-matter is not; and molecules are constantly moving. He did not express that he understood goal conceptions 10 or 12: Molecules are too small to see, even with a microscope; and molecular motion continues independently of observable movement. Jose demonstrated using learning Strategy 3 for the Introduction to Molecules instruction. He produced acceptable answers to questions about instruction in his Introduction to Molecules activity booklet, but relied on his real-world knowledge to answer real-world problems about molecules in substances---molecules are a substance that builds things, but are not found in steel, smell or mud. He did not seem clear about what matter is, or the relationship of molecules to matter. He tended to draw on textbook schema and "big words" such as the movement and arrangement of molecules in substances, but he did not use this information to explain real-world phenomena.

States of Matter. Jose showed radical restructuring as a result of the States of Matter lesson cluster. He began the unit with little prior knowledge for understanding molecules or their behavior in different states of matter. He had some schema at the macroscopic level, such as heat causes water to bubble up, but little else. Jose showed greater numbers of concepts (R1) and different relations among his concepts at the posttest (R2), and involved new theories (R4), that ice will weigh the same as water when it melts, and the bubbles in boiling water are molecules of some kind. However, Jose's new schema was not complete. He was still unclear about why solids melt when heated, and had difficulty explaining why weight stays the same when ice melts. He said when explaining why heat makes solids melt "the molecules are going to slow down and get more and more slowing down". Jose attained States of Matter goal conceptions 2, 3, and 9: Matter is conserved in all physical changes; substances expand when heated; and all matter is made of molecules. He showed no evidence of understanding the other goal conceptions for the States of Matter lesson, 14, 17, and 18: The only effect of heat on substances is to make the molecules move faster; states of matter are due to different arrangement and motions of molecules; and heating and cooling cause changes of state by making molecules move faster or slower. Jose demonstrated that he might have used a learning strategy that focused on details in the instruction without making sense of their meaning. He used isolated words without relationship to what they mean, or understanding how to explain them. For instance, Jose said that water weighs the same as ice "because the same ice is being melted and the same water gonna turn into water". Part of the instruction emphasized that weight stays the same when substances change state, so Jose picked that up. He did not seem to assimilate what that meant in terms of molecules, and change of state. Jose added facts to his memory, and used them to answer questions in his activity booklet, but reverted to his real-world knowledge to make explanations about real-world phenomena about changes of state in water and melting solids, Strategy 3. Experience seemed to influence his explanations. Jose demonstrated more evidence that he used Strategy 3 to accomplish his tasks when he wrote in his activity booklet that a reason for taking liquid water on a spaceship was that water "is the most abundant liquid on earth and is needed by all living things". His statement was correct, and came right out of the text, but it had little relevance to why he might want to take water in liquid form to space, rather than water in solid or gaseous form. He used text answers to answer text questions, but did not seem to assimilate meaning of what the text was saying to build new understanding with the information.

Dissolving. As a result of instruction in the Dissolving lesson cluster, Jose demonstrated radical restructuring. His schema at the posttest was more complex, and possessed more and different *core concepts* (R1, R2, R4). At the pretest Jose possessed little schema for understanding dissolving, but by the posttest he added conceptions about molecular behavior, and used this theory to explain dissolving. Jose created a new schema for understanding dissolving, but mostly at the macroscopic level. He talked about molecules, but did not use his knowledge of molecules to explain dissolving. He said sugar dissolves because "the molecules start to push against the sugar which breaks it down". . . and "the temperature is hot and the hot water dissolves the sugar quicker". Even at the post clinical interview, Jose mentioned that molecules go in and out of the teabag, but he did not use molecular behavior to explain dissolving. He relied primarily on his macroscopic understanding, and real-world experiences with dissolving sugar. Jose did not attain any of dissolving goal conceptions, since they were all at the molecular level, and Jose did not use molecular behavior to explain dissolving at the posttest, post clinical interview, or on his freewrite. He mentioned molecular behavior at the posttest---molecules push against the sugar breaking it down---but he did not relate this behavior to sugar mixing with water, increased motion of the molecules, or the different arrangements of molecules in the two states of matter. The goal conceptions that Jose did not attain are 13, 14, 15, and 17: Molecules of a solute break away and mix with molecules of a solvent; the only effect of heat on substances is to make the molecules move faster; increased motion moves molecules farther apart; and states of matter are due to different arrangements and motions of molecules. He did not use these conceptions for any of his written or verbal explanations after instruction. Jose completed the dissolving lesson cluster with a new schema about how dissolving occurs at the macroscopic level, but did not use his knowledge of molecular behavior to explain the process, demonstrating a learning strategy 3, overreliance on unrelated facts, and separation of disciplinary knowledge from real-world knowledge. Jose was able to answer the questions in his activity booklet with acceptable answers about molecules in dissolving, but totally relied on his real-world knowledge to answer questions about real-world phenomena at the posttest and post clinical interview.

Thermal Expansion. During instruction in Thermal Expansion, Jose demonstrated both weak and radical restructuring in his writing. He possessed little schema for molecules and their role in expansion and contraction at the pretest. By the posttest he added concepts for macroscopic events when air and metal get heated, and some molecular understanding of why heating a metal causes it to expand. His conceptual system had greater numbers of concepts (R1), and involved new ***core concepts*** about when and why substances expand (R5). Jose talked about thermal expansion mostly at a microscopic level, and did not use his knowledge about molecules to explain expansion, so he added new relations rather than principles (W4), and he demonstrated some weaker forms of restructuring for concepts. At the posttest, Jose explained why metal expands when heated by saying that a heated metal ball would be larger "because it would not fit through the ring after it was heated". Jose understood Thermal Expansion goal conception 3: Substances expand when heated. He did not use goal conceptions 14, 15, and 17---the effect of heat on substances is to make the molecules move faster; increased motion moves molecules farther apart; and different molecular arrangement and motion in different states---for any of his explanations after instruction. In his writing, Jose seemed to understand thermal expansion at the macroscopic level, and answered the questions in his activity book correctly about molecular behavior in thermal expansion. When it came to explaining real-world phenomena, Jose was still strongly influenced by his real-world knowledge. He stated "the balloon is bigger and when you warm the bottle with your hands, the air in the bottle expands and the balloon gets bigger". When Jose spoke about thermal expansion at the post clinical interview, he added molecular behavior to his explanations. He said, "when we

heat it up [cool bottle], the molecules are going to move faster, and it is not going to have enough air and so its going into the balloon. . . they [molecules] move faster and expand, and like it's going up, so they expand and there is more air to go into the balloon". He still seemed to rely on his real-world conceptions to explain thermal expansion--something is not going to have enough air, and will go up, and there is "more air" for the balloon---even though he added molecular behavior to the explanations. Jose still demonstrated use of Strategy 3 in his learning: He seemed to rely on unrelated facts, add them to memory, and not integrate them with real-world knowledge, or use them to explain real-world events. Table 4.6 summarizes Jose's writing that showed his knowledge restructuring, goal conception attainment, and learning strategy use across the lesson clusters.

Summary

The above sections presented evidence for knowledge restructuring, attainment of goal conceptions, and kinds of learning strategies for each of the six target students. All of the students showed some form of restructuring in their writing from pretest to posttest. All students showed weak restructuring during some lessons. Artie showed weak restructuring for the Pure Substances and Mixtures, and Introduction to Molecules information, Kenny showed weak restructuring for the Introduction to Molecules information, Carol for Pure Substances and Mixtures, Melinda for Pure Substances and Mixtures and Introduction to Molecules, and Antoine for Pure Substances and Mixtures. In four of these seven instances, students possessed some prior knowledge schema, so added to and refined their conceptual systems to assimilate the new information (Artie and Melinda, each for both lesson clusters). Both Artie

TABLE 4.6

Jose - Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

Student	Lesson Cluster	Restructuring	Notes	Strategy	Goal Conceptions Attained
Jose	Pure & Mixt	R1 R3 Ⓡ	Changes def of pure; doesn't seem to use	3	Goal-9 No-1,1a
	Intro to Mol	W4 W2 W6 R1 R2 Weak/Ⓡ	still seems rel to air; some understanding, not used	3	Goal-9,11 No-10,12
	St of Matter	R1 R2 R4 Ⓡ	understands macro; still not clear mol; exper influ expl	3	Goal-2,3,9 No-14,17,18
	Dissolving	R1 R2 R4 Ⓡ	understands macro; does not use mol to expl	3	Goal-0 No-13,14,15,17
	Thermal Exp	W4 W6 R1 Weak/Ⓡ	understands macro; does not use mol to expl, exper infl	3	Goal-3 No-14,15,17

and Melinda attained most of the goal conceptions for these lessons, even though they showed weak more than radical restructuring, due to their prior experience with the information.

In the other three cases where students showed weak restructuring, the students missed being able to incorporate some of the instruction into their schema. In Kenny's case, he was able to use the correct "big words" during instruction in his Introduction to Molecules activity booklet, but at the posttest and post clinical interview he used his real-world knowledge to explain molecules, and separated his textbook knowledge from his real-world knowledge. For the Introduction to Molecules lesson, Kenny used Strategy 3, which is overreliance on separated facts and separation of disciplinary knowledge from real-world knowledge. Kenny attained less than half of the goal conceptions. He did not use Strategy 3 in the other lesson clusters, where he used more conceptual change-like thinking, Strategy 5, and in the other lessons he attained more of the goal conceptions, except in understanding States of Matter, where he used Strategy 5, and accomplished some radical restructuring, but still did not understand or use some of the conceptions about molecular behavior in changes of state.

Carol virtually ignored the instruction in Pure Substances and Mixtures, and though she placed acceptable answers to the questions in her activity booklet, she reverted to her real-world schema about pure being "clean" at the posttest. She seemed to separate the book knowledge from her real-world knowledge and use a Strategy 3 learning approach for the Pure Substances and Mixtures lesson. Carol was still able to attain two of the three goal conceptions for pure substances and mixtures even though she retained some alternative conceptions. Carol used a similar learning strategy (3) approach for the States of Matter lesson, but demonstrated more radical restructuring at that lesson, and was able to attain most of the goal conceptions. It was confusing for me at first to find that Carol might have used an ineffective strategy yet still attain all of the goal conceptions for the Introduction to Molecules lesson cluster. After further study, I interpretted that the Introduction to Molecules lesson might have been an easier lesson for students like Carol to learn, since the words to explain the concepts and answer activity book questions and tests required only that she restate the definitions for acceptable performance. She was able to state concepts such as in water "molecules are bumping and sliding past each other". When she needed to use the definitions to explain events such as melting, she had difficulty. For all the other lessons, Carol used Strategy 5, conceptual change learning, and attained all but one of the goal conceptions.

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Antoine showed weak restructuring for the Pure Substances and Mixtures lesson cluster because he reorganized his knowledge to fit an inaccurate definition. He seemed to use a learning strategy to just finish the task, and overrelied on his real-world knowledge to accomplish that task. Antoine did not attain any of the goal conceptions for Pure Substances and Mixtures. He continued to use a "complete the task" goal strategy (2) in the Introduction to Molecules and States of Matter lessons, but accomplished some radical restructuring of his schema, retained some real-world understandings, and attained less than half of the goal conceptions. For the Dissolving and Thermal Expansion lessons, Antoine moved closer to demonstrating a conceptual change learning strategy because now he attempted to <u>use</u> the new information to <u>explain</u> the events of dissolving and thermal expansion, something he had not attempted to do previously. Antoine demonstrated radical restructuring in these lessons, and attained the macroscopic goal conception for the lessons, but not those at the microscopic level.

Jose demonstrated some radical restructuring for all the lesson clusters. But since he used a learning strategy (3) in which he separated his text learning from his real-world understandings, he showed understanding of less than half of the goal conceptions. He started building new schema about the nature of matter and physical change, but most of his restructuring was at a macroscopic level—he attained only one microscopic goal conception, 9, that all matter is made of molecules. He had yet to understand the nature of molecular behavior in substances, and changes of state.

Results of the analysis of the six target students' writing for evidence that the students showed in their writing that they were restructuring their

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science knowledge reflected that students' writing can provide a window into their thinking. This was confirmed in almost all cases by the similarity of students' written statements about content and their verbal statements before instruction, and after. When a students' verbal statements were not similar to his or her written statements, it was because the student verbally added more details, but invariably their *core concepts* were the same, except for one student, Jose. For some reason, after instruction, Jose was better able to express his ideas about molecules in his verbal statements than he was able to in his written statements. However, for all the other target students, their written statements about their *core concepts* were similar to their verbal statements about their *core concepts*. These students provided evidence that students' writing provides a "window" into their thinking, and we can at least see their core concepts for organizing and making sense of their science knowledge.

There was evidence in students' writing of how much knowledge restructuring the were accomplishing, as well. When their *core concepts* or their number of concepts, their theories and principles changed from pretest to posttest there was evidence of radical restructuring. When students did radically restructure their knowledge, they changed their way of organizing and explaining scientific events. They were not always correct in their explanations, but the evidence showed that they are attempting to make sense, because they seemed to be "in the process" of constructing new schema to incorporate and make meaningful the new scientific information.

Table 4.7 is a chart of the kinds of knowledge restructuring, goal conception attainment, percent goal conceptions reached, and learning strategy used for each lesson cluster by each target student.

Summary of target students' perceptions of writing. When I asked each of the six target students to tell me about the plans and strategies they used to accomplish their writing tasks, most of them replied that they would just write down whatever ideas came to mind. For example, when I asked Antoine what strategies might have used to get his ideas into written form, he said, "I just write down what I remember". Other students' responses were similar: Carol said, when I asked her the same question, she said she was "just putting my ideas down." And Kenny said the same, "I just put them [my ideas] down". Jose said similar things about his strategies. Melinda and Artie were similar but said the same thing in different words. Melinda said, "I think it just came out as I thought it". Only Artie said he made some kind of plan before wrote. He thought of what he was going to write first, and then what he would write second.

I asked students to inform me about whether they found that writing their ideas ever helped them think. Artie, Carol, Kenny, Melinda, Antoine, and Jose all said that they thought that writing helped them think. When I asked them if they could think of a time that happened so they could explain it to me, or show me in one of their writings, most of them said they could not remember an exact time when it happened, but they knew it happened to them. Even when looking at their writing pieces, most of the students could not show me a place where their writing helped them to think, although they thought it did, but maybe not all the time. One student could show me a place where writing helped him think. Artie explained that when he was writing about explaining sugar dissolving to his little brother during a freewrite, he remembered that he forgot to write about something, he said, "I was sitting right there [points to his desk], writing down an explanation for something, and

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TABLE 4.7

RESULTS FOR TARGET STUDENTS
Knowledge Restructuring, Goal Conception Attainment, and Strategy Use Across Lesson Clusters

	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expans	
Artie	Weak 1,1a 66% 3	Weak 10,11,12 75% 4	Radical 2,3,14 50% 5	Radical 13,14,15 75% 5	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Kenny	Radical 1,1a 66% 5	Weak 11,12 50% 3	Radical 2,3,14 50% 5	Radical 13,14,15 75% 5	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Carol	Weak 1a,9 66% 3	Radical 9,10,11 12 100% 5	Radical 2,3,9,14 18 83% 3	Radical 13,14,15 75% 5	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Melinda	Weak 1,1a,9 100% 5	Weak 9,10,11 12 100% 5	Radical 2,3,9,14 17,18 100% 5	Radical 13,14,15 17 100% 5	Radical 3,14,15 17 100% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Antoine	Weak None 0% 1	Wk/Rad 9,11 50% 2	Radical 3 17% 2	Radical 13 25% 5	Radical 3 25% 4	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Jose	Radical 3 30% 3	Wk/Rad 9,11 50% 3	Radical 2,3,9 50% 3	Radical None 0% 3	Radical 3 25% 3	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use

then all of a sudden I remembered some other stuff, and I started writing more".

When students were asked if they ever noticed that their ideas changed as they wrote. Three of the students said they thought it did, but none of them could show me a time in their writing where they remembered their thinking changed (Jose, Artie, and Kenny). But all three reported, at one time or another, their thinking would change as they wrote. Jose said it was easier for him to remember his ideas because he could look back at what he just wrote. Artie came the closest to providing an example when he explained how he thought of more to write as he was writing (in the quote above). Carol said during the instruction that sometimes her ideas changed as she wrote, but at the post clinical interview she said that her ideas did not change when she wrote. Melinda said she did not think that her ideas ever changed much as she was writing, and Antoine said his ideas did not change when he wrote.

Students' ideas about the purposes for their writing during the lesson unit stayed about the same from the beginning of instruction to the end. In the beginning, most thought that the teacher had them write so she could see what they thought, to see if they were paying attention, to see what they knew, and for grades. By the end of the unit, most students said the same things about the writing with the exception of Melinda, Jose and Kenny. Melinda said that the teacher had her write to see what is going on in her mind, which is similar to what students said in the beginning, but Melinda added that the teacher had her write to help her learn, that writing her ideas helped her clear her mind, and then helped her pick up where she left off in her thinking the next day. She said,

> *It cleared my mind, and I could think freely about science and then I went to reading. I could come back in and come back and fresh open. . . just like a can of sardines! Just about everyday that happens. It's just like when you're done with the can you close it and you put it in the fridge, but then when you come back you can open it up real easy. . . and you can pick up what you want and write about it.*

Jose said that he thought the teacher had him write to see what he was learning, but also to help him learn more, "it helps you think more better. . . when you write on paper it helps you think more, but if you're thinking in your brains, you know, you don't really know. . .". Kenny thought the teacher might be having them write so that they could learn from the notes they wrote on their ideas.

Essentially, the six target students did not use any strategies to put their ideas into writing, or they were not aware that they used strategies if they used any. Most of the six thought that their writing helped them think, even though few of them could show me of a time when that happened in their writings. Only three of the six students thought their ideas ever changed as they wrote. And students' perceptions of why the teacher had them write seemed to stay the same across the lesson unit: The teacher had them write so she could see what they were thinking, if they had learned, and to give them a grade. Three of the students saw that the teacher might be having them write to help them learn.

Results from Students across the Class

Semantic node-link networks were constructed from each of the other students' writing across the class, and the concepts analyzed from pretest to posttest. Each student's scientific goal conception attainment for each lesson cluster was assessed based on students' posttest statements, and based on their statements from pretest to posttest, and during the lessons. I used the same statements to analyze the learning strategy students demonstrated based on Anderson and Roth's (1988) descriptions. If students added the new conceptions to their schema, and used the information to explain real-world events, they used a conceptual change strategy, Strategy 5. If they added new information to their schema, and attempted to use it to explain real-world phenomena, but retained prior, inconsistent, conceptions within t

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within their schema, they overrelied on prior knowledge to make sense of their new knowledge, Strategy 4. When students were able to answer text questions with acceptable answers, but totally relied on real-world knowledge to answer real-world questions, they demonstrated using Strategy 3, overreliance on unrelated facts, and separation of disciplinary knowledge from real-world knowledge. When students' goals appeared to be to "finish the task", and they either relied on their prior knowledge, or the words in the text to answer the questions, they demonstrated Strategy 1 or 2. The findings are summarized for each student's success with each of the five lesson clusters in Table 4.8. I did not include two of the 27 students in this report. For one student, I had only her pretest, activity book writings, and freewriting, so it was difficult to tell what she might have retained on the posttest. The other student took neither the pretest or the posttest, so I was unable to follow his thinking very effectively, except to observe his activity book writing and freewriting. Both of these students performed effectively writing interesting and acceptable ideas in their activity booklets and on freewrites, and appeared to restructure their thinking to incorporate and use many of the new concepts. Their writing was analyzed for the concepts they identified. The first student, for whom I had no posttest, Susan, possessed some schema for pure and mixtures, and molecules before the instruction; during the instruction she demonstrated using new information to rebuild her schema about pure and mixtures, and molecules. She used the new information to explain real-world phenomena on her freewrites. The other student, for whom I had neither pretest or posttest, Chico, seemed to follow instructions and write acceptable explanations in his activity booklet. He used some of his new ideas to explain real-world phenomena on his freewrites, as well. For me to feel more confident about

whether these two students actually restructured their schema so that it was useful, and attained the scientific goal conceptions, I needed more information from more of their writing following instruction, or an interview with the students, which I did not have.

Summary of All Students' Knowledge Restructuring, Goal Conception Attainment, and Strategy Use

All of the students were successful with some kind of knowledge restructuring and 20 of the 25 students attained at least half of the scientific goal conceptions across the entire unit. A few students had trouble on isolated lessons, and five students seemed to have trouble in general (Antoine, Jose, Winston, Anita, and Candice). These five students used ineffective learning strategies, and did not attain half of the intended goal conceptions.

In general, when a student demonstrated a more weak form of restructuring one of two conditions existed: The students either possessed some prior knowledge and schema for understanding the new information, or they possessed little prior knowledge schema, and had difficulty making use of the new information. Often when students had difficulty, they also used ineffective learning strategies. For instance, of the target students, Artie and Melinda demonstrated weak restructuring for two of the lesson clusters because in both cases, they possessed some schema for understanding the new information. The other target students who demonstrated weak restructuring for some lesson clusters, Kenny, Carol, Antoine, and Jose, in all instances, used an ineffective learning strategy, and did not retain all of the goal conceptions. Across all of the students, when they demonstrated a weaker form of restructuring they often possessed some prior knowledge schema for the topic to be learned. When they did not possess a schema for

TABLE 4.8

RESULTS: Knowledge Restructuring, Goal Conception Attainment, and Strategy Use Across Lesson Clusters						
	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expans	
Doug	Weak 1,1a,9 100% 4	Weak 9,10,11 12 100% 5	Weak 2,3,9,14 17,18 100% 3	Radical 13,14,15 17 100% 5	Radical 3,14,15 17 100% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Norman	Radical 1,1a,9 100% 5	Weak 9,11,12 75% 5	Weak 2,3,9,14 17 83% 4	Radical 13,14,15 17 100% 4	Radical 3,14,15 17 100% 4	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Winston	Wk/Rad 1a 33% 1	Radical 9,11,12 75% 2	Radical 14 16% 3	Radical 14 25% 3	Radical 14 25% 4	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Bill	Radical 1,1a,9 100% 5	Wk/Rad 9,10,11 12 100% 5	Radical 2,3,9 14,17,18 100% 5	Radical 13,14,15 17 100% 5	Radical 3,14,15 17 100% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Ron	Weak 1,1a,9 100% 1	Radical 9,10,11 12 100% 3	Radical 3,9,14,18 66% 4	Wk/Rad 14,15 50% 3	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Peter	Radical 9 33% 3	Radical 9,10,11 12 100% 5	Wk/Rad 3,9,14 17,18 83% 4	Radical 13,14,15 75% 4	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Lucy	Weak 1,1a,9 100% 1	Radical 9,10,11 12 100% 5	Radical 2,3,9 14,17,18 100% 4	Radical 13,14,15 17 100% 5	Wk/Rad 3,14,14 17 100% 3/5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Sam	Radical 1,1a,9 100% 4	Weak 9,10 50% 5	Radical 2,3,9,14 66% 5	Radical 13,14,15 75% 5	Wk/Rad 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use

TABLE 4.9 (continued)

RESULTS: Knowledge Restructuring, Goal Conception Attainment, and Strategy Use Across Lesson Clusters (continued)						
	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expans	
Holly	Radical 1,1a,9 100% 5	Radical 9,10,11 12 100% 5	Radical 2,3,9 14,17,18 100% 5	Radical 13,14,15 17 100% 5	Radical 3,14,15 17 100% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Linda	Weak 1,1a,9 100% 5	Radical 10,11,13 75% 5	Radical 2,3,9 50% 5	Radical 13,15 50% 5	Radical 3,15 50% 4	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Seth	Weak None 0% 2	Weak 10,11,12 75% 2	Radical 2,3,17 50% 3	Radical 13,15,17 75% 5	Radical 3,15,17 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Agnes	Weak 1,1a,9 100% 5	Wk/Rad 9,10 50% 4	Wk/Rad 2,3,9,14 66% 5	Radical 13,14,15 75% 5	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Dennis	Radical 1,1a,9 100% 5	Weak 9,10,11 75% 4	Wk/Rad 3,9 33% 2	Radical 13 25% 5	Radical 3 25% 4	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Irma	Radical 1a,9 66% 3	Wk/Rad 9,10,11 12 100% 3	Radical 2,3,9 14,17,18 100% 5	Radical 13,14,15 17 100% 5	Radical 3,14,15 17 100% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Charles	Wk/Rad 1,1a,9 100% 5	Wk/Rad 9,10,11 12 100% 5	Radical 2,3,14 50% 5	Radical 13,14 50% 5	Wk/Rad 3,14 50% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Samantha	Radical 1,3 66% 4	Radical 9,10,11 12 100% 4	Radical 2,3,9,14 66% 5	Radical 13,14,15 75% 5	Radical 3,14,15 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Anita	Wk/Rad 1a 33% 2	Wk/Rad 10,11,12 75% 2	Wk/Rad None 0% 2	Wk/Rad None 0% 2	Wk/Rad None 0% 2	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use

TABLE 4.9 (continued)

RESULTS: Knowledge Restructuring, Goal Conception Attainment, and Strategy Use Across Lesson Clusters (continued)						
	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expans	
Emily	Weak 1a,9 66% 3	Wk/Rad 9,10,11 12 100% 4	Radical 2,3,9,17 18 83% 5	Radical 15,17 50% 5	Radical 3,15,17 75% 5	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use
Candice	Radical 1,1a 66% 4	Radical 12 25% 3	Wk/Rad None 0% 3	Wk/Rad 14 25% 3	Wk/Rad 14 25% 2	Knowledge Restruct Goal Concepts % Per Lesson Strategy Use

the topic, students who demonstrated weaker forms of restructuring used an ineffective learning strategy. In 23 of the 25 total instances of weak restructuring for students who possessed little prior knowledge, these students also used ineffective strategies.

Just because a student used an ineffective learning strategy did not mean he or she did not learn the information and radically restructure their knowledge. In 25 instances of the total 80 instances of more radical forms of restructuring, students radically restructured their knowledge while still using an apparently ineffective learning strategy. For 55 of the 80 instances of radical restructuring, however, students used an effective learning strategy, which led me to think that using an effective learning strategy might help students accomplish difficult restructuring.

The number of students who held little prior knowledge about matter and molecules and radically restructured their knowledge per lesson cluster was correlated with the number of students who attained more than 70% of the goal conceptions per lesson, for a relationship of -.10. Ability to radically restructure knowledge was not related to attainment of the goal conceptions. This may have been due to the fact that students could radically restructure their knowledge and attain some of the goal conceptions, but not all of the goal conceptions.

The number of students who radically restructured their knowledge per lesson cluster was correlated with the number of students who used effective strategies per lesson cluster, for a relationship of +.88. Students who radically restructured their knowledge strongly tended to use an effective learning strategy, Strategy 5.

When students possessed a prior knowledge schema, they usually attained all of the goal conceptions for a lesson cluster and weakly restructured their knowledge. When students possessed little schema for understanding matter and molecules, they were able to attain more of the goal conceptions if they (1) radically restructured their knowledge, and (2) used an effective learning strategy. Of the 25 instances where students began with little prior knowledge schema and attained all of the goal conceptions for a lesson cluster, all 25 radically restructured their knowledge. Ability to radically restructure knowledge did not guarantee that students would attain all of the goal conceptions, however. Of all the students who demonstrated radical restructuring of their knowledge all attained at least one goal conception for each lesson cluster. These findings do not imply that radical restructuring is any more valued or more desirable than weaker forms of restructuring. Often weak restructuring is desirable when the individual possesses prior knowledge schema and experience. When an individual does not possess prior knowledge, radical restructuring may be a more desirable outcome. Students doing radical restructuring may need to undergo some conceptual change and modify existing schema with new concepts and principles. In this study, most students began the unit with little prior knowledge for matter and molecules, so radical restructuring and conceptual change was a desirable outcome for them. It is for this reason that the study focused primarily on radical restructuring in the analysis.

Of the 40 instances where students attained all of the goal conceptions for a lesson cluster, students used Strategy 5, an effective strategy for conceptual change learning, in 28 instances. For the other 12 instances, students used a less effective strategy, seven students used Strategy 4, three students used strategy 3, two students used Strategy 1. Thus, use of an ineffective strategy did not in all cases keep students from learning the goal conceptions, even when they had little prior knowledge schema. Students were more likely to attain the goal conceptions when they used an effective learning strategy (28 out of 40 instances).

The number of students who attained more than 70% goal conceptions for each lesson cluster was correlated with the number of students using effective strategies for each lesson cluster for a positive correlation of .38. This correlation indicated that there was mild positive relationship between attaining the goal conceptions and using effective learning strategies. In other words, if a student attained more than 70% of the goal conceptions for a lesson cluster, he or she tended to have used an effective learning strategy as well.

How Do the Findings about Knowledge Restructuring, Students' Strategy Use, and Goal Conception Attainment Relate to Instruction?

To answer the second question about students' learning and what ***mechanisms*** from classroom events might be associated with students'

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knowledge restructuring, and what seemed to make the difference for those students who restructure their knowledge and those who have difficulty, the researcher analyzed the differences in the students' success with each lesson cluster for restructuring, goal attainment and strategy use.

If a student attained more than 70% of the scientific goal conceptions in a lesson cluster, he or she had accomplished more than the average for the class as a whole. The students who had attained 100% of the goal conceptions were often more successful students, and a larger cross-section of students was more desirable to assist the analysis. If a student had attained most, but not all, of the goal conceptions for a lesson, they were considered to be successful with that lesson cluster. Students who had been able to attain more than 70% of the scientific goal conceptions for each lesson cluster were chared to get a picture of which lessons might have been more supportive for students' learning the scientific ideas. The results are shown in Table 4.9. Students had most success with the Introduction to Molecules, Dissolving, and Thermal Expansion goal conceptions. There might be something about these three lesson clusters that distinguished them from the others that was worth observing more closely.

The researcher was also interested in finding out which of the lesson clusters might have supported students' use of successful learning strategies more than others, so charted the lessons in which students had more success using effective learning strategies. The results are shown in Table 4.10. Pure Substances and Mixtures, Introduction to Molecules, and States of Matter lessons showed fewer students using effective learning strategies. More students used effective strategies with the Dissolving and Thermal Expansion lessons. The researcher looked closely at the events in one of the lessons in which students were able to attain more than 70% goal conceptions, and used

TABLE 4.9

RESULTS: Students Attaining More than 70% Goal Conceptions by Lesson					
	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expansion
	Agnes	Anita	Bill	Agnes	Agnes
	Bill	Artie	Carol	Artie	Artie
	Charles	Bill	Doug	Bill	Bill
	Dennis	Carol	Emily	Carol	Carol
	Doug	Charles	Holly	Doug	Doug
	Holly	Dennis	Irma	Holly	Emily
	Linda	Doug	Lucy	Irma	Holly
	Lucy	Emily	Melinda	Kenny	Irma
	Melinda	Holly	Norman	Lucy	Kenny
	Norman	Irma	Peter	Melinda	Lucy
	Ron	Linda	(10)	Norman	Melinda
	Sam	Lucy		Peter	Norman
	(12)	Melinda		Sam	Ron
		Norman		Samantha	Peter
		Peter		Seth	Sam
		Ron		(15)	Samantha
		Samantha			Seth
		Seth			(17)
		(18)			

effective strategies, and compare those events with the events of a lesson in which students did not attain as many goal conceptions, and where more students did not use effective learning strategies. The classroom events of the Dissolving lesson (most students attained the goal conceptions and used effective strategies) were compared with the events of the Pure Substances and Mixtures lesson (fewer students attained the goal conceptions and few used effective learning strategies).

TABLE 4.10

RESULTS: Students' Use of Effective Learning Strategies by Lesson					
	Pure & Mixtures	Intro to Molecules	States of Matter	Dissolving	Thermal Expansion
	Kenny	Carol	Artie	Artie	Artie
	Melinda	Melinda	Kenny	Kenny	Kenny
	Norman	Doug	Melinda	Carol	Carol
	Bill	Norman	Bill	Melinda	Melinda
	Holly	Bill	Sam	Antoine	Antoine
	Linda	Peter	Holly	Doug	Doug
	Agnes	Lucy	Linda	Bill	Bill
	Dennis	Sam	Agnes	Lucy	Ron
	Charles	Holly	Irma	Sam	Lucy
	(9)	Linda	Charles	Holly	Sam
		Charles	Samantha	Linda	Holly
		(11)	Emily	Seth	Seth
			(12)	Agnes	Agnes
				Dennis	Irma
				Irma	Charles
				Charles	Samantha
				Samantha	Emily
				Emily	(17)
				(18)	

To answer the second research question, about what classroom events seem to be associated with students' effective science knowledge restructuring, all of the aspects for two lessons that might be important events were compared based on the literature review of the classroom events that seemed to encourage knowledge restructuring: I compared the events from one lesson that encouraged students' restructuring and conceptual change, the Dissolving lesson, with the events from a lesson that was more difficult for students to restructure knowledge and accomplish conceptual change, the Pure Substances and Mixtures lesson.

In the following section the findings from the two different lesson clusters, Pure Substances and Mixtures, and Dissolving are presented.

What Made the Difference?

The Differences in Two Lessons: Pure Substance and Mixtures, and Dissolving

Based on the literature reviewed in Chapter 2, I identified several mechanisms in classroom events that might be associated with knowledge restructuring. All forms of classroom dialogue might be important, instances of argument or controversy, and social interactions between students and the teacher, and students with other students. Certain forms of teacher talk might be associated with knowledge restructuring, as well: Socratic dialogue, providing cognitive conflict, surprise, use of metaphor and analogy, the structure of the teacher's presentations, the teacher's language, how the teacher explains phenomena to the students, and provides verbal explanations for students' experiences are just a few events that might trigger students to change their conceptions about new science information. Students' prior knowledge and their learning goals might influence what students take from the information and the meanings they make.

The following section presents the evidence gathered from the videotaped classroom records of lessons, what the teacher said, student interactions in small groups, and the text materials to show the differences in each of two lesson clusters, to see if any important differences emerged. Added to the suggested events from the literature review were events Posner, Strike, Hewson, and Gertzog (1982), Roth, Anderson, and Smith (1986), and Minstrell (1984) said were important features of effective instruction for conceptual change learning and looked across the two lessons for evidence of classroom learning events. The chart in Table 4.11 summarizes the findings. In the following section the features of each lesson are reviewed. The reader will see many features in the two lesson clusters that were similar. For instance, both contained the same number of instructional days, and both engaged students in activities related to the lessons. The curriculum design was similar. Both lessons begin with a story to engage students' prior conceptions about real-world phenomena related to the lesson. Both lesson clusters engaged students in activities that were directly related to what they were learning. Students wrote about their ideas and plans, and conferred with peers in both lessons. The teacher led group discussions, asked students qeustions that reflected content, emphasized main points, engaged students' alternative conceptions, and provided open-ended verbal interactions for students to express their real-world notions. There were discussions in both lessons that lead to closure and consensus about activities and ideas. Finally, students practiced applying their new conceptions with concrete applications in both.

The differences at first seemed minute, but upon closer investigation, these seemingly small differences held a key to students' success with the Dissolving lesson cluster. As can be seen from the chart, the main differences between the two lessons resided in

(1) The relationship between the activities and students' initial conceptions,

(2) the relationship between the activities and the goal conceptions students were to learn, and

(3) students' opportunities to use language---writing and speaking---to use their new conceptions to explain phenomena.

What stood out as different in this analysis was the kinds of activities and writing tasks in which students participated, and how closely the activities and writing tasks related to students' initial conceptions and the goal conceptions. The following section contains a review of the findings from each of the two lesson clusters.

Instructional Time

Both lesson clusters took approximately the same amount of time, 8 days. Some days the lessons were shorter, others were longer, depending on the amount of business at the homeroom period before the class started, and on finishing another lesson cluster, and beginning a new one.

Activities

Pure Substances and Mixtures. The Pure Substances and Mixtures lesson cluster contained two activities. In the first activity, students identified real-world substances in small plastic vials as to what the substance might be, whether it was matter or non-matter, pure or mixture, and how sure they were. Students did the activity first individually, writing the answers in their activity booklets. They then compared their answers in small groups. In the second activity students attempted to separate a mixture of their choice from the vials in the first activity. They planned for this activity individually, then conferred in their small groups to attempt to separate some of the mixtures. The students in Group 1 (Melinda, Artie, Jose, and Norman) attempted to separate only the mud mixture. The students in Group 2 (Carol, Kenny, Antoine, and Doug) attempted to separate sawdust and iron filings, salt water, and mud.

TABLE 4.11

Comparison: Lesson Elements	
Pure Substances and Mixtures	Dissolving
Instructional Days	
8 days of varying length, between 15 minutes and 40 minutes	8 days of varying length, between 15 minutes and 40 minutes
Activities	
Two: 1) Identifying Substances, pure/mixtures, matter/non-matter 2) Separating Mixtures	Three: 1) Getting the Sugar Out and careful observation 2) Dissolving Races 3) Group Presentation of dissolving races explanations
Writing Activities	
1) Write pure and examples of pure 2) Write a new definition of pure 3) Write identification of substances, individual 4) Write identification of substance, group 5) Write separating mixtures plans, individual 6) Write separating plans, group 7) Write how it worked 8) Write on quiz "What I Have Learned" 9) Freewrite flasks story	1) Write plan for getting sugar out of bag, explanation, substance and molecules, individual 2) Write plan for getting sugar out of bag, explanation, substance and molecules, group 3) Write what happened when tried the plan 4) Write a careful observation 5) Write explanation of observation, what happened to substance, and molecules, individual 6) Write explanation of observation, what happened to substance, and molecules, group 7) Write plans and explanations for three dissolving races: slow, fast, and no-touch fast race, individual 8) Write plans and explanations for three dissolving races: slow, fast, and no-touch fast race, group 9) Write explanations for dissolving, group on overhead 10) Freewrite about dissolving 11) Write explanation for each dissolving race, individual

TABLE 4.11 (continued)

Opportunities to Answer Questions (Large Classroom Group)	
1) Answers to "Two Flasks" story, Day 1 2) What is "pure"? Examples? Day 2 3) Review identification of substances, Day 4 4) Understanding separating mixtures, Day 5 5) Science history/Aristotle and misconceptions, Day 5 6) Debriefing on separating mixtures, Day 6 7) How do people separate mixtures?, Day 6 8) Questions about clear = pure, seeing mixtures, pure poisons, Day 8	1) Sizes of sugar grain, teabag hole, sugar molecule, good explanations, Day 2 2) How did the plan work? What did you see? Debriefing, Day 3 3) Debriefing about observations, substances and molecules after Activity 1 group discussion, Day 3 4) Explaining dissolving, Day 3 5) Explaining how to draw sugar crystal and water molecules, Day 3 6) How did sugar get out of teabag?, & choral responses, Day 3 7) Explanations (obs, subs, mols), Day 3 8) Explanations (obs, subs, mols), Day 4 9) Review for races, and rules, explanations, Day 5 10) Good explanation, Day 5 11) Parts of a good explanation and explaining dissolving, Day 6 12) Finding the parts of a good explanation, Days 7 & 8
Use of Metaphor or Analogy	
1) How to be sure? (Bracelet), Day 4 2) for Aristotle and misconceptions, Day 5 3) Separating bananas from jello, for separating mixtures, Day 5 4) Separating other mixtures, Day 6 5) "Filtering" through desk or plastic vs. paper, Day 8	1) Keeping food hot, keeping water cold, without putting ice in water, Day 6
Cognitive Conflict (for target students)	
1) Melinda: Is air matter? Day 3	1) In group: Melinda and Jose (Yes) vs. Artie and Norman (No) : When sugar dissolves does it change from a solid to a liquid?

TABLE 4.11 (continued)

Argument (for target students)	
1) Sand, gravel, or dirt? (Antoine, Lucy, Kenny, and Doug) Day 3 2) Salt water or chlorine? (Antoine vs. Lucy) Day 3 3) Salt water or chlorine? (Melinda vs. Jose) Day 3 4) Is air matter? Is it pure? (Melinda vs. Artie, Norman) Day 3 5) Salt vs. sand? (Jose vs. Melinda, Normal and Artie) Day 3 6) Sawdust/sand vs. sawdust/dirt (Melinda, Jose, Artie, Norman) Day 3 7) Sawdust vs. wood chips (Kenny vs. Doug) Day 4	1) Sugar dissolving or coming out of teabag, whose idea is it? (Carol vs. Doug) Day 2 2) Sizes of sugar grain, holes in teabag, molecules (Melinda, Artie, Jose, Norman) Day 2 3) Sugar dissolves (Artie, Norman) vs. becomes a liquid (Melinda, Jose) Day 3
Socratic dialogue	
Not found in teacher's talk specifically; the curriculum materials were designed to help students form general rules from known cases, pick counterexamples, make predictions, test hypotheses, formulate general rules, apply to new situations.	
General rules about what is pure, How can we tell? How can we separate mixtures? Students made predictions about separating mixtures; tested a hypothesis; formulated general rule about separating mixtures.	General rules about what is a good explanation; students made predictions about dissolving sugar in water; did not pick counterexamples; tested their hypotheses about dissolving in slow, fast races, formed general rules, as individual, small group, and whole class discussion.
Surprise (for target students)	
Separating salt and water, Day 5 (Doug, Carol, Lucy, Kenny)	Seeing sugar go into water from teabag, Day 2 (Both small groups)

TABLE 4.11 (continued)

Inactivity and Reflection	
1) During discussion about group activity 1. Day 4 2) Writing plans for separating mixtures? Day 5 3) During quiz. Day 6 4) Writing most important thing they learned. Day 7 5) Playing with vials of substances during free time. (Carol, Jose, Artie, Melinda) Day 7	1) During questioning of Jose, and what he saw. Day 3 2) Writing what they observed and parts, individual. Day 3 3) Writing individual plans for races. Day 4 4) Freewrite about dissolving. Day 7 5) Writing explanations. Day 7 & 8
Teacher Emphasis	
1) Matter = solid, liquid, gas Non-matter = heat, light, love, emotions Day 2 2) Matter = liquid, solid, gas Non-matter = heat, light, live, emotions Day 4 3) mixture = 2 or more kinds of matter, 2 or more substances pure = only one kind of matter, only one kind of substance Day 5 4) matter, non-matter, pure and mixture Day 6 5) Seeing mixtures, smelling mixtures; clear = pure?; pure poison Day 8	1) Parts of a good explanation Day 1 2) Parts of a good explanation Day 2 3) Parts of a good explanation and what happens to sugar Day 3 4) Explanations-especially molecule behavior and arrangement Day 4 5) Rules for races, good explanation Day 5 6) Good explanations Day 6 7) Parts of a good explanation and what happened in races Day 7 8) Parts of a good explanation and what happened in races Day 8
Students' Dissatisfactions with Existing Conceptions (for target students)	
1) Antoine: Dirt, salt, non-matter? mixture? Day 3 2) Melinda: Matter = can see it? Is air matter? Yes/No Day 3 3) Doug, Kenny, Carol, and Lucy: Salt goes through filter? Day 5	1) Melinda and Norman: Powers of ten Day 2 2) Melinda: Sugar changes from solid to liquid? Day 3

TABLE 4.11 (continued)

Questions, Engaging Alternative Conceptions, and Open-ended Verbal Interactions	
1) What would you do to find out what is in the flasks? Day 1 2) What is pure? Examples Day 2 3) What is matter? What is pure? Day 4	1) What is dissolving? Explain observations, what happens to substance, what happens to molecules/in groups Day 3 2) Explanations in group presentations; debriefing discussion Day 6
"Why" Questions	
1) Why is air matter? A mixture? Day 4	None specifically asked
Discussion Opportunities to Resolve Discrepancies	
1) Air: Why matter, mixture Day 4 2) Separating salt & iron Day 6 3) Separating mud Day 8	1) Practice explaining, tell out loud how did sugar come out of teabag? Day 3 2) Small group discussion of plans for dissolving races Day 4 3) Group writing explanation for presentation Day 6 4) Review what happened during dissolving races Day 7
Discussion Leading to Closure and Consensus	
1) Can't be sure about substances being PURE & what each substance was. Day 4 2) Separating salt and iron; salt water?, salt and sand Day 6 3) Pure, mixtures, matter Day 8	1) Observations for sugar coming out of bag; reading from text scientific explanation Day 3 2) Explaining what happened when sugar came out of teabag Day 4 3) Group presentations Day 6 4) Practice applying new conceptions to what happened during races Day 7
Practice Applying New Conceptions	
1) Classifying substances; matter, pure, mixtures, sure? Day 3 2) Planning, separating mixtures Day 5 3) Practice real-world examples of separating mixtures Day 6 4) Quiz? Day 7 5) Apply separating ideas to mud Day 8	1) Dissolving Activity 1 - Getting sugar out of teabag and observe Day 2 2) Explaining observations using "observations, substances and molecules" Day 3 3) Dissolving races Day 5 4) Dissolving races explanations Days 6, 7, 8

TABLE 4.11 (continued)

Concrete, Accessible Ideas and Experiences Directly Related to Initial Concepts	
1) Classifying substances; pure, matter, mixtures (All substances are matter, mixtures) Day 3	1) Activity - Getting the sugar out of the teabag Day 2 2) Explain/discuss observations Day 3 3) Dissolving races Day 5 4) Group presentation of explanations, observations of races Day 6
Repeated Opportunities to Reuse New Idea Arguments, Review & Apply in New Contexts	
1) Separating mixtures Day 5	1) Ideas and plans for races Day 4 2) Individual practice explaining races Day 8

Dissolving. The Dissolving lesson cluster contained three activities. In the first part of Activity 1, students made a plan and attempted to get sugar out of a closed teabag without opening or tearing the bag. Students made individual plans first, then conferred in their small groups to reach a consensus on a plan, and carry it out. For the second part of Activity 1 students individually wrote a scientific explanation for what they observed. They had to write facts or assumptions for what they observed, and explain what happened to the substances, sugar and water, and what happened to the molecules. They then conferred in their small groups to come to a consensus explanation for their observations.

In Activity 2, students made plans for "Dissolving Races"---a slow race, fast race, and a no-touch fast race. They first wrote down individual plans for each race, with a plan, and explanation for why it would work, then they conferred in small groups to make a group plan and explain why it would work.

In Activity 3, students met in small groups to plan a group explanation for what happened during their dissolving races, what they observed, and what happened to the substances and molecules. They wrote their group explanation on an overhead transparency, and one member from the group presented the explanation to the rest of the class.

Writing

Pure Substances and Mixtures. During the Pure Substances and Mixtures lesson cluster, students accomplished eight short writings about their thinking, and activities. They wrote their real-world definition of pure, and examples, then after class discussion and textual information about the scientific definition of pure, wrote a new definition of pure in their activity booklets. At the beginning of Activity 1, students wrote individual ideas about what substances they thought were contained in each of seven vials, and then classified each substance as matter or non-matter, pure or mixture, and whether they were sure, or not sure. After completing their individual investigations, students met in small groups, and wrote the group ideas for each vial. Students wrote individual plans for separating one of the mixtures in the vials, then tried one of the plans in the small group, and wrote how their plans worked. Their last two writings for the lesson cluster were writing on the quiz to define pure, mixture, matter, and non-matter, and answer application questions; and a freewrite to finish the story of the two flasks, relating what the young man did to determine which flask contained the water, and which the water mixed with poison. Students wrote primarily definitions and examples, classification of mixtures and plans for separating mixtures, and answers to quiz questions about pure and mixtures. They did not write any explanations for their answers.

Dissolving. During the Dissolving lesson cluster students accomplished eleven short writing assignments. Most of the writing involved either (1) making plans for dissolving sugar, and making plans for dissolving races, first individually and then in small groups; or (2) writing explanations containing observations, statements about substances, and statements about molecules when sugar dissolves. The one other writing involved a freewrite where students were asked to explain to their little brother whether he should use hot or cold water to dissolve sugar. Students practiced writing scientific forms of explanation during eight of the eleven writing exercises.

Opportunities to Answer Questions

Pure Substances and Mixtures. From review of the videotapes from the Pure Substances and Mixtures lessons, every questioning period that the teacher entertained with the students in the whole classroom session was reviewed. During this lesson cluster, as listed in Table 4.11, the teacher held a question and answer period on Days 1, 2, 4, 5, 6, and 8. Questions were almost always directed from the teacher to the students and few questions were directed from the students to the teacher. The topics the teacher covered were the two flasks story (Day 1), students' real-world definitions of pure (Day 2), questions about the substances in the vials (Day 4), how to separate mixtures (Day 5), scientific understandings and misconceptions (Day 6), a debriefing session on separating mixtures (Day 6), real-world applications of separating mixtures (Day 6), and questions about whether or not pure means clear, whether we can see mixtures, and whether there are such things as pure poisons (Day 8).

Dissolving. During the Dissolving lessons, there were twelve instances where the teacher provided a question and answer session about the new information were located on Days 2, 3, 4, 5, 6, 7, and 8. Questions were almost always directed from the teacher to the students and few questions were directed from the students to the teacher. The topics of the teacher's questions to the students related to reviewing the sizes of a sugar grain and holes in a teabag from the powers of ten chart (Day 2), questions about how students' plans worked when they tried to get the sugar out of the teabag, and what they did (Day 3), debriefing questions after Activity 1 on what they observed, and how to write a good explanation of what they observed (Day 3), debriefing about what they wrote in their groups for their observations, and explanations (what they observed, what happened to the substances, what happened to the molecules, Day 3), how to explain dissolving, and how to draw the sugar crystal, and water molecules breaking it down (Day 3), how did the sugar get out of the teabag (Day 3), and explanations (observations, talk about substances, talk about molecules) for sugar getting out of the teabag (Day 3), what are good explanations? (Day 4), review for the races and rules, how to explain plans (Day 5), what are the parts of a good explanation? (Day 5), what are the parts of a good explanation and how to explain dissolving (Day 6), and finding the parts of a good explanation in model explanations, and their own explanations (Days 7 & 8).

Teacher's Use of Metaphor or Analogy

Pure Substances and Mixtures. As the videotapes were viewed, every instance the teacher used a metaphor or an analogy to explain concepts for this lesson was reviewed. The teacher used analogies to explain how students can be sure, and what constitutes evidence by using what they could actually see and prove on Day 4, and to explain misconceptions when she talked about the history of science and Aristotle's thinking (Day 5). She used common household analogies such as removing the bananas from jello to explain separating mixtures (Day 5). She had students supply analogies from their own experiences for separating mixtures on Day 6. On Day 8, the teacher used analogies to explain filtering to separate mixtures, such as which would work better to filter mud, the desk top or filter paper, and why?; and which would work better, filter paper or a Kleenex tissue, and why?

Dissolving. During the Dissolving lesson, I detected only one time that the teacher used metaphor or analogy to explain a phenomenon. On Day 6, she told students how to keep water very cold for a slow dissolving race by putting the jar of cold water in a bowl of ice. She used the analogy of keeping food hot on a hot tray to help the students understand why this might work.

Cognitive Conflict (for target students)

Pure Substances and Mixtures. During the videotapes of the Pure Substances and Mixtures lessons, only one apparent instance of cognitive conflict was located, for one target student, Melinda. Cognitive conflict was assumed to occur if a student showed visible signs of disturbance over his or her understandings, such as questioning, arguing with others, and appearing unsure about ideas in small group conversations. During her group discussion identifying and classifying substances, Melinda was unsure of whether or not air was matter (she could not see it), and if it was matter, if it was pure or a mixture. The teacher had a conversation with Melinda, using questioning, to help her resolve the conflict, since Melinda already knew that there were gases such as oxygen and hydrogen in the air (see partial transcript from this conversation below in the section titled, Argument).

Dissolving. Only one instance of apparent cognitive conflict was detected for the target students within the dissolving lesson content. On Day

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3, during their small group discussion, Melinda and Jose seemed convinced that when sugar dissolved in water, the sugar turned from a solid into a liquid. Artie and Norman argued that the sugar molecules only mixed with the water molecules, that the substance, sugar, did not become a liquid. Melinda and Jose seemed visibly uncomfortable with the disagreement, but not sure if they were correct, thus likely experiencing some cognitive conflict. There was no evidence in the videotapes that this conflict was ever resolved.

Argument (for target students)

Pure Substances and Mixtures. There were seven instances of argument within the two target small groups during the Pure Substances and Mixtures lesson. Argument was considered to be verbal interactions where students showed disagreement about concepts, and verbally confronted one another with their dissenting opinions. On Day 3, Antoine, Lucy, Kenny and Doug (Group 1) argued over whether the substance they were classifying was sand or gravel or dirt. After several exchanges about whether it was gravel, because "sand can be in gravel because gravel can break up" (Doug), and "you can't break gravel" (Lucy and Kenny), and "it looks like pencil lead" (Antoine), the group finally resolved the conflict by writing all three, after Kenny said, "Then put all three---rocks, dirt and salt!" Also on Day 3 in the same small group, Lucy and Antoine argued over whether a liquid substance was chlorine (Antoine) or salt water (Lucy). They finally resolved the conflict by shaking the substance and smelling it again, and Lucy said, "Yeah, number 3, its chlorine, you guys". On the same day, Day 3, the other small group also had arguments about the substances: Artie, Jose, Melinda, and Norman argued about whether the substance in vial #3 was salt water or chlorine. After smelling it, Artie said, "I don't smell it", and Jose said, "That's salt water", then "number 7 is chlorine, . . .smell it". They finally resolved this argument near the end of the session when Jose said, "This is chlorine, I told you (referring to #7). . .This is salt water! (referring to #3)". Melinda said, "I couldn't smell any chlorine!", but when Jose said, "We're talking about number 3, so write #3 is salt water", and they all wrote that #3 was salt water. This group had another argument on Day 3 about whether air was matter, and if it was pure. Melinda was convinced that if she could not see air, it must not be matter. The following conversation transpired about the air in vial #1:

Melinda: *Matter or non-matter?*

Artie: *I say matter.*

Melinda: *Air is matter?*

Artie: *Yeah, and it's a mixture, too . . because . . .*

Melinda: *But you can't see air, can you?*

Norman: *I put matter.*

Artie: *There are many gases you can't see. . . you can't see a gas. .*

Norman: *Yeah, that's true. .*

Melinda: *Then how come when I look on the elements chart all the time, and I see them?!*

Artie: *You can see air anytime. . .If you have a bar-b-que, and the sun's right out, you can see air!*

Melinda: *Yeah, . . that's smoke. . .*

The conversation continued until the teacher walked over to the group, and helped resolve Melinda's conflict. The conversation went like this:

Melinda: *Mrs. Peters, we're unagreed. They say we're outvoted, but is air a matter?*

Mrs. Peters: *What's the definition of matter?*

Melinda: *Something you can see.*

Mrs. Peters: No,. . . matter is a solid, liquid or gas.

Melinda: I didn't know air was a gas. . . I thought air has oxygen and hydrogen. . .

Mrs. Peters: Are those gases?

Melinda: Yes.

Mrs. Peters: So air is a mixture or pure?

Melinda: Mixture.

Mrs. Peters: Why is it a mixture?

Melinda: Because it's got two different ingredients in it.

Mrs. Peters: Its got more than one gas, more than one substance. . .

From here, Melinda seemed satisfied that air is matter, and a mixture because of the gases she knew are in air. This group had one other argument on Day 3. They were not sure whether vial #2 was salt or sand, or both, and whether vial #4 contained sawdust and sand or sawdust and dirt. They seemed to resolve these arguments by putting whatever they each thought for their own answer. The questions about the substances got confusing, and the group did not resolve what some of the substances were on Day 3. For instance, the following conversation showed their confusion:

Melinda: I want to smell number 7.

Norman: OK, . . . now let me use the eyedropper. . .

Melinda: Smells like chlorine to me. . .

Norman: [smells #7] . .

Jose: [referring to #3] This is salt water!

Norman: [referring to #5] This is mud and water, . . . mud and water. . .

Artie: Yeah, just put mud,. . . and it's matter . . . no, that's number 4 [he is writing in the wrong space]

Norman: Number 4 is sawdust.

Artie:	*Hold on. . .what's number 3?!*
Jose:	*Salt and water. . . it's matter,. . . mixture. . . salt water and smell. . .*
Artie:	*Salt water doesn't have a smell. .*
Jose:	*Well to me it does.*
Norman:	*Sawdust and sand. . .*
Jose:	*I put sawdust and dirt.*
Artie:	*Yeah, it's sand. . . it's sand. . . it's wood and sand. .*
Jose:	*What is it?. . .matter or non-matter?. . .*
Artie:	*Hold on! We're not done yet. . . what's number 5?*
Melinda:	*This is rock!*
Jose:	*Smell it. . .*
Artie:	*It's salt---taste it!*

[The bell rings and students clean up to leave.]

The teacher resumed the groups to complete their work on the following day, Day 4 of the Pure Substances and Mixtures lesson, and more arguments transpired in Group 1 (Antoine, Carol, Doug, and Kenny). They had trouble deciding whether #2 was gravel or dirt and salt, and whether #4 was wood chips or sawdust. They finally resolved both arguments, because Doug said his dad had a table saw, and he knew what sawdust was, and the vial did not have sawdust in it, they were wood chips. The other members of the group agreed. They seemed to resolve the gravel question by putting what each of them thought the vial contained, gravel or dirt and salt. On Day 4, Group 2 (Melinda, Norman, Artie, and Jose) agreed on most substances, after asking one another a few questions.

Dissolving. During the Dissolving lesson cluster several arguments transpired in the two target groups. On Day 2 In Group 1 (Carol, Doug, Kenny, and Antoine), Carol and Doug had a short argument about whose idea it was to write "the sugar is dissolving and coming out of the teabag". After some back-and-forth comments, they went on with further business, writing in their activity books what happened when they tried their plan for getting the sugar out of the teabag. Also on Day 2, Group 2 (Melinda, Norman, Artie, and Jose) argued about the size of the sugar grains, and the size of the holes in a teabag. Melinda had written 10^{-3} for the size of a sugar grain, but Artie had 10^{-5}. Jose had 10^{-4}, and Norman had 10^{-2}. Artie's reasoning was that two grains of salt was 10^{-3}, so one grain of sugar had to be smaller, thus 10^{-5}. They resolved the argument like this:

Artie: *So our group answer is* 10^{-5}.

Melinda: *How big is* 10^{-5} *anyway?*

Artie: *It says two grains of salt is* 10^{-3}, *so . . .*

Melinda: *So why did you say it was* 10^{-5}?

Norman: *Because we wanted to! . . . [writes] it's smaller than two grains of salt. . . [all write the same answer].*

Shortly thereafter, the teacher came by the group and recognized they were off-base for their conceptions of powers of ten, and told the group to rethink their numbers. They revised to say sugar grains are 10^{-4}. The next week, Day 4, as the same group discussed what happened when they tried their plan, and attempted to write an explanation for what they saw, an argument ensued. Melinda and Jose, who said that the sugar dissolved and turned from a solid into a liquid, argued with Artie and Norman, who said that the sugar did not turn into a liquid, it just dissolved and broke down into little tiny pieces, but it did not turn into a liquid. After several exchanges, Melinda went to ask the teacher about the correct answer. Before she could ask, the teacher told the students to begin their next activity, and began reviewing the guidelines, so Melinda had to go back and sit down with her group. Her dilemma did not get resolved on Day 4. Later the same day, when the teacher asked each group to recite what they wrote in their explanation, Carol, from Group 1 read that their group wrote "the sugar turns into a liquid." The teacher let that pass, and moved on to the next student. Melinda raised both of her arms in victory sign, and looked at Artie and Norman as if to say, "See, I told you so!".

Teacher's Use of Socratic Dialogue

Pure Substances and Mixtures. Socratic Dialogue is the use of questioning technique that asks students to formulate general rules from known examples, pick counterexamples, make predictions based on their general rules, test their hypotheses, and apply their ideas to new situations. The teacher in her talk with the students did not use any specific Socratic dialogue consistently. The curriculum materials were designed to offer some form of the thinking that occurs during Socratic dialogue by asking students to form some general rules with regard to "pure" and "separating mixtures", and test some hypotheses about how they might separate mixtures. But they did not pick counterexamples, make predictions, or formulate any general rules that they then apply to new situations in the Pure Substances and Mixtures lesson cluster.

Dissolving. The same ideas for some parts of Socratic dialogue are contained within the Dissolving lesson cluster curriculum materials. Students were asked to form general rules about what a good explanation includes, and make predictions and test hypotheses about how to dissolve sugar out of a teabag, then how to dissolve sugar very slowly, and very quickly. They formulated some general rules about how sugar dissolves in hot and cold water. But students did not have opportunities to consider counterexamples, or apply their new ideas to new situations in the Dissolving lesson.

Elements of Surprise

Pure Substances and Mixtures. Surprise occurred when any student working in the target group expressed that what they saw happening or heard about that was different than what they expected. In some cases, the surprise students expressed was more obvious, and they made loud outbursts about their new discoveries. In some cases, the students expressed that the outcomes were different than what they expected, and even though they did not make loud outbursts, surprise was considered to be any occurrences where students found something different than what they expected. I observed all of the videotaped records of classroom discussion, and group activity for events in which students expressed some kind of surprise. There was one instance in the Pure Substances and Mixtures lesson cluster when Group 1 (Carol, Lucy, Doug, and Kenny) were attempting to separate salt from water using a filter paper on Day 5. The students expressed surprise when they discovered that there was salt in the bottom of the container, and that the salt had gone through the filter paper with the water. The following conversation transpired after Doug had put the filter paper over the top of the jar, and poured the salt water into the filter paper:

Lucy: *There's nothing catching it doesn't look like.*

Doug: *Sounds like it though . . .*

Kenny: *Anything going through?*

Lucy: *Don't add any more though, or this is the one we'll be klutzy. . . . I see something down there like salt. . .*

Carol: *The magnet worked fine [referring to their first separating attempt, iron filings from sawdust].*

Lucy: *Go get a magnet. . .not a magnet, but a magnifying glass.*

Doug: *There's something down in the bottom of the glass!*

Kenny: *I got this one. . .someone go. .*

Lucy: *Oh, go tell her [teacher]! We're supposed to tell her. Someone to read to her for me. . . Did someone tell her?*

Kenny: *The salt went through, I told you!*

Lucy: *There's salt in the bottom of the glass. Was it there before?*

Doug: *I don't think so, I washed it out.*

Lucy: *Well that didn't work!*

Carol: *It didn't work.*

There were no other instances of surprise that I found for this lesson.

Dissolving. During the Dissolving lesson, there were only two instances on the videotaped records of classroom interactions where students appeared to express surprise. During Day 2 of the lesson, in both Groups 1 and 2, students expressed surprise as they watched the sugar go into the water from the teabag. For instance, the following conversation transpired in Group 1:

Carol: *It says only to the rim. . . that's how far you're supposed to put it in. .*

Kenny: *I know how to put it in, it says right here. . .*

Doug: *You can see it coming out already!*

Kenny: *It's working. .*

Doug: *I know. . . that's cool!*

Later Kenny said, "Look at it through the magnifying glass!", and "It's awesome!", and Carol repeated, "Oh, that's awesome. . . cool!"

In Group 2, the students expressed similar surprise to see the sugar going into the water. They expressed surprise by saying things like, "It worked!. . .look you guys, it worked!" (Artie), and "See, . . it's coming out!" (Jose). I did not find any other evidence of surprise in the students' conversations about content in the Dissolving lesson cluster.

Opportunities for Inactivity or Reflection

Pure Substances and Mixtures. Opportunities for inactivity and reflection were assumed to be instances where the students might have had a quiet time to reflect or think back on their ideas. Possible opportunities for students to be inactive and reflective were instances where the classroom was fairly quiet, and students were individually thinking or writing. During the Pure Substances and Mixtures lesson, there were five instances where students might have had such opportunities. On Day 4, when the teacher led a group discussion about the first activity, she moved at a slow pace, and asked questions of the students about pure and mixtures, and what they planned to do during the activity. Students had opportunities to look over their booklets quietly and think about their plans as the discussion progressed. On Day 5, students wrote their individual plans for separating mixtures. Most students appeared quiet, and could have been in the process of thinking about their answers. On Day 6, during the quiz, students were engaged and quietly writing their answers. On Day 7, the teacher had students write about the most important thing they had learned so far. Most students were quiet and writing during this activity. The last instance of inactivity and possible reflection I observed was on Day 7 when some of the students had finished their activity booklets, and the teacher let them take some of the vials of substances and play with them, thinking about how they might separate the mixtures. Those students who played with the vials did so quietly and individually most of the time, and seemed to be engaged in the materials (Carol, Jose, Artie, and Melinda). Occasionally one student would quietly motion to a neighbor to look at something.

Dissolving. There were also five instances during the Dissolving lesson where it appeared from the videotape record that the room was quiet enough that some students might have had opportunity for individual reflection. During Day 3, the teacher spent several minutes questioning Jose about what he observed when he put the teabag of sugar in to the cup of water. She stayed with Jose until she was able to hear him say what he actually observed, while the other students watched and listened to what teacher and Jose were saying. Students might have been reflecting on their own thinking about the events, during this exchange between the teacher and Jose. Later during the same day, the students wrote individual observations about what they saw, and explained what was happening to the substances, and the molecules. During this writing, students were quiet and engaged with writing. The next day, Day 4, students wrote individual plans for the dissolving races. The room was relatively quiet while they wrote, and most students were writing. On Day 7, students completed a freewrite to explain what they would explain to their little brother about dissolving sugar. Again, students were quietly writing. Sometimes students would write, then stop to look at what they wrote, sometimes erase, sometimes stare away for a moment, then continue writing, as one does when reflecting on ideas to write them on paper. During the last two days of the lesson cluster, Day 7 and Day 8, students wrote individual explanations for what happened during the dissolving races. They used colored markers to review what they wrote, underlining their written observations in red, their statements about substance in blue, and statements about molecules in green. Students were quiet, and engaged in thinking, writing, and reviewing during this activity.

Opportunities for reflection through writing. The fact that six target students reported without fail that writing helped them think suggests that the times students wrote at various points in both lessons may have offered them opportunities for thinking and reflection. The writing itself could be a mechanism that is associated with knowledge restructuring, but there was little evidence for that other than the verbal reports of the six target students. These six students provided reports that writing "sometimes" helped them think, and "a little". Only one of the students could tell me of a specific time when his writing helped him think, even when students were looking back at previous writing pieces. If writing is a mechanism that can be associated with knowledge restructuring, it may be because writing provides students with opportunities for reflecting on their thinking. All of the six target students reported that writing helped them think, and three of them reported that their ideas sometimes changed as they wrote. Melinda, Kenny, and Jose thought the teacher had them write because it would help them learn. If some of the students were beginning to see a value in writing for learning, they may have been aware that writing was helping them learn, providing evidence that writing and reflecting on ideas through writing was a mechanism that might be associated with knowledge restructuring.

Teacher's Emphasis in Talk

Pure Substances and Mixtures. Teacher emphasis was interpreted as instances when the teacher repeated ideas, or used special voice inflections to cue students to pay attention to what she was saying, and times when she had the students join in chorus-style to help her finish her sentences, and answer her questions. The teacher emphasized these key ideas during the Pure Substances and Mixtures lesson cluster: Matter is a solid, liquid, or gas; non-matter is heat, light, love, or emotions; mixtures contain two or more kinds of matter, or kinds of substances; pure contains only one kind of matter, or one kind of substance. She emphasized these key points at least three times during the lesson. On the last day, she also emphasized that students might not be able to see or smell mixtures, or know when something is pure.

Dissolving. The main things that the teacher emphasized during the Dissolving lesson were the parts of a good explanation (facts, assumptions, or observations, statements about the substances, and statements about the molecules), which she emphasized at least once each day. She also emphasized what happens to sugar when it dissolves (on Day 3), molecule behavior and arrangement in dissolving (Day 4), and what happened when sugar dissolved during the races (Days 5, 6, 7 & 8).

Students' Expressed Dissatisfactions with Existing Conceptions

Pure Substances and Mixtures. When students expressed some confusion, or non-belief either about their own or others' ideas about content within conversations in the small target groups they were supposed to be expressing some dissatisfaction with their existing conceptions. Often they would argue about the ideas, or ask questions of one another to express their confusion. During the Pure Substances and Mixtures lesson cluster, there were three such instances: On Day 3, in Group 1, Antoine asked as he was writing about chlorine, "What is it? . . .matter or non-matter?. . [no one answered him]. . . Matter" He resolved his insecurity after some thought and answered his own question. On the same day in Group 2, Melinda was unsure of what air was, because she could not see it, and thought air might be non-matter. After some coaching from the teacher, Melinda seemed to accept a new conception, that because air contained oxygen and hydrogen, which she knew, it must be matter, and a mixture (see part of the transcript in the above section titled, Argument). One other time during the Pure Substances and Mixtures lesson that students showed some dissatisfaction with their existing conceptions was in Group 1, when the students attempted to filter salt water through filter paper on Day 5. Each student seemed to disbelieve that salt could go through the filter paper at first, but after further investigation, each seemed to be able to resolve the conflict by seeing the salt in the bottom of the cup (see partial transcript in the above section, titled Surprise).

Dissolving. Target students expressed dissatisfaction with their existing conceptions during the Dissolving lesson were Melinda and Norman (Group 2) on Day 2, and Melinda on Day 3. In the first instance, Melinda and Norman were unsure whether the powers of ten answers that Artie and Jose wanted to write were correct. Norman quickly switched to agreeing with Artie, so Melinda went along, but did not seem convinced that the others were correct about their answers. Later, when the teacher came by the group and corrected them, they revised their answers closer to what her original idea had been. In the second instance, Melinda seemed unsure whether sugar became a liquid to mix with the water in dissolving, or whether the sugar grains just broke up and mixed with the water. She seemed more sure of her own conception about sugar becoming a liquid, and there was no evidence that she did not retain that idea.

Questions about Alternative Conceptions and Open-ended Verbal Interactions

Pure Substances and Mixtures. The teacher provided at least three opportunities for students to discuss their alternative or real-world conceptions about pure substances and mixtures during this lesson cluster. An open-ended verbal interaction was one in which the teacher elicited students' ideas and opinions about a concept or topic, and let all the ideas students had come out into the discussion. Each time she did this, the interactions were open-ended, allowing students to verbalize any ideas they had that might answer the questions, or provide more information. On Day 1, she asked students what they would do to find out which flask in the "Two Flasks" story contained the water and which contained the water mixed with poison. She entertained ideas from the class without making judgments until she had exhausted all of the students' ideas. She used the discussion as a point of departure to talking about "what is a pure substance?". On Day 2, the teacher solicited students' real-world ideas about what they thought pure was, and their examples for pure. She moved around the room from student to student and got all possible ideas from the students out in the open. She used this discussion as a point of departure to reading and talking about the scientific definition of pure. On Day 4, she held an open-ended discussion for students to throw out ideas about what is matter, and what is pure, and what they thought was in each vial they investigated. She moved around the room, and asked several students what they thought they found, and what they thought it was. She asked students for any other ideas, until she had exhausted the possible ideas students had. She used the discussion as a point of departure to showing students what the substances in the vials actually were, and discussing whether the substances were pure, mixtures, and how they could be sure. On Day 6, the teacher asked students how they separated mixtures, what they separated, and how it worked. She had someone from each group tell what the group did, and what they found out. Students voiced their ideas about their separating mixtures activities without judgments placed from the teacher. All ideas were accepted in an open-ended fashion.

Dissolving. During the Dissolving lesson, I located two instances where the teacher held open-ended discussions about the students' conceptions. On Day 3, she asked for students' statements they had written about their observations, what happened to the substance, and what happened to the molecules after they tried their plan for getting the sugar out of the teabag. She solicited all the explanations that were different until students had no new ideas. She used this discussion as a point of departure to explaining how a scientist would explain what was happening when the sugar dissolved in the water. The teacher had another open-ended discussion on Day 6, after the dissolving races, as a debriefing session, where students from each group told what their explanation was for what happened during the dissolving races in their groups. She gave each group a chance to talk about their observations, what happened to substances, and what happened to molecules during the dissolving races. She used this discussion as a point of departure to remind students of the parts of a good explanation, and how a scientist would explain each of the races.

"Why" Questions

Pure Substances and Mixtures. There was only one instance during the videotape records of classroom interactions in the Pure Substances and

Mixtures lesson when the teacher asked the students "why" questions to engage their thinking about reasons for their answers in whole class discussions. This was during Day 4, when she was clarifying pure and mixtures, and asking students for examples of each. When students talked about air being in the first vial, the teacher asked if air is matter, then asked them "why", and asked if air was a mixture, then asked them "why". Artie answered that air is matter because it is a gas. Charles answered that air is non-matter, but could not back up his answer with reasons, and no other student in the class agreed with him. He changed his mind. Artie said that air was a mixture because it has oxygen and carbon dioxide in it and those are gases, and Norman said that air is a mixture because it's a gas, made up of gases. The other students agreed. There were no other instances of the teacher asking "why" questions to the large group that I could find during this lesson.

Dissolving. There were no instances of the teacher asking "why" questions during the large group discussion in this lesson cluster.

Discussion Opportunities to Resolve Discrepancies

Pure Substances and Mixtures. There was evidence that the teacher held discussion opportunities to resolve discrepancies. There were discussions where the teacher reviewed ideas, or had students review ideas in their small groups to resolve discrepancies between what they were thinking, and what the right direction for their thinking might be. There were three times during the Pure Substances and Mixtures lesson cluster that students were able to discuss their ideas and think about how their ideas matched the ideas of the teacher and other students. On Day 4, the teacher had the students discuss why air is matter and a mixture to resolve any students' alternative conceptions about air being otherwise. She also engaged students in thinking about "why" during this discussion, and when one student, Charles, said he thought air was non-matter, but could not state a reason, she questioned whether the other members of the class agreed with him. No one did. Other students offered reasons why air is matter, and a mixture. The teacher emphasized that their reasons were good reasons, and that air is matter, and a mixture. On Day 6, the teacher resolved student discrepancies about students' abilities to separate salt from iron with a magnet. She reviewed with the groups who tried it, what they did, and what happened, and stated that a magnet works to separate the iron from the salt, for any group that might not have experienced that separation experiment. On the last day, Day 8, the teacher provided resolution to the discrepancies about what mud is. She showed the students that the mud contained both liquid and solid particles, that it was matter, a mixture, reviewed what the students found when they attempted to separate the mud from the water, and that they were able to separate most of the mud from the water, but the water that had been filtered was still greenish, evidence that the filter did not separate all of the mud particles out of the water. She used this discussion as a point of departure to a discussion of the smallest particles in water, molecules.

Dissolving. During the Dissolving lesson cluster, the teacher provided four opportunities for students to resolve their discrepancies about dissolving sugar. On Day 3, she asked students from each group to tell the rest of the class how the sugar came out of the teabag. She coached some students, and provided supportive help for their explanations to help them resolve foggy thinking about what might have happened. For example, when asked how did we know the sugar got out of the teabag, Emily responded that she saw it dissolve, and the teacher coached her to say exactly what she saw, the wavy lines through the water, and her observation that the water tasted sweet, so Emily and the other students would realize that they did not really "see" sugar dissolve, but saw evidence that the sugar was dissolving. On Day 4, students discussed their plans for the dissolving races in small groups, and were able to resolve some of their unclear ideas about how sugar might dissolve faster or slower by sharing ideas and receiving feedback from other group members. For example, the members of Group 1 shared their ideas and resolved the differences in their ideas about their procedures for dissolving sugar slowly as follows (Antoine was absent):

Kenny: *I know how to do it the fast way.*

Doug: *It's easy.*

Kenny: *easy. . .*

Doug: *I know.*

Kenny: *Let's see your plans [looks at Doug's booklet].*

Doug: *[to Carol] What do you have for your slow one?*

Carol: *Cold water.*

Doug: *Cold water. . .I said put the cup of water into a bowl of ice. [to Kenny] What did you put?*

Kenny: *Cold water. . . put it in cold water.*

Carol: *. . .melt. . .*

Doug: *It would not melt.*

Carol: *OK, . . put it into a bowl of ice. . . you'd better be right. . . no, put the sugar cube---we can't use pronouns. . .*

Doug: *Put cup of water into bowl of ice.*

Carol: *What?*

Doug: *Put cup of water into bowl of ice.*

Carol:	***I don't get it.***
Doug:	***It's going to be in a cup of water, too. . that's how my hot plate is.. .the sugar will be in a cup.***
Carol:	***Well, . . OK.***
Doug:	***[writing] Put sugar cube into cold water.***
Carol:	***Put sugar cube [writing] into cold water. . . with ice in it?***
Doug:	***Well, we can't have anything <u>in</u> the cup, but we can set the cup in a bowl of ice.***
Carol:	***Put the cup. . .***
Doug:	***in a bowl of ice, then put sugar cube in it. . . . [writing] Facts or observations. . .cold water dissolves sugar slowly.***

As the conversation continued, the students resolved their differences about their plans, came to a consensus, and wrote the ideas in their booklets. Students had the opportunity to verbally express their ideas about how sugar dissolves, such as in Doug's case when he said, "cold water dissolves sugar slowly", and then had a chance to hear what other students thought of his idea. The other group, Group 2, had a similar conversation, checking each others' ideas, straightening one another out about the rules, and procedures, then writing their ideas in the activity booklet. Students had another opportunity to resolve discrepancies about their explanations of what happened during dissolving in their small groups on Day 6. They met in small groups to plan and write explanations for one of the races on an overhead transparency that one member of the group would then present to the whole class. During the group discussion, students verbally tested their explanations, and got feedback from the other students as they tried to come to a consensus about what to write on the overhead. During the Group 2 conversation between Artie, Melinda, Norman, and Jose, the following occurred:

Melinda:	***So, we put the sugar cube in frozen water. . . What is our plan?***
Artie:	***[writing on overhead] OK, now what is it?. . .Put the sugar cube in frozen water, right?***
Jose:	***Ice cold.***
Artie:	***Put. . [writing]***
Norman:	***. . sugar cube. . Put sugar cube in freezing cold water. . .***
Melinda:	***You gotta put a little dash. . .***
Artie:	***Uh. . .facts and observations. . .***
Norman:	***We assume the temperature will slow down the process?***
Melinda:	***The temperature will <u>affect</u> the process.***
Artie:	***So, we assume that the temperature will affect the process.***
Artie:	***OK. . . the process. . .what's a fact?***
Norman:	***That the sugar cube was going into the cold water.***
Artie:	***We'll put an observation. . . that the sugar cube dissolved. . .***
Melinda:	***Dissolved in water.***
Artie:	***The sugar cube can dissolve in water.***

The students went on to discuss, Artie wrote, until they had listed their observations and facts, what happened to the substances, and what happened to the molecules during the slow dissolving race. Each student had opportunities to verbally express his or her ideas about dissolving and get feedback from the other members of the group about the appropriateness of the idea. Artie drew a picture on the overhead transparency, to depict what the sugar looked like when the cube dissolved in the water. Within this ongoing conversation to accomplish writing the overhead as a group, the individual students verbally rehearsed what they thought described the dissolving process in cold water, the facts and observations, statements about substances, and statements about molecules, having an opportunity to resolve some of their discrepancies about their understandings. There were some confusions that remained, however. Melinda and Norman disagreed about whether the sugar goes into the water to become one substance, or a mixture. Norman insisted that he heard someone say that the sugar goes into the water and becomes one substance, and that was correct. Melinda insisted that sugar and water became a mixture. The group wrote Norman's idea on the overhead transparency.

One last opportunity arose for the students to enter into discussion for resolving discrepancies during Day 7. The teacher lead a whole class discussion to talk about what happened during the dissolving races. She reviewed what students had done for each race, what they had observed, and how they should talk about the process in their explanations. She questioned students about what they had written. She asked such questions as "What are our two substances?", "How about the molecules?", and "Did the sugar disappear?", "How did the sugar break down?", "How are the molecules in a sugar cube arranged?", and "What's the difference between hot and cold water?" Sometimes the students would answer as a group in choral response, and sometimes individual students would give an answer. During Day 7, the students analyzed model scientific explanations of each dissolving race from their activity booklets, and found the "facts or observations" and underlined them with red marker, the "statements about the substances" and underlined then with blue marker, and the "statements about the molecules" and underlined them with green marker. Reading and analyzing the scientific explanations, and then writing and analyzing their own explanations provided opportunities for students to compare their own thinking with the thinking of experts, and might have helped them resolve some discrepancies in their thinking.

Discussions leading to Closure and Consensus

Pure Substances and Mixtures. Evidence of discussions leading to closure and consensus were instances where the teacher called the group together and reviewed an activity, or reviewed what the students found, before moving on to another activity. During these discussions the teacher often reviewed main points, and the concept ideas she wanted students to remember. There were three instances of this kind of discussion during the Pure Substances and Mixtures lesson cluster. On Day 4, the teacher lead a discussion where students told what they found in the seven vials they investigated, the teacher told the students what was in the vials, and they discussed whether the substances were matter, pure, mixtures, and whether they were sure. She provided closure to the activity by telling the students what they should have found, and how they needed to provide reasons for believing in what they found. She emphasized that we often cannot be sure whether a substance we observe is pure or a mixture. On Day 6, the teacher lead a discussion to provide closure to the separating mixtures activity. She reviewed with the students what some small groups had found when they attempted to separate salt and iron with a magnet, or salt water with filter paper, or mud from water. She asked students to think about ideas for separating salt and sand, and how they might separate salt from water, as possible extra credit projects they could do after school. On Day 8, the teacher provided more discussion with a review of the meaning of pure, mixture, and matter, for review and closure to the Pure Substances and Mixtures lesson, before going on to the next lesson cluster, Introduction to Molecules.

Dissolving. During the Dissolving lesson cluster, there were four instances of discussion for closure and consensus. On Day 3, the teacher lead a discussion of students' observations of the sugar coming out of the teabag when it was placed in water. They reviewed how some of the students explained what they saw, then read what scientists would say about the same phenomenon in their activity booklets to provide closure for how they should think about what they saw in scientific terms. The next day, Day 4, the teacher reviewed students' observations of the sugar coming out of the teabag again, and provided opportunities for students to put their thinking into similar terms as the scientific explanation in their activity booklets had demonstrated for them. There was more opportunity for students to bring their thinking out before the group and establish consensus and closure when each group presented their explanation for a dissolving race on the overhead. As each group presented information, the teacher asked if there were any questions from the class, then asked questions herself if she thought clarification was necessary for any of the explanations. On Day 7, students received another opportunity to bring their ideas into consensus with scientific thinking. The students practiced applying their new conceptions about dissolving to explaining what happened during the dissolving races, placing their explanations in written form, then reflecting on and analyzing what they wrote to see if they had included all the parts of a good explanation in their writing.

Practice Applying New Conceptions

Pure Substances and Mixtures. Anytime students explained to one another, explained to the teacher, planned and carried out laboratory activities, and described and explained their laboratory activities, students showed that they were practicing with new conceptions. Using this as criteria for instances of practice, there were five instances during the Pure Substances and Mixtures lesson cluster that students had practice applying their new ideas about pure and mixtures. On Day 3, when students investigated the vials of different substances, they practiced talking about pure and mixtures and matter, and used their new definitions to help them classify the substances. All of the substances were matter, so they had no application to non-matter, and all of the substances were mixtures, so they did not apply their thinking to pure substances. On Day 5, students made plans to separate mixtures, so had opportunities to talk about how they might separate the various substances in the vials. They applied their new ideas about mixtures to their discussions about plans. On Day 7, the students took a quiz over the lesson cluster, and had practice applying their new ideas about pure, mixture, and matter to the quiz questions, some of which were new problems they had not encountered before, such as a question about whether they could make water molecules out of glass, and why or why not. On Day 8, students applied their new ideas about pure and mixtures to talk about how they might separate mud.

Dissolving. During the Dissolving lesson cluster, students had at least three opportunities to practice applying their new conceptions about the behavior of substances and molecules during dissolving. On Day 2, students planned and executed their plans to get sugar out of a teabag without tearing or opening the bag. Students used the knowledge they had about how molecules behave in liquids and solids, and their real-world knowledge about how sugar dissolves, to carry out a plan. On the following day, Day 3, students again used their new conceptions about molecular behavior in solids and liquids by explaining their observations of dissolving sugar using scientific forms of explanation—talking about their observations, and the facts or assumptions, explaining what happened to the substances, sugar and water, and explaining what happened to the molecules, during dissolving. On Day 5, students practiced applying their new conceptions about the molecular behavior of sugar and water in dissolving to a new situation: How could they get the sugar to dissolve as slowly as possible?, and How could they get the sugar to dissolve as quickly as possible? And what if they could not touch the sugar, could they still get the sugar to dissolve quickly? When they wrote their explanations as a group on the overhead transparency on Day 6, they practiced applying their new conceptions about dissolving. On Days 7 and 8, the students practiced applying their new conceptions about dissolving by writing explanations about dissolving, then analyzing their written explanation for the three essential parts of a good explanation.

Concrete, Accessible Ideas and Experiences *Directly Related* to Initial Concepts

Pure Substances and Mixtures. Activities that students performed that allowed them some "hands on" experience manipulating substances about which they were learning, and that allowed them to "manipulate" the information in other ways such as explaining, classifying, and trying out new activities with the new information were considered to be concrete, accessible experiences. An important criteria for selecting these concrete activities was how closely related the activity was to students' initial concepts. For instance,

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one initial concept that students had about mixtures, was that a mixture contained many things mixed together, and was the opposite of pure, which meant clean or clear, so mixture might mean unclean or not clear. During the Pure Substances and Mixtures lesson cluster, one activity that allowed students to use their new ideas about mixtures being made of more than one substance in concrete, accessible ways was the classifying substances activity. Students had seven vials with unknown substances, that they investigated and classified. All of the substances were matter, and all were mixtures, so they could see that some mixtures, like air, were not unclean, nor unclear, but were made of more than one substance. Another mixture was salt water, an example of a mixture that was not unclear, nor unclean, but contained more than one substance, salt and water. Another activity that provided students with concrete, accessible ideas directly related to their initial concepts was the separating mixtures activity, which gave students more opportunities to work with mixtures. This directly related to their initial conceptions about what substances are mixtures, and how easily mixtures can be separated. For those who weren't sure about whether salt water, or mud were mixtures in the beginning there was now opportunity to try to separate them, and talk about how to accomplish separation. They could see that separating mixtures was not very easy, and sometimes it was difficult to know if they even had a mixture. These were the only concrete activities that related ***directly*** to students' initial conceptions about pure substances and mixtures.

Dissolving. I found students had opportunities to apply their new ideas to four concrete, accessible experiences directly related to their initial conceptions in the Dissolving lesson cluster. The first activity on Day 2, Getting the Sugar out of the Teabag, was concrete and accessible and directly related to students' ideas about molecular behavior in solids and liquids. It tied their new knowledge about molecular behavior with their real-world knowledge about how sugar dissolves in water, and dissolves faster in hot water than in cold. Day 3's experiences, where students explained and discussed what they observed when they put the sugar in water, was also concrete and accessible, and related new information about molecular behavior to their real-world understanding about dissolving. During the Dissolving Races, Days 4 and 5, students again had an opportunities to use their new ideas with concrete, accessible experiences as they used their new ideas about molecular behavior in solids, liquids, and the dissolving process to make and carry out plans to dissolve sugar slowly, quickly, and quickly without touching. When the students presented their explanations of what happened during the races, they had another concrete, accessible experience that related to their new ideas and how these ideas fit with their real-world experiences.

Repeated Opportunities to Reuse New Idea Arguments, Review and Apply in New Contexts

Pure Substances and Mixtures. Students had opportunities to reuse new idea arguments, and review and apply them in new contexts when they used ideas about what was pure, what was a mixture, and what was matter or non-matter in new situations. After students classified the substances in the seven vials (all were mixtures), and attempted separating some of the mixtures--both opportunities to use their new idea arguments about pure and mixtures, matter and non-matter---there were no other opportunities for students to reuse their new ideas about what was pure, or mixture, matter or non-matter. Even during subsequent lesson clusters, although the teacher verbally reviewed what was pure, and what was mixture in relation to molecules, the students had no further experiences ***directly related*** to their initial concepts of pure and mixture, matter and non-matter. There were no further activities or opportunities to explain or use their new ideas about pure substances and mixtures in the other lesson cluster, with one exception. During the dissolving lesson, students used the concept "mix" to explain dissolving, and referred to the sugar and water substance as a "mixture". They did not explicitly explain how this "mixture" fit with the previous lesson in pure substances and mixtures.

Dissolving. Students had opportunities to reuse new idea arguments, and review and apply them in new contexts when they used ideas about molecular behavior in solids and liquids during dissolving in new situations. There were two instances in the Dissolving lesson cluster where this occurred. On Day 4, when the students planned the Dissolving Races, they could reuse their new ideas about how molecules behave when sugar is dropped into water to plan, discuss and explain how to accomplish the races. On Day 8 when the students practiced explaining what happened during the races, they again had experience reusing their new ideas about molecular behavior in dissolving. Every other time that students practiced explaining what they saw and what happened during the races, which was at least one opportunity every day of the lesson, they reused their new arguments about molecular behavior during dissolving. They had no further opportunities to reuse their ideas with other substances than sugar and water.

Summary

Many features in the two lesson clusters were similar. The curriculum design was similar. Both lessons engaged students' prior conceptions about real-world phenomena related to the lesson and engaged the students in activities that were related to what they were learning. Students wrote about their ideas, and conferred with peers in both lessons. Students had opportunities to participate in discussions, answer questions, and express their real-world notions as they related to the new information. The differences between the two lessons was located in the relationship between the activities and students' conceptions, and in students' opportunities to practice using their language to explain activities and events. The primary differences I found were

(1) The relationship between students' activities and writing tasks, and their intial conceptions,

(2) the relationship between students' activities and writing tasks, and the goal conceptions for the lesson, and

(3) students' opportunities to use their new knowledge in new contexts, especially in the form of using their language to explain and predict events using their new scientific understanding.

In the Dissolving lesson cluster the activities and writing tasks were ***directly related*** to the information that students were to learn, and students' initial conceptions. The Pure Substances and Mixtures lesson contained some activities of this nature, but some important pieces were missing: In the Pure Substances and Mixtures lesson cluster, the ideas students were to learn by the posttest, the learning objectives, were that solids, liquids, and gases are matter, other things (e.g., heat, light) are not matter; and pure substances are made of one kind of substance, and mixtures are made of two or more kinds of substances. Students' initial conceptions for pure and mixtures ranged from pure being clean or clear, to pure being made of one kind of thing by itself. Their initial conceptions of mixture ranged from mixture being unclear or unclear, to made of many things mixed together. The following activities are those that ***directly related*** to students' initial concepitons and the learning goals:

(1) Activities: Identifying mixtures, matter; Separating mixtures;

(2) Writing:
·definitions and examples of pure
·identification of mixtures
·separating mixtures plans, and observations;

(3) Arguments/or cognitive conflict (for target students): Is air matter? Is it pure? (Melinda Day 3);

(4) Surprise: separating salt from water, Group 1 Day 5;

(5) Resolving discrepancies for air, separating salt and iron, and separating mud; and

(6) Opportunities to reuse new ideas for mixtures by separating mixtures.

Activities and writing tasks focused primarily on matter that was in mixture form, and separating mixtures, and not for students' initial conceptions or the goal conceptions of "pure" and "non-matter".

For the Dissolving lesson, the objectives for students' learning were goal conceptions 13, 14, 15, and 17: Molecules of a solute break away and mix with molecules of solvent; the only effect of heat on substances is to make its molecules move faster; increased motion moves molecules farther apart; and states of matter are due to different arrangements and motions of molecules, especially solids (sugar)---vibrate in rigid array---and liquids (water)---molecules take on random motion. Goal conceptions 14 and 17 had been taught in the States of Matter lesson cluster, as well. Students' initial conceptions about dissolving ranged from sugar disappearing in water to sugar being absorbed by the water or somehow becoming part of the water or going to the bottom of the cup. The following activities from the Dissolving lesson ***directly related*** to the students' initial conceptions about dissolving, and the lesson learning goals:

(1) Activities: Getting the Sugar out of the teabag, and careful observation; Dissolving Races, and Group Presentation of dissolving races explanations;

(2) Writing:
·plans for getting the sugar out of the teabag
·explaining what happened
·careful observation, explanation, substances and molecules
·plans and explanations for three dissolving races
·explanations for differences in dissolving races
·explanations for group presentation on overhead transparency
·freewrite about dissolving
·individual explanations for each dissolving race, analyzing the writing for all the parts of a good explanation;

(3) Arguments/or cognitive conflict (for target students): Group 2: Sugar dissolves and changes from solid to liquid?;

(4) Surprise: seeing sugar go into water, both Groups, Day 2;

(5) Resolving discrepancies for explaining, observing, dissolving process; and

(6) Opportunities to reuse new ideas about dissolving by planning and running dissolving races, and by individual practice in careful explanation of what students observed, and what happened to substance and molecules.

Activities and writing tasks for the Dissolving lesson focused on (1) what happened to sugar when it dissolved in water, (2) the substance behavior, (3) molecular behavior, and (4) how to explain the events in scientific language. Students were directly confronted with activities that encouraged new ways of thinking about dissolving and provided the scientific language to explain what they observed. This lesson cluster then provided students with opportunities to write and verbally use their new scientific words to predict and explain in new contexts. Most often students' reflecting and writing activities were focused on writing an explanation either for their plan or for what they had observed. Students had to think of their ideas about the dissolving process and put their words on paper so that they made sense and were accurate about the process. Their explanations needed to fit the three essential parts of a good explanation---a statement of the facts or observations and assumptions, a statement about what happened to the substances, and a statement about what happened to the molecules. Students' consistent writing about the three parts of a good explanation offered many opportunities for them to make sense of the new information about molecules and molecular behavior in dissolving. When later asked to explain dissolving, students were able to talk about it, because they had several opportunities to practice producing their thoughts in language, both written and verbal. These opportunities for students to practice expressing their own ideas in written and verbal form encouraged knowledge restructuring and conceptual change about dissolving. Writing down one's ideas, then reflecting on them to reproduce new writing, and talking about the ideas with other students appeared to be important mechanisms for students' radical knowledge restructuring.

The Social Context for Learning in The Classroom

For a better understanding of students' learning in this sixth grade classroom, here is a broad view of the social context in the whole class and the two small target groups. Students' understanding of subject matter develops within a social context that influences the meaning students build. The social perspective presented in this section follows Erickson's (1982) approach for studying learning from instruction from three angles within a "pedagogical encounter". The pedagogical encounter serves as a unit of analysis and contains three parts:

(1) The sequence of the interactions between teacher and students and their organization, notwithstanding the curriculum materials with which students interact;

(2) changes over time in the interactions and the organization of the interactions; and

(3) the meanings the teacher and students make of their learning interaction experiences.

Sequence of interactions. The underlying organization of the students' encounter, the curriculum organization, was described in Chapter 3 in the section titled The lessons and curriculum materials, page 87. Essentially, in each of the five lessons in the unit the teacher began with a story or anecdote, elicited students' alternate or real-world conceptions, presented scientific information, and provided opportunities for lecture, classroom discussion, writing and group work to clarify ideas, brought the disucssion to consensus, and provided practice using the new scientific ideas.

The interactions that occurred between the teacher and the students and their sequence were determined by the curriculum, but were influenced by the teacher's approach to presenting lessons. Most science lessons follow a sequence of activity structures (Lemke, 1990). An activity structure is a "sequence of predictable options for who will say or do what sort of thing next" (p. 49). Following Lemke's research into the dialogue structure in science classrooms, the researcher found many of the same events in the Matter and Molecules lessons. The more outstanding of these events is outlined here.

One of the more common activity structures that Lemke found was *triadic dialogue*, a three-part Question-Answer-Evaluation pattern that functions to engage students in dialogue. In triadic dialogue the teacher asks a question, a student answers, and the teacher evaluates and elaborates on the information. Triadic dialogue was evident throughout the Matter and Molecules learning encounters. For instance, the teacher conducted such a dialogue at points during six of the eight days of the Pure Substances and Mixtures lesson, and each of the eight days of the Dissolving lesson. The teacher used triadic dialogue for review of the scientific information, for beginning discussion of new topics, for going over student work, and for working step-by-step through problems.

Another common activity structure is ***teacher monologue/teacher narrative/review***, when teachers tell a story to create student interest, introduce a topic, or review information from previous lessons. The teacher in this study used the teacher monologue activity structure during each day of both the Pure Substances and Mixtures and Dissolving lesson clusters. She most often used monologue as a narrative to tell a story, or to review previous information. Sometimes she used the monologue to introduce new information.

Another common activity structure found in the Matter and Molecules unit of this study was ***external text dialogue***, which is a variation on triadic dialogue in which written text substitutes for the teacher's voice. The texts for the Matter and Molecules unit often presented information and asked students questions they were to think about, or to write answers for in their activity booklets, much like the Question-Answer-Evaluation/Elaboration sequence found in triadic dialogue.

Occasionally, during a lesson, the teacher engaged in ***teacher-student duolog*** with a student in an extended one-on-one exchange. In all cases, the teacher held the initiative much like she did in triadic dialogue. There was no right for students to question the teacher. The teacher most often used teacher-student duologues to make sure that a student understood and make a particular point with the class.

Due to the small group interactions, another activity structure was evident in this classroom, the ***cross-discussion.*** Cross-discussion is dialogue directly between students, in which the teacher plays only a moderating role or has an equal standing with the students. In the classroom in this study, the teacher always played a moderating role. Cross-discussion was evident every time students performed activities in small groups.

Other activity structures found by Lemke (1990) in science classrooms were rare in this sixth grade classroom: ***True dialogue***, a give and take between two participants was rare in the whole class lessons. True dialogue tends to occur in science classrooms only when the subject is not science. ***Teacher-student debate*** and ***student questioning dialogue*** were not evident. There were no instances where the teacher engaged in debate or argument with any of the students, and no instances where the students in the class carried on questioning of the teacher about the subject matter.

Changes over time. There were no major changes over time within the teacher's activity structures, or the curriculum structure. The first lesson cluster followed similar structure as the last lesson cluster. However, in the last two lesson clusters some new activity structures were added that Lemke did not address. Students had more opportunities to talk in groups in cross-dialogue---three times during the eight days for Pure Substances and Mixtures and six times during the eight days for Dissolving. Students also began using more writing as part of their dialogue in the last two lesson clusters. During the Pure Substances and Mixtures lesson, students wrote their definition of "pure" and gave an example, wrote plans for separating mixtures individually and in groups, and wrote some ideas about what they learned. In the Dissolving lesson, students made plans and explained in writing each time before entering into dialogue with their groups. Then groups constructed written plans and explanations as part of their activities. Written dialogue by individuals and groups might have added another dimension to the dialogue when it took place verbally. Lemke's research did not address activity structures that involved writing. There might have been something about the writing integrated into the activity structures during the later lessons that encouraged students' learning. I discussed the writing activities in a previous section, Writing, on page 239.

Small group interactions. Groups accomplished the following activities during the Pure Substances and Mixtures lesson cluster. The first activity was to identify substances contained in seven vials. All substances in the vials were mixtures, and all were forms of matter. The second activity involved choosing one or more of the mixtures in the vials and attempting to separate it using filter paper, a magnet, or tweezers.

During the Dissolving lesson cluster students had to make plans for getting sugar out of a teabag, try the plans, and make observations about what happened. In another activity, students made plans for dissolving races, a slow race, fast race, and a no-touch fast race. In other group activities students planned a group presentation, and discussed group explanations for what they observed during dissolving.

Before the unit began, the teacher spent a week instructing students in the social norms for working in groups (Anderson & Palinscar, 1990). The norms that students were expected to follow were that all members contribute ideas, they listen to one another's ideas, clarify and ask questions of one another to understand, and build on one another's ideas. Students were reminded of these norms periodically during the unit group work. During the Matter and Molecules unit group work, the two groups carried out their business in the following ways.

Group 1 consisted of Carol, Kenny, Antoine, and Doug. Throughout the Pure Substances and Mixtures lesson, which occurred immediately following instruction in the social norms, each student could be seen talking and contributing ideas to the group. No leader emerged at first, and the students followed the social group norms they had received during previous instruction. Toward the end of the Pure Substances and Mixtures lesson cluster, Doug began to emerge as the student who often had the "right" or "good" answers, and the other students began to listen to him particularly. At the end of the Pure Substances and Mixtures lesson, the students were all still talking and contributing their ideas, but now some roles were starting to emerge. Doug was seen by the others as often being "right" and Carol began pushing her ideas more. Kenny became more quiet, listening to what Carol and Doug said, but interjecting his ideas when he had them, or saw an opening. Kenny was one of the more shy students in the class. Antoine and Carol were both absent during one of the three group meetings in this lesson cluster.

Students learned the Dissolving lesson cluster four weeks after the Pure Substances and Mixtures lesson cluster. Students had been working in the same groups during this time to learn about molecules and states of matter. By the Dissolving lesson, clear roles emerged in Group 1. Students recognized that Doug usually "gets his way" (Kenny) because "mostly he's right" (Carol). Carol and Doug did most of the talking, but Kenny chimed in and sometimes challenged their ideas if he did not agree. Antoine had often been absent from the group, due to illness, truancy, and suspensions. He missed two of the six group sessions, and was unprepared to participate in one. Most of the time Antoine was off-task and tried to get the others to give him the answers. The students continued to contribute ideas, except for Antoine. Kenny began to take on daring assignments to establish a place for himself in the group. For example, during the "Getting the Sugar Out of the Teabag" activity, when someone needed to taste the water, Kenny volunteered, while Carol and Doug thought it was "gross". Often Doug and Carol ignored Kenny's statements. At one point near the end of the lesson, Doug and Carol acknowledged something Kenny said: Kenny said, "Water hit against the sugar and broke the sugar down", and Doug said, "Yes", Carol nodded "yes". Kenny excitedly said, "I was right!" Antoine had contributed so little that the group essentially ignored him toward the end of the lesson cluster. The group did not follow the social group norms of their instruction during three of the six group sessions, but during three of the sessions, all contributed ideas, listened, and built on one another's ideas.

Group 2 consisted of Melinda, Artie, Jose, and Norman. During the Pure Substances and Mixtures lesson cluster, the group functioned according to the social norms they had been taught. All contributed and each listened to the ideas of the others. No leader or other roles emerged until later in the lesson cluster when Artie began to move the group along by getting the others to vote on ideas, and pushing them to complete the tasks. Four weeks later during the Dissolving lesson cluster, each continued to talk equally and contribute ideas. Artie still pushed the group to accept his answers and complete the task. Sometimes the others followed and sometimes they did not. Often Artie and Norman sided together against Melinda and Jose in debates. Even though Artie pushed the group, Melinda and Norman were interested in getting their answers right. During arguments, all contributed and attempted to support their ideas. As the group worked during the Dissolving lesson, Artie continued to push the group to complete tasks and accept his answers, Melinda and Norman kept trying to get the right answers, and Jose contributed, even though the group did not often use his ideas. The members of Group 2 continued to use the social norms throughout the lesson cluster. These students took turns leading the discussion, or bringing the group back on task following a side discussion.

Meanings made by the teacher and students. The teacher believed it was important to acknowledge students' alternate conceptions, and engage them in dialogue to help them understand the new scientific ideas. She also believed it was important to provide students with the kinds of scientific verbal expressions that reflected their knowledge accurately. For instance, she thought it was important that students learn that when substances are heated, the molecules themselves do not get hot, but only begin to move faster. Consequently, she often said to the students, "Molecules don't change, only their behavior changes." She knew that students possessed little prior knowledge about matter and molecules, and had as her goal that all of the students would begin to understand the concepts even though they might not attain all of the goal conceptions for the lesson. The researcher did not formally request that the teacher provide information about the meanings she was making from the lesson as it progressed, and only informally debriefed her following the unit, since her interpretations of the teaching were not a focus of this study.

This study was concerned primarily with the meanings students made of the new science information. The researcher did not explicitly ask students about the meanings they made in the social context. There are some meanings implicit in their writing and verbal statements about the lesson information. Students thought they were supposed to come up with "right answers" in their activity booklets and on quizzes, even though the teacher accepted many ideas during discussions. From their previous schooling experience and the dialogic activity structures within the classroom, students got the idea that there was only one right way to talk about molecules and molecular behavior, and they attempted to reproduce that talk, even at the expense of their understanding. An example of this was Melinda's statement that the writing was difficult when she "couldn't think of the words". This was likely due to knowledge that producing the right words would get students a good grade regardless of whether they understood what they talked about. During the Dissolving and Thermal Expansion lesson clusters, students' statements containing the proper parts of a good explanation could get them a good grade. Students learned to write the three parts of a good explanation with some of their own interpretations of how to scientifically explain what they saw. As evident in the target students' interviews, students thought they had accomplished the learning necessary when they could complete the activities and write the right phrases in their activity booklets. For example, when asked if they were good at science, each target student said he or she was. They all explained that the writings were easier when they "knew the answer" or knew what to write.

<u>Summary</u>. The social context in the classroom of this study consisted of a curriculum organization in which lessons began with a story or anecdote,

then helped students realize their intial conceptions about the information to be learned. New information was presented and students then practiced using the new information in new contexts during discussion and activities. The social structure was also influenced by the activity structures in the teacher's dialogue. Most of her dialogues were either triadic dialogues, monologues, and external text dialogues. Occasionally she entered into teacher-student duolog to make a point or be sure a student understood. Cross-discussion between students occurred in small group discussions. There were no instances of true dialogue, teacher-student debate, or student questioning dialogue in this teacher's activity structures.

Over time, the activity structure added more opportunities for students to write before discussion in their groups, and more opportunities for students to enter into cross-dialogue in small groups. In small group interactions, one group established roles and became more effective at dealing with each others' ideas. The other group had difficulty continuing their use of the social norms, and established roles that allowed two students to monopolize the idea-giving and leadership.

Results Summary

This first part of this chapter presented the results from analyzing student writing about content and the evidence to answer the first research question. Students' conceptual structures pictured by the semantic node-link networks showed differences in student schema as a result of instruction along a continuum from weak to radical restructuring. When students showed a weaker form of restructuring in their conceptual frameworks, they were more likely to either possess more experience in a domain, or have had difficulty learning the content. When students showed a more radical form of restructuring in their conceptual frameworks, they were adding new concepts to their schema and using them to explain new phenomena; but they had not necessarily reached complete conceptual change to attain all of the scientific goal conceptions.

When students did attain all of the scientific goal conceptions for a lesson cluster, they usually had also radically restructured their knowledge, or, if they already possessed a well-developed schema for the concepts, they demonstrated a weaker form of restructuring. When students had radically restructured their knowledge, they also tended to use effective learning strategies (r = +.88). The difference between students who attained scientific goal conceptions and those who had difficulty seemed related not to the amount of restructuring a student accomplished (r = -.10), but more to the learning goals and strategies the student might have used (r = +.38). The researcher analyzed the lessons in relation to amount of students' restructuring, scientific goal conception attainment, and learning strategy use to get a better picture of what lessons might have been more supportive for students' knowledge restructuring. More that half of the students were able to attain most of the scientific goal conceptions for Introduction to Molecules, Dissolving, and Thermal Expansion lesson clusters. Less than half of the students attained the goal conceptions for the Pure Substances and Mixtures, and States of Matter lesson clusters. The lesson clusters in which students seemed to use more effective learning strategies, and that might have supported students' use of such strategies were the Dissolving, and Thermal Expansion lessons, in which only a third or less of the students had difficulty using effective learning strategies.

The last section of this chapter presented the evidence to answer the second research question. The differences between two lesson clusters were analyzed. The Dissolving lesson cluster for which more than half of the students attained at least 70% of the goal conceptions, and used effective learning strategies was compared with the Pure Substances and Mixtures lesson cluster, for which less than half of the students attained 70% of the goal conceptions, and less than half of the students used effective learning strategies. The lessons were similar in many aspects: The number of instructional days were similar in number. During both lessons students engaged in activities related to learning, and wrote their ideas about the new conceptions. Students conferred with peers about problems and their ideas in both lessons. The teacher led group discussions, provided opportunities for students to answer questions and have their questions answered. There were opportunities for argument within small group interactions in both lessons. The curriculum for both lessons provided practice with Socratic dialogue kinds of thinking--forming general rules, making predictions, and testing hypotheses. There were elements of surprise in both lessons. Students had opportunities for inactivity and reflection, mostly through their writing activities, in both lessons. The teacher emphasized the main points verbally, and provided closure and consensus about the main concepts students were to learn, in both lessons. Students practiced applying their new ideas in both lessons, and had limited opportunities to repeat reusing their ideas in new contexts. Much within the two lessons was similar. Where were the differences that showed up in students' uses of effective strategies and learning?

The differences between the two lessons were located within the following:

(1) The relationship between the activities and writing tasks, and students' initial concepts;

(2) the relationship between the activities and writing tasks, and the goal conceptions to be learned; and

(3) in the opportunities students had to reuse their new ideas verbally---written and spoken---in new contexts.

During the Pure Substances and Mixtures lesson cluster, the activities related to mixtures and separating mixtures, but there was little direct relationship to pure substances, and non-matter. There were few opportunities for students to reuse their new ideas in new contexts, or to explain verbally or in writing any scientific understandings of pure and mixtures. In the Dissolving lesson cluster, the activities and writing tasks related directly to students' initial conceptions, their real-world ideas about dissolving, and directly to the goal conceptions that students were expected to learn. In the Dissolving lesson, students were provided repeated opportunities to explain their ideas about dissolving in scientifically structured explanations, both verbally within their small groups, and class discussions, and in writing. Students had another opportunity ***directly related*** to concepts when they used their ideas and observations to explain the dissolving process and reused their ideas to plan and observe the Dissolving Races and explain those events. More students were successful using a conceptual change strategy for learning for this lesson cluster because they were guided and coached to use such a strategy as they learned. Recall that when a student uses a conceptual change learning strategy she abandons alternative or conflicting ideas and integrates new knowledge into her schema. The student begins to use her new knowledge to explain real-world phenomena. During the Dissolving lesson cluster, the teacher provided students with language and explanation strategies to use when scientifically explaining dissolving phenomena. Students were asked to explain scientific phenomena by talking first about facts or observations, then making statements about the substances, and statements about the molecules. Students practiced using their new language about dissolving and the explanation strategies over and over again in new contexts. They used their language to make plans for dissolving sugar and explain what they observed. Students used their language to make plans for dissolving races and explain what they observed. Students used their language to present their observations to the class. They practiced writing good explanations and shared them with the members of their group. At the end of the lesson, most students had retained an ability to use scientific language to explain dissolving.

In the next chapter, Chapter 5, I discuss the findings presented here and draw conclusions to answer the research questions. I extend the discussion to implications for further research and classroom teaching.

Chapter 5

DISCUSSION AND CONCLUSIONS

Overview

The context: Teaching and learning in science. The subject of this study was students' science learning. I chose this subject as a result of my experience as a teacher, and what I learned from other teachers and researchers: Students often have difficulty learning new science concepts (Anderson & Roth, 1988; Anderson & Smith, 1983; Carey, 1986; Glaser, 1982; Posner, Strike, Hewson, & Gertzog, 1982). When students learn new concepts, they either fit the new knowledge within their existing knowledge structures, or they need to modify their prior knowledge to fit the new information (Bransford, 1979; Rumelhart & Norman, 1981). Researchers report that the kind of learning that requires learners to modify their existing knowledge to fit with new information is difficult, and students often do not make the shift as a result of instruction (Carey, 1986; Driver & Easley, 1978; Roth, 1989; Smith & Lott, 1983). It is important that science students learn science as a meaningful system of useful concepts, rather than a memorized list of unrelated facts, but in order for students to accomplish this, they need to change their existing real-world alternative conceptions about phenomena to a more scientific outlook. This change often requires radical knowledge restructuring, and conceptual change, and may require that students abandon their alternative conceptions, and take up new theories about how the world works.

The problem: Uncovering the mechanisms associated with knowledge restructuring. Because conceptual change in science seems difficult for students to accomplish, students' learning processes deserve close observation to understand and assist the necessary changes students need to make. With this study, the researcher sought to learn more about the usefulness of students' writing to inform teachers and researchers about students' understandings. And the researcher also attempted to observe the instruction for events that might be associated with effective knowledge restructuring and understand the strategies that successful and unsuccessful students demonstrate when they attempt to learn about matter and molecules.

Learners' knowledge structures are difficult to study because we are unable to "see" those structures. Knowledge as a structure is a useful metaphor for understanding how knowledge might be stored and processed and how individuals accumulate and use new knowledge, but viewing those structures has always been a matter of inference based on what individuals say about content, and what they say aloud when solving problems.

A solution: Describing restructuring changes and uncovering the mechanisms through student writing. In this study the researcher used learners' writing about content to make inferences about their knowledge structures. During science instruction, when the writing task is not difficult, students write about what they understand and explain relationships among concepts. Students' writing might provide a "window" into their thinking. The researcher studied the ideas students wrote before, during, and after instruction to observe what might be the structure of their knowledge, and attempted to answer the following questions:

(1) Do students show in their writing that they are restructuring their science knowledge, and how much restructuring seems to occur for students during a typical lesson unit?

(2) What mechanisms from classroom events seem to be associated with science knowledge restructuring, and what seems to make the difference for students who restructure their science knowledge and those students who have difficulty?

In this study I observed sixth grade students as they attempted to learn about the nature of matter and physical change during a twelve-week lesson unit. The students were heterogeneous for ability and ethnicity, and came from an urban middle school within a low to middle socioeconomic neighborhood. This study used students' writing to make inferences about their knowledge restructuring changes over the course of a learning unit, Based on the knowledge changes observed, the classroom events that occurred in conjunction with the knowledge changes were analuzed to understand how the classroom events might have influenced students' knowledge restructuring and conceptual change.

<u>The methods: Looking for knowledge restructuring and its mechanisms</u>. The purpose of this study was to analyze students' writing in science as a representation of their knowledge structures. The researcher asked: Would the writing that occurs within ordinary classroom lessons reveal students' understanding and misunderstanding of science concepts? Once the researcher found that writing revealed students understanding, she looked for classroom events that might be associated with knowledge restructuring and content understanding. During the instruction about matter and molecules in this study, students wrote about their ideas. They wrote about concepts, their plans for activities, and explanations of real-world phenomena in scientific terms. This writing was analyzed to answer the research questions. The following data was collected: Student writing, clinical interviews before and

after instruction with six target students, interviews with the same six target students about their perceptions of writing, videotapes of the classroom lessons and two target small group interactions, teacher interview, and all of the text materials.

To answer the question about whether students show in their writing that they are restructuring their knowledge, it was important for the analyses to assure that what students wrote was close to what they were thinking. Target students' writing on their pretest and posttest was compared with the verbal statements they made during their clinical interviews. The researcher's reasoning was that If the ideas students expressed in the pretest and posttest, and clinical interviews, were similar, what they wrote might have been a close approximation to what students thought about the concepts. These same six students were interviewed about their perceptions of the writing tasks to see if they perceived any difficulty with the tasks, or writing their ideas. If students expressed that the writing tasks were relatively easy, and they could write their ideas without hindrance from the writing task, what students wrote about a concept might have been a close representation of their thinking.

Students' written statements were transcribed into a spreadsheet program, and files created for each student's ideas about matter and molecules. Semantic node-link networks were constructed for students' statements about similar concepts across time from pretest to posttest. Students' semantic node-link networks were compared, looking for changes in number of core concepts, differences in core concepts, organization, and principles. Once I understood the relationship between what students wrote and what students said verbally, and that the writing tasks were not perceived by the students to be difficult, I used the semantic node-link networks to determine how much restructuring the students might have accomplished, focusing on whether they attained the scientific goal conceptions for the unit. Judgments were made about the learning goals and strategies students might have used based on their writing across the unit. Evidence of knowledge restructuring, goal conception attainment, and learning goals and strategies showed which lesson clusters within the unit were more supportive for students' learning, and which lesson clusters were less supportive. The researcher studied the differences in two lesson clusters to better understand what classroom events might have served as knowledge restructuring mechanisms and seemed associated with knowledge changes.

Summary of the Findings of the Study

What I Found: Results for Question 1

The first research question asked whether students show in their writing if they are restructuring their knowledge. If so, how much restructuring seems to occur during a lesson unit? Each student showed some form of knowledge restructuring in their writing across the lesson clusters, along a continuum from weak to more radical forms of restructuring. When students showed weak restructuring, they were likely to either have prior experience in the domain, or to have had difficulty learning the content. When students showed radical restructuring in their conceptual frameworks, they added new concepts to their schema. However, just because students radically restructured their schema did not mean that they had attained all of the scientific goal conceptions for the lesson. Students' conceptual change was often not complete for all the conceptions, but when students' schema showed radical restructuring, they understood at least one goal conception from the instruction. When students understood all of the scientific goal conceptions for a lesson cluster, they had also radically restructured their knowledge, unless they possessed prior knowledge schema for the concepts before instruction.

What I Found: Results for Question 2

The difference between the students who were able to attain the scientific goal conceptions, and those who had difficulty seemed related not as much to the amount of restructuring a student accomplished, as it was to students' prior knowledge, and/or students' use of effective learning strategies. More than half of the twenty-five students were successful in learning more than 70% of the goal conceptions on three lesson clusters: Introduction to Molecules, Dissolving, and Thermal Expansion. More than half of the twenty-five students used effective learning goals and strategies for two lessons: Dissolving and Thermal Expansion. More than half of the twenty-five students used less effective learning goals and strategies on the Pure Substances and Mixtures, Introduction to Molecules, and States of Matter lesson clusters, and attained less than 70% of the goal conceptions for Pure Substances and Mixtures, and States of Matter.

Two lesson clusters that seemed different in their support of students' learning were identified for further analysis: The Pure Substances and Mixtures lesson cluster, for which fewer than half the students attained 70% goal conceptions, and used less than effective strategies; and the Dissolving lesson cluster, for which more than half of the students attained the goal conceptions, and most students (all but eight) used effective learning strategies. For each lesson, all of the classroom events that might have influenced knowledge restructuring were compared.

The lessons for Pure Substances and Mixtures, and Dissolving, were similar in many aspects. They both contained the same number of instructional days. Students engaged in activities during both lesson clusters. Students wrote about their ideas and used their new conceptions in both. In both lesson sets, students conferred with peers in small groups and had opportunities to check out discrepancies in thinking, arguing, and talking about their ideas. The teacher lead group discussions in both lesson sets to provide opportunities for students to engage in open-ended verbal interactions expressing alternative conceptions and resolving discrepancies to reach closure and consensus. The curriculum for both lessons provided practice with Socratic dialogue forms of thinking, such as forming general rules, making predictions, and testing hypotheses. Students had opportunities for quiet reflection in both lessons, primarily through their individual writing tasks. The teacher emphasized main points verbally in both lessons, and students practiced applying their new ideas in both.

The differences between the two lesson clusters involved the relationships between

(1) students' activities and writing tasks, and their initial conceptions,

(2) students' activities and writing tasks, and the goal conceptions to be learned,

(3) students' opportunities to reuse their new knowledge in new contexts, and

(4) students' opportunities to explain, verbally or in writing, their scientific understanding of new concepts.

In the Pure Substances and Mixtures lesson cluster, the less effective of the two clusters, students' activities related only partially to students' initial conceptions and the goal conceptions. Students' initial conceptions about pure ranged from pure being clean or clear, to pure being made of one kind of thing by itself. Students' initial conceptions of mixtures ranged from mixtures being unclear or unclean to made of many things mixed together. The scientific goal conceptions that students were to learn were:

(1) Matter is solid, liquid or gas, and non-matter is not solid, liquid or gas; and

(2) pure is made of one kind of substance, and mixtures are made of more than one kind of substance.

An activity that related to both students' initial conceptions and the goal conceptions, for instance, would have students experience pure substances that were not clear, and explanations for why pure substances were considered pure instead of mixtures. Students would have experience with clear mixtures that were made with more than one substance. Students would have direct experiences with different kinds of non-matter, and have opportunities to explain their new scientific understanding in speaking and writing. In the Pure Substances and Mixtures lesson cluster, students' had experiences with matter, and mixtures---talking about mixtures, investigating, separating mixtures, and explaining what they did and what happened. But they had no direct experiences in classroom activities, writing, or explaining, with "pure" or "non-matter" except through the teacher's verbal definitions during class discussions.

In the Dissolving lesson cluster, in contrast, students' activities related ***directly*** to their initial alternative or real-world conceptions about dissolving, and the conceptions were ***directly*** linked to the goal conceptions that students were expected to learn. Students' initial conceptions about dissolving ranged from sugar disappearing in the water, to sugar being absorbed by the water or somehow becoming part of the water, or to sugar going to the bottom of the glass. The goal conceptions for students' learning were:

(1) Sugar breaks down into molecules and mixes with the water molecules;

(2) the effect of heat is to make molecules of the water move faster;

(3) increased motion moves molecules farther apart; and

(4) the different state of sugar is due the arrangement and motion of the molecules, especially that in solids, like sugar, molecules are arranged in a rigid pattern, and vibrate in place, and in liquids, like water, the molecules move randomly.

In the Dissolving lesson, students observed sugar going into water. The teacher explained how the solid, sugar, broke down into sugar molecules, which mixed with the water molecules. This observation related directly to students' initial conceptions because they could observe the sugar going into the water. The observation related directly to the goal conceptions because the instruction provided students with scientific words to describe their observations. Students were provided with repeated opportunities to explain their ideas about dissolving in scientifically structured explanations, both verbally within their small groups and in writing. Students had other opportunities to reuse their new ideas when they planned, observed, and explained the Dissolving Races.

Not only were the activities different for the two lessons, but the writing and speaking that students did was also different. During the Pure Substances and Mixtures lesson cluster students wrote definitions of "pure" with examples. They shared this writing only briefly in whole class discussion. They wrote their ideas about identification of substances in seven vials as matter/non-matter and pure/mixture. They shared these written ideas with their small groups and came to a consensus within the group about each substance they classified. Students wrote plans for separating one or more of the mixtures, shared their plans in small groups, then wrote about how the plan worked. Their last writing was to list some of the ideas they had learned about pure and mixtures. Students did little writing to explain their ideas about pure/mixtures or matter/non-matter. They had few opportunities to engage in cross-dialogue to explain the concepts.

The writing for Dissolving was of a different sort. Most of the writing for the Dissolving lesson cluster involved writing and talking about explanations for what they planned or observed when sugar was placed in water. They were taught to specifically write plans or explanations that included a statement of the facts or assumptions, a statement about the substances, and a statement about the molecules. Students wrote such explanations several times during the lesson: They wrote complete explanations individually to support their plan for getting the sugar out of the teabag. They wrote a group explanation to support the group's plan for getting the sugar out of the teabag. They wrote an individual explanation of what they observed when they put the teabag into water, and they wrote a group consensus explanation for what they observed. When students made plans for the dissolving races, they practiced writing complete explanations for each race plan, then shared their plans with the group. Each group reached a consensus on the plans for the races, and wrote a group complete explanation to support their plans. Following the races, each individual again wrote complete explanations to support what they observed during the races. The groups each composed a group explanation for one of the races that was placed on an overhead and presented to the class. Students practiced writing complete explanations for what they observed in each race, with colored pencils to mark each part of the explanation, to check if they had included the essential pieces. Students practiced writing complete explanations each day of the Dissolving lesson cluster.

When students took their individual writing into the group to reach a consensus for a group explanation, they had a chance to check their ideas with one another, and hear themselves say the words. They heard others use similar words to make new explanations, and considered the correctness of the expressions to fit a complete scientific explanation. Students used *cross-dialogue* to practice verbalizing what happens during dissolving to the substances sugar and water, and the molecules. They practiced using one another's words to construct a group explanation, and wrote the explanation in their activity booklets. Students reflected on their language as they wrote to explain dissolving, then used their language in group cross-dialogue. The students used their verbal explanations to construct new written explanations that each could use to construct his or her own new verbalizations about dissolving. Consequently, at the posttest, more than 60% of the students had attained most of the goal conceptions---students had learned how to explain molecular behavior during dissolving. And more than 70% of the students were encouraged to use effective learning strategies---the instruction guided students in using their new knowledge to explain real-world phenomena.

It seemed likely that the differences in students' learning was due to their engagement in activities related to their initial conceptions and what they were to learn, and related to their opportunities to verbalize their ideas in writing and oral speech. Engaging in closely related activities, writing and reflecting on ideas, and opportunities to verbalize ideas may be important mechanisms associated with knowledge restructuring.

Qualifications of the results. There are other reasons that should be mentioned, as well, for why students might have done better on the Dissolving lesson. First, the Pure Substances and Mixtures and Dissolving lessons contained different subject matter. Understanding what is pure and what is mixture are abstract terms, especially when there are few concrete ways for students to tell if a substance contains one or more substances or kinds of molecules. It was difficult to provide concrete experiences for non-matter, for instance, because non-matter such as heat and light are not tangible. The abstract nature of the pure and mixtures subject matter may have been more difficult for students to understand. Dissolving, on the other hand, at least at the macroscopic level, was tangible and concrete. Students could see the results of the sugar grains breaking down into molecules and spreading out in the water.

Second, the Pure Substances and Mixtures lesson cluster was the first lesson in the unit, whereas the Dissolving cluster came later in the unit, following students' experiences with Introduction to Molecules and States of Matter. It could have been that students had learned how to learn the Matter and Molecules subject matter, and began to be more successful with it. They had more experience writing about their ideas, and more experience talking with their group members. They may have become "wiser" about how to make sense of molecular behavior. This argument is not as strong as the first qualification for subject matter differences, however. The subject matter of pure and mixtures did not require that students master knowledge of molecules. There was evidence that one of the groups interacted better during the pure and mixtures lessons than they did during dissolving, and students still did not understand pure and mixtures ideas more than they understood dissolving ideas as a result of group cross-dialogue. There may be some credence to students' increased ability to learn the subject matter in time over the unit. But regardless of the effect of subject matter and lesson timing on the results, students' increased opportunities to confront their alternative conceptions and use new ideas in writing and speaking scientific explanations were present in the Dissolving lesson and not present in the Pure Substances and Mixtures lesson. Students written answers on the posttest reflected their written and verbal explanations from class lessons, leading this researcher to believe that classroom opportunities for using language in writing verbalization were influential for students' learning.

Limitations of the results. How should we view these results in light of the many limitations of the methods? In Chapter 2 the limitations to this study were discussed. This section returns to them now to qualify the results and the conclusions drawn from the results. One limitation of the way students' knowledge restructuring was studied was the use of students' writing to represent students' thinking. Even though their writing was compared with their verbal statements, and care was taken to assure that the writing tasks did not interfere with students' ability to write their ideas, the fact remains that some students may not express their ideas very well in writing. Thus, using such writing to make inferences about students' thinking may have missed important ideas that students did not mention when they wrote. I attempted to modify this limitation by comparing what six target students said about the same concepts they wrote, to be more confident that their written ideas were similar to their verbal expressions. But this difference was checked for only six students. For the other twenty-one students whose writing was analyzed, there were no verbal statements with which to verify the interpretations, and so many of the interpretations could be off the mark. If we assume that is the case, and the interpretations are sometimes incorrect about students' thinking, some students may have accomplished more radical restructuring than I gave them credit for. It could mean that some students reached goal conceptions that they were not given credit for, or that they used strategies that were more or less effective than presumed. If this is the case, the methods of looking across students for patterns might still have yielded similar results. But we should not base future judgments about students' knowledge restructuring and instruction on this study and interpretations alone. It is important to remember that this study found that student writing can provide teachers with a "window" into students' thinking, but that is qualified by the difficulty of the writing task, whether the task interferes with students' idea generation, and whether students are able to express their ideas in writing. Teachers or researchers who decide to use student writing to understand knowledge changes will need to support their methods with other means of determining student thinking, to verify their results. And because learning is recursive and dynamic, I may have tapped student thinking at a time when a student was reconsidering old ideas in light of new, and so his or her thinking did not reflect full understanding of the concepts. Anytime writing will be used to understand students' thinking, it should be verified with spot checks of other kinds, such as verbal statements, observations, and listening to students' explanations, or using more writing about similar concepts.

The semantic node-link network method used to picture student conceptions has limitations in the number of concepts that could be followed. Due to the structure of the curriculum, text, and pretest and posttest, students' writing followed that structure and limited conceptions were asked for by the teacher and the curriculum. Students may have known more about matter and molecules than we were able to ask, and more than was followed with the limited writing that students accomplished within the constraints of completing lessons and curriculum. Students may have recognized and identified concepts that demonstrated their understanding about matter and molecules, but did not mention the concepts when they wrote or spoke about them. This limitation was modified for the target students, because I was able to interview them individually, and probe their understanding of the concepts. But for the other twenty-one students, I may have missed some understandings because of the structure of the posttest, and the questions we asked. Students may have understood things we did not ask, that would show better understanding of the concepts. This limitation is modified to a degree because the pretest/posttest has been used in prior studies, reviewed, and modified to improve reliability for relating students' understanding of matter and molecules. The tests seem to reliably measure students' understandings of the goal conceptions, as long as students are able to write their ideas, and understand the directions for the test.

Interpretations of the restructuring evidenced in students' writing is another limitation of the methods and these results. Interpretations were based on this researcher's prior knowledge and experience with learners, so the interpretations are biased to the degree that her beliefs about how students learn influenced the interpretations. This limitation was modified by providing as much information as possible given the constraint of these pages, to show what was done, and how the students' writing was interpreted, so that others can revisit the data, and attempt similar analyses to see if their interpretations are similar or different. The interpretations were checked with two other researchers in matter and molecules and children's learning to see if the interpretations were similar to theirs, and thus more reliable. Even with these checks on the interpretations and biases, the interpretations remain a limitation of this study, and the results should be considered in light of this.

Only a narrow cross-section of students was observed in this study, with limited access to their thinking processes, limited by students' ability to write their ideas, and my ability to interpret students' writing. It almost sounds as if we cannot warrant anything that arose from this study, given the limitations. On the contrary, the results of this study now become part of a growing body of knowledge that describes the learning processes that sixth grade students go through when learning about matter and molecules, and the kind of instruction that seems to support their learning. As teachers and researchers, we cannot take the results of one study, and make them law, but we combine and compare the results with the results of many other similar studies to get a composite picture of what the learning processes look like, and what good, supportive instruction looks like in the nature of matter and physical change.

CONCLUSIONS

Based on the findings, and what was learned from this study, the following conclusions were drawn. With regard to the first question, whether students show in their writing that they are restructuring their knowledge, my conclusion is a resounding "yes". When students reported verbally similar conceptions that they identified in their writing, students' writing was a close representation of their thinking. And when they reported that the writing tasks were relatively easy, except when they had trouble thinking of ideas to write, what students wrote might represent what they were thinking. This was also confirmed by students' statements about their writing, such as "I just put down my ideas", and "I knew everything I was going to write". When a student had difficulty with the writing, he or she often stated that the reason was due to difficulty with the concepts. For example, Artie said that one of the writing tasks was more difficult because, "I didn't understand these very well so I couldn't figure out what we were supposed to. . [write]". And Jose said that one of the writing tasks was difficult for him, because "some of it I knew, and some of it I didn't. . . the parts that I didn't understand some of the meanings. . . matter, I didn't understand too good". The writing tasks seemed to be easy and straight-forward enough that students could grapple with finding the right ideas and words, without worrying about how to write them down correctly for the task. Thus, it was likely that they placed their thinking on the page in their words. And their words showed that over time, as a result of instruction, students were restructuring their knowledge. I found no disconfirming evidence in students' writing to show that there was no change in students' knowledge structures.

Students who demonstrated a weaker form of restructuring did so because they already possessed well-developed schema and prior experience in the domain, or because they had difficulty learning the information. All students who showed a more radical form of restructuring understood at least one goal conception for a lesson cluster. Of the students who understood all of the scientific goal conceptions, most either possessed some prior knowledge and showed weak restructuring forms, or radically restructured their knowledge.

Whether students showed a more weak or radical form of restructuring may not be important in light of whether they attained the goals for their learning. As a teacher this researcher is also interested in whether student writing can show their thinking about the goal conceptions. The evidence in this study showed that student writing about their science concept ideas can provide teachers with a "window" into students' thinking, their understanding, and their misunderstanding. We may need to keep the writing task structure at a fairly simple and easy-to-accomplish level to be sure we get a good picture of students' understandings, as Ammon and Ammon (1987) suggested. This researcher did not address the question of whether more difficult writing tasks might interfere with students' writing about their ideas as Ammon and Ammon did. The researcher was more interested in keeping the writing tasks simple, so students approximated their thinking in their writing, to see if student writing provided clues about students' knowledge restructuring and the mechanisms associated.

The findings of this study point to an important phenomenon about learning. The students in this study were all in the process of restructuring their knowledge to some degree as a result of instruction. Encountering the text, listening to the teacher, trying out activities, and talking with peers engaged students' thinking processes to the extent that all of them were processing information and apparently attempting to make sense of the new information.

The literature review showed that conceptual change knowledge restructuring is often difficult for students to accomplish (Carey, 1986; Driver &

Easley, 1978; Roth, Smith, & Anderson, 1983; Smith & Lott, 1983; West & Pines, 1985), and some researchers have suggested that conceptual change knowledge restructuring is a developmental process that takes a long time in some domains, even under conditions of good instruction (Nussbaum & Novick, 1982). The restructuring changes that the students in this study demonstrated supported these contentions. As a result of twelve weeks of good instruction, students, on the average, attained only half of the goal conceptions, unless they already possessed some prior knowledge, and then they attained more. Students who had little prior knowledge about matter and molecules began radically restructuring their knowledge, but attained only some of the goal conceptions. This may be because students were still in the process of understanding the new conceptions about how the world works. We may need to be more patient with students' difficult restructuring changes, and either take time to provide them with more rich experiences, or settle for fewer goals attained in a lesson unit of twelve weeks duration.

The second research question asked if students show in their writing that they are restructuring their knowledge, what mechanisms from classroom events seemed to be associated with that knowledge restructuring, and what seemed to make the difference for students who restructure their knowledge and those who have difficulty? The answer to this question is more complex. Some of the students seemed to attempt to make sense more than others, and this could be one mitigating factor for whether students were successful in their learning. For those students who appeared to use unsuccessful learning strategies, four students used them consistently across the lesson clusters. Other students occasionally used unsuccessful strategies, but seemed to employ more effective strategies as the lesson unit progressed, with the exception of one student who appeared to use less effective strategies as the lesson progressed. Most students tended to use more effective learning strategies as the lesson unit progressed. This could have been due to students becoming "wiser" about how to learn the matter and molecules information. Students' improved strategies might also be attributed to the curriculum design that guided their use of more effective strategies in the later lessons. Students' who used effective strategies were more likely to have attained most of the goal conceptions ($r = +.38$). Students' use of an effective strategy seemed to be a mitigating factor in students' ability to learn new information, and may tend to offset the mechanisms influencing knowledge restructuring in the classroom events.

The curriculum for the two later lessons, Dissolving, and Thermal Expansion, seemed to support the use conceptual change learning goals and strategies. The definition of a conceptual change learning strategy is that students <u>use</u> their new ideas to <u>explain</u> and <u>predict</u> real-world events. The instruction for Dissolving and Thermal Expansion taught the students <u>how</u> to <u>use</u> the language of science to <u>explain</u> what happened to the substances and the molecules during real-world events such as sugar dissolving, metal expanding, and heated air expanding to fill a balloon. The instruction taught students <u>how to use</u> the scientific ideas and words to make sense of real-world events, and guided them through the process of applying that experience of making sense. These last two lesson clusters seemed to guide students in the use of a conceptual change strategy.

When this study began, I believed that students needed concrete activities to experience and make sense of science concepts. And I believed that the teacher's talk--how she explained concepts, drew conclusions, and put correct scientific words on students' experiences for them---was an important part of the instruction to encourage knowledge restructuring. So I expected that I might find these two events---concrete activities and teacher talk---influencing knowledge restructuring. And they may have. It is difficult for me to assert from the results that they did not influence knowledge restructuring, or that they did influence it either. There were opportunities in both lesson clusters for students to have concrete experiences. And the teacher's talk provided closure, consensus, and gave the students words they could put on their experiences to explain events. The results are the same for the other classroom events that I supposed might influence knowledge restructuring. Most of these elements were present to some degree in both lessons, so it was difficult to tease out any differences here and say one way or another that any distinct features of the classroom dialogue had an effect or non-effect on learning. It is likely they did effect learning, but I could not locate any specific evidence for one kind of classroom dialogue being any more closely associated with knowledge restructuring than any of the others, except for students' ***cross-dialogue***. Students had twice as many opportunities for cross-dialogue activity structure in the Dissolving lesson cluster.

Here was the surprise: The differences between the two lessons were so minute, that an important piece of instruction that might be associated with knowledge restructuring was made evident. These findings were based on the evidence that all other classroom events being similar, the activities and writing tasks were different in the Dissolving lesson cluster---students had more opportunities for explaining, writing, and cross-dialogue. These differences might have contributed to better learning. Students might have needed concrete experiences with the new ideas, and teacher's talk to help them put words with those experience, but the experiences might have needed to be ***directly related*** to students' initial conceptions about the concepts, <u>and</u> ***directly related*** to the goal conceptions the students needed to learn. And beyond that, students might have needed opportunities to <u>practice</u> the words that their teacher (or the scientific community) had placed on their experiences. It did not seem to be enough that the teacher said it: The students may also have needed to say it, and practice explaining their new ideas in new contexts with new problems.

This study showed that students who restructured their knowledge and understood the goal conceptions were more likely to have used an effective learning strategy. <u>In addition</u> to classroom dialogue events, students might have needed to be <u>engaged</u> and persuaded to use effective learning strategies. Instruction that seemed to encourage that engagement and productive thinking involves students in activities that were ***directly related*** to their initial conceptions and the goal conceptions of the lesson, and provided them with the words to <u>explain</u> and <u>practice</u> applying and explaining. Students were better able to explain and make meaningful use of their knowledge of dissolving than they were their knowledge about pure and mixtures.

CONTRIBUTIONS OF THE STUDY

This study contributes to the body of conceptual change literature by supporting those studies that have shown that conceptual change learning is difficult for students to accomplish, even under conditions of good instruction. The results support the studies that have suggested that conceptual change is a developmental process that takes time. This research also supports what Lee, Eichinger, Anderson, and Blakeslee (1990) found with regard to students' initial conceptions about matter and molecules, and students resultant learning after the Matter and Molecules unit. The students in this study had similar conceptions before and after instruction as those in Lee and her colleagues' studies.

The study also supports and contributes to the conceptual change literature by demonstrating that semantic node-link networks are useful for studying an individual's conceptual understanding and schema changes. Semantic node-link networks had previously been used only for subjects' verbal statements. This study showed that semantic node-link networks might also be useful for studying subjects' written statements.

There is support from this study for the conceptual change teaching studies that showed the need to confront students' alternative or real-world conceptions and engage students in activities related to those conceptions and the goal conceptions (Roth, Anderson and Smith, 1986; Minstrell, 1984). There is also support for the writing studies that showed that students' understanding of content can interfere with their ability to write their ideas (Ammon & Ammon, 1987). For example, students in this study reported that when they were unsure of the content they had difficulty writing about it. Furthermore, the results support studies that have shown that writing about content helps students learn (Langer & Applebee, 1987). In this study, increased writing was used to explain that what students accomplished during one lesson cluster appeared to influence their ability to remember how to explain the concepts.

This study contributes to the current body of science learning research by showing that students' language experiences might be an important part of their conceptual change. Language experiences provide students with the scientific words to explain their observations and language experiences the practice for applying the words to explain in writing and verbal interaction with peers.

IMPLICATIONS FOR RESEARCH

One of the purposes of this study was to find the mechanisms that could be associated with knowledge restructuring. As defined in Chapter 1 and 2, the mechanisms for knowledge restructuring are those external events that occur in an individual's experience that triggers some internal change in their thinking. Even though I was able to find certain kinds of classroom activities that helped students engage in more effective science learning, such as the activities directly related to the goal conceptions, it is still difficult to pinpoint directly the mechanisms of knowledge restructuring as a result of this study. Future studies of knowledge restructuring mechanisms might be more fruitful if students were followed in case study-like analyses, using their writing and verbal statements to understand their thinking processes, at a very close level during an instructional unit—talking to them before a lesson, directly after a lesson, letting them study and write, and debriefing them again about their thinking before the next lesson, and so on.

Future research needs to observe instruction that engages students' initial conceptions and the goal conceptions in concrete activities directly related to those ideas. This research should observe students using words to explain and practice explaining their experiences to provide more support for these techniques as effective pieces of instruction. A modified version of the Pure Substances and Mixtures lesson cluster could be tested against the current version. The modified version would have new activities, or parts of activities that helps students address their conceptions of "pure" and "non-matter", and provides them with the definitions in scientific terms to apply and explain in new contexts. This might confirm that the addition of directly related concrete activities, and the language to talk about them, is more effective for supporting students' learning.

It might be interesting to observe learning that results from the Dissolving lesson with more opportunities for students to apply their ideas and scientific explanations in new contexts with solutions other than sugar and water.

Further research using writing to understand students' thinking processes should be undertaken to further tease out the conditions under which student writing is a valid indicator of students' thinking, and when it is not. We already know that the difficulty of the content, and the difficulty of the writing task, can interfere with students' abilities to write their ideas. What other variables do we need to be aware of when we use student writing as an indicator of student progress? And how can teachers tell if students are able to express their ideas in writing and when they cannot? What other means are available to teachers to understand students' conceptions?

How much can writing in science help students make sense of the information? In this study students wrote their ideas about explanations for scientific phenomena, wrote plans and answered questions about the new information. Some teachers are now having students write about their science ideas in dialogue journals, in which the teacher responds to students' thoughts (Roth & Rosaen, 1990; Staton, 1982, 1988). Teachers are also beginning to provide opportunities for students to cross-dialogue in groups about their learning. Research that observes students' attempts to make sense of new science information through writing and other forms of language in the classroom might help support the importance for students' use of language in various forms as they learn to use new scientific information and make it their own.

Research that continues to follow students longitudinally across their knowledge development about matter and molecules in science through middle school, high school and college would be interesting and might shed more light on how important students' experience with the subject matter is during their sixth grade science lessons.

IMPLICATIONS FOR TEACHING AND TEACHER EDUCATION

Teaching. There are several ideas for teaching that arise from the results of this study. First are the implications that writing has for student learning, second the implications for teacher assessment of student learning in the science classroom, and third, the implications for ways to provide students with opportunities to express their new ideas and reuse them in new contexts.

This study showed that teachers can find out what students might be thinking about a concept by having students write about the concept. Some of the effective activities of the Dissolving lesson were activities where students practiced writing good scientific explanations, and reflecting on what they wrote to observe how well they had done, learning to self-evaluate and self-regulate their learning. Below are suggestions of ways teachers might use writing in science classes to support students' conceptual change learning:

(1) Teachers can use student writing to assess students' real-world and alternative conceptions about the science topic before instruction begins. This can help the teacher plan instruction that will directly relate to students' understandings, and the goals for their learning. Journal writing or learning

logs might provide an arena for student-teacher written dialogue about alternative conceptions. This writing can also inform the teacher of the various initial conceptions that students might have.

(2) Once teachers have outlined the goal conceptions for students' learning, they can have students periodically write about the concepts in new and novel situations, to see how the students are making sense of the new information as it relates to their real-world conceptions, and see if they are using scientific language for their explanations. This is another place where students' writing in journals could be used to help students write and talk about their new ideas. Using this writing, the teacher can get a picture of student thinking and the effectiveness of her lessons over time.

(3) Teachers can use writing for students to practice using their new ideas to explain and predict real-world phenomena. This writing can then be used for students to make presentations to the class, or to their small groups, allowing them one more avenue for rehearsal and practice of their new ideas.

(4) Teachers can use student writing for establishing consensus and closure, by having students write what they think is the general rule, or the main point, then having students share their writing, with the teacher serving to emphasize the using scientific language for their explanations and expressions.

When teachers use students' writing to asess their learning, there are important implications for teachers' ability to guage learning, and their use of teaching time. Using student writing to asses their ideas needs to be supported with other means of probing students' understandings, as was demonstrated in this study. Teachers need to ask students verbal questions, listen to students' questions, and listen to what students say to one another to help assess student understandings. Reading students' writing requires more

time than many teachers have available given their present schedules. With 90 students in her sixth grade, it would be difficult for the teacher in this study to read everything every student wrote every evening after dinner. There might be other ways to approach this enormous task, and we teachers need to begin thinking of creative ways to handle the paper load when we ask our students to do more writing. We might have students in different classes write on different days. Rather than reading everything, we can spot check students' writing for their ideas. We can have students read and respond to one anothers' written ideas, and get feedback occasionally from peers rather than from teachers. It will be indeed a challenge to find new ways to manage the heavy reading load, if teachers begin to use more writing in the teaching of science.

There are implications from this study for classroom lesson events, as well. From the results comparing the two lessons clusters, the Dissolving lesson format seemed most supportive of students' conceptual change learning. This lesson contained many of the features suggested by Roth, Anderson, and Smith (1986), and Minstrell (1984) as necessary parts of effective teaching for conceptual change. The features they mentioned that were particularly evident for effectiveness in this study are things that teachers can attempt to incorporate in their lessons:

(1) Elicit students' alternative conceptions, challenge them, and be aware of how these conceptions might influence students' responses. Small group discussions can provide some of these practice challenges.

(2) Provide several activities, and other experiences that are ***directly related*** to students' initial conceptions; make them first hand, and concrete; and relate them to the goal conceptions. Students can perform and discuss

the activities in small groups for opportunities to use language as they attempt to understand the new information.

(3) Provide students with the words to put their experiences into scientific language that they can understand, that is scientifically acceptable, then give them opportunities to practice using these words to explain and predict new events. Working in small groups might provide students with meaningful opportunities to explain their thinking.

(4) Provide students with repeated opportunities to reuse their new idea arguments, review them, and apply them in new contexts. Writing, reflecting, and talking about ideas in small groups and the whole class provides important opportunities for student uses of new idea arguments.

An important part of these activities and students' language use might be students' opportunities to discuss their ideas in *cross-dialogue* with their peers. The Dissolving lesson provided several opportunities for students to share their explanations with one another, listen to their own words, the words of others, and use both to construct new meanings and explanation. The explanations students wrote and discussed were part of their language at the posttest, showing that students' use of language might have influenced more successful learning for them. Teachers can provide more opportunities for students to discuss their ideas in small groups, and to present their ideas formally in front of the class.

This list of recommendations suggests ways teachers can use writing and cross-dialogue in their science classroom to enhance their understanding of student thinking, and encourage students to engage in more conceptual change kinds of learning strategies. By proposing this list of recommendations, this researcher proposes, also, that teachers may need to change the structure of their classroom time, and the kinds of time they spend reviewing students' progress. Classroom time will need to be restructured so that teachers spend less time in triadic dialogue or text dialogue, and teacher monologue than they do now, and spend more classroom time having students write, reflect, and talk about their ideas in peer groups. Teachers will likely have to teach their students how to behave according to the social norms of group behavior to make the group interactions fruitful. As in this study, students will need to be reminded from time to time about the social norms.

All of these activities---having students write, speak to one another, reading students' writing, and listening to their verbalizations---take a lot of time. Ask any teacher who has integrated peer group work in their classroom and they will tell of the increased time necessary to cover the same amount of curriculum they could cover in a monologue-triadic dialogue activity structured classroom. But students do not learn any better just listening to the teacher's dialogue, as was shown in this and numerous other studies (cf. Minstrell, 1984), so covering a larger amount of curriculum does not translate to students' learning a larger amount. Students' learning, as indicated in this study, seemed more effective when they could (1) participate in activities related to the conceptions; and (2) write, reflect and talk about their new ideas. Teachers and committees who determine students' curriculum may have to settle for less curriculum coverage to get better depth of understanding.

Teacher education. First, teacher education courses will need to help pre-service teachers understand the importance of students' initial conceptions for their learning. They will need strategies for discovering and confronting students' initial conceptions. They will aslo need strategies for devising activities that will directly relate to both the students' initial conceptions and the goal conceptions. Then, once they have planned activities, pre-service teachers need help devising ways that their students can use language to assist them in making sense of the new information and the activities.

Second, pre-service teachers will need to be committed to the importance of students' using written and verbal language to learn. In addition, they will need help with strategies for providing creative and unique opportunities for their students to use written and verbal language as they attempt to use the new ideas. Pre-service teachers may also need help understanding the social norms of group behavior, what to expect when students engage in group learning, and how to monitor and make productive their students' group interactions.

Further, pre-service teachers may need help with strategies for guiding students in using conceptual change strategies of learning, so their students learn to learn when encountering new science concepts. Pre-service teachers may need help structuring their own classrooms so they can plan and implement lessons without reverting to primarily teacher monologue and triadic dialogue. Like the students in this study, it might not be enough that the pre-service faculty "tell" the pre-service students how to accomplish the strategies with teacher monologue and triadic dialogue. Pre-service teachers may also need concrete activities that relate to their initial conceptions. These advanced students may also need opportunities to try out their new ideas in written and verbal language with peers, and younger students like those they will teach.

Finally, teachers currently teaching in classrooms may need assistance with changing their strategies for classroom activity structures to provide more opportunities for student writing and verbal interactions. There exist several conceptual change modules that teachers can use to assist them with well-designed instruction like the instruction in this study. But having the curriculum alone may not assist students' learning. Teachers may need help learning how they can best model the appropriate strategies for thinking about science, and coaching/scaffolding students as they try to use the strategies (Roth & Anderson, 1990), as the teacher in this study did during Dissolving and Thermal Expansion. Even though the teacher in this study accomplished modeling, coaching and scaffolding with the curriculum, she may have found the change in classroom structure difficult to manage. Teachers will need help learning to manage the more student-centered language classrooms that are suggested here.

FINAL COMMENTS

The instruction in the Dissolving and Thermal Expansion lesson clusters seemed to <u>engage</u> students in the kinds of effective thinking they needed to practice with conceptual change learning strategies. The means for this engagement might have been the practice students had using and explaining their new ideas about molecular behavior. If conceptual change thinking is our goal as teachers, then we need to teach our students <u>how</u> to use conceptual change thinking, and how and when to apply such thinking. Conceptual change thinking is a lofty goal for students' learning. When students use conceptual change thinking, they reflect on their prior knowledge, understand why they might have thought as they did, are able to take it into account when they encounter and use new knowledge. They make sense of new information, and use the new information in some kind of meaningful way so that it connects with their prior knowledge. Our goals as teachers might be to help students learn new information, and also learn ways of thinking and reflecting on their own thinking. If the most effective strategy for learning new science concepts is that students "use and integrate new knowledge with their real-world prior knowledge. . . and attempt to use their new knowledge by applying it to real situations, and explaining, and predicting" (Anderson & Roth, 1988), then these strategies need to be an explicit part of the instruction, just as they were in the Dissolving and Thermal Expansion lesson clusters. We need to provide students with the words to make sense of their experiences, so students learn to say what they mean and be understood, and understand the scientific ways of explaining the world. For instance, they need to learn that "matter is made of molecules", rather than "molecules are in matter"; and they need to learn "sugar mixes with the water" when it dissolves, rather than sugar "goes into" or "turns into liquid" in water.

And here is the tension in teaching science. On one hand, teachers need to help students see connections of new science knowledge to their prior knowledge. They need to help students make connections among the science concepts and theories they learn (Roth and Anderson, 1990). Students need to be able to describe, explain, predict, and understand the design of systems and phenomena. This implies that there are "correct" answers for scientific questions. And there are accepted ways of looking at the world in the scientific community. On the other hand, learning is more meaningful for students when they are able to reflect on old and new knowledge, and use it to construct their own ideas. Teachers cannot pour scientific information into learners' heads---students need to manipulate and make sense of new information to make it their own. So here lies the "tension" for science teachers. This tension arises most blatantly when the classroom activity structure allows for more student cross-dialogue, student questioning dialogue, and student-directed questioning. How much do we allow students to explore their alternative ideas about the world, and when do we step in with the ideas and words of the scientific community to lead students to more useful and accurate understandings of the world? Teachers may need help resolving this tension to be more effective in classrooms helping students explore and make connections for more scientific thinking. We may need to be more explicit about the language of science and teach our students how to use it. And we need to be more explicit with our students about the origins of scientific knowledge, and the strategies that lead to effective conceptual change, and teach them how to use those strategies.

As a final note, one of the important ideas this study demonstrated is the usefulness of students' writing as a "window" for our understanding of knowledge changes: Students' writing can show how they are thinking and struggling with concepts. And students' writing in conjunction with dialogue may help students make sense of their own science knowledge. It seems that writing can serve as a "window" for students into their own thinking, and serve as a mechanism for stimulating knowledge changes.

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APPENDICES

APPENDIX A

SAMPLES OF STUDENT WRITING

APPENDIX A

SAMPLES OF STUDENT WRITING

Antoine

Your little brother wants to dissolve some sugar in water, but he doesn't know whether to use cold or warm water. Explain to him which he should use. What will happen to the molecules and the sugar crystals in cold and warm water?

He sauld use Hot water so that the sugar crystals can dissalve faster and when the sugar will mix with the water molecules.

sugar can also dissolve in cold water except it take longer for the sugar crystals to dissolve in the water molecules.

The sugar crystals break down by bumping against the Water molecules

SAMPLES OF STUDENT WRITING

Artie

Your little brother wants to dissolve some sugar in water, but he doesn't know whether to use cold or warm water. Explain to him which he should use. What will happen to the molecules and the sugar crystals in cold and warm water?

Sugar can dissolve in both cold and hot water.
The hot water will disolve the sugar faster.

In hot water the behavior of the molecules change.
The molecules become faster witch put more pressure on the sugar wich seperates it into tiny little grains of sugar.
The molecules in the cold water move very slowly wich makes the sugar take a longer time to dissolve.

SAMPLES OF STUDENT WRITING

November 21, 1990

Carol

A. A molecule is a very tiny particle of a matter, which is a solid, liquid, or gas. Molecules of water look like "Mickey Mouse's Head". Sugar Molecule is just a big blob. Some people might think that everything is made up of molecules but, it is not true. For instance the sun, light & emotions are not matter. Also, a molecule is smaller than the eye could see. One little drop of water like this. is full of trillions of molecules. This is what a molecule is.

Q. Your (mom) dad wants to know more about molecules. Write what you would explain to an adult about molecules.

SAMPLES OF STUDENT WRITING

Kenny

1. They are the smallest thing. A water molecule is trillions of times smaller than dust. You can't even see them with the most powerful microscope. Scientist use a lasers to see them. On the powers of ten chart a water molecule is 10^{-10} and a sugar molecule is 10^{-9}.

SAMPLES OF STUDENT WRITING

Kenny

Your friend Tom just brought a snowball over to your house to save in the freezer. By the time he got it into the house, it was starting to drip and break apart. Tom wonders why. Explain to your friend what is happening to the snowball in terms of the molecules.

The molecules in The snowball are getting farther apart and The snow ball is changing into the liquid state.

11-21-90

Melinda

Molecules are the smallest things that make up larger things. All matter is made up of molecules.
There are Trillions of water molecules in a tiny drop of water. Molecules are to small to see, even with a microscope. They use laser equipment to find them.
Molecules are made of atoms. The water molecule has three; two atoms of hydrogen and one atom of oxygen. Not all molecules have three atoms. Some have lots. But even the biggest cannot be seen.

APPENDIX B

PRETEST / POSTTEST

APPENDIX B

PRETEST / POSTTEST

Period ______________ Name ______________________

Date ______________ Teacher ______________________

This test asks questions about topics that scientists deal with. We would like to know your ideas about these topics. Please answer each question as carefully and as thoroughly as you can. Do not worry about trying to finish the test, just do what you can in the time allowed. Explain your own ideas; good explanations are more important to us than "correct" scientific words.

1. Try to decide whether each of the things below is:

   - a pure substance
   - a mixture of different substances
   - something else that is neither a pure substance nor a mixture of substances

air	pure	mixture	something else
light	pure	mixture	something else
helium	pure	mixture	something else
heat	pure	mixture	something else
steel	pure	mixture	something else
water	pure	mixture	something else
the smell of popcorn	pure	mixture	something else
mud	pure	mixture	something else
salt water	pure	mixture	something else

2. What is the difference between things that are pure and things that are not?

____

____

____

PRETEST / POSTTEST

-2-

3. Choose solid, liquid, gas, or other for each thing below:

air	solid	liquid	gas	other
light	solid	liquid	gas	other
helium	solid	liquid	gas	other
heat	solid	liquid	gas	other
steel	solid	liquid	gas	other
water	solid	liquid	gas	other
the smell of popcorn	solid	liquid	gas	other
mud	solid	liquid	gas	other
salt water	solid	liquid	gas	other

4. Have you ever heard of molecules? ______ If you answered yes, what do you think molecules are?

____

____

____

5. Which of the following do you think is made of molecules (Circle yes, no, or I don't know.)

air	yes	no	I don't know
light	yes	no	I don't know
helium	yes	no	I don't know
heat	yes	no	I don't know
steel	yes	no	I don't know
water	yes	no	I don't know
the smell of popcorn	yes	no	I don't know
mud	yes	no	I don't know
salt water	yes	no	I don't know

PRETEST / POSTTEST

-3-

6. What do you think is bigger, a molecule or a speck of dust?

   a. They are the same size.

   b. The molecule. How many times bigger? ________________

   c. The speck of dust. How many times bigger? ______________

   d. I don't know.

7. John stirred some sugar into a glass of water. After a while the sugar had all dissolved--the water was clear and John could not see any sugar.

   What happens to sugar when it dissolves in water?

   ____

   ____

   ____

8. Choose one of the following:

   a. Sugar dissolves faster in hot water
   b. Sugar dissolves faster in cold water
   c. Sugar dissolves about the same in hot and cold water
   d. I don't know

   Explain your answer.

   ____

   ____

   ____

9. A solid iron ball exactly 3 inches across was heated on the stove. If it did not melt, would you expect it to

   a. Be larger
   b. Be smaller
   c. Stay the same size
   d. I don't know

PRETEST / POSTTEST
-4-

Explain your answer.

___

___

___

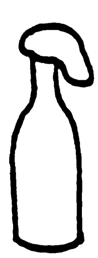
10. When a piece of metal is heated:

    a. The number of molecules increases
    b. Molecules expand or get larger
    c. Molecules stay the same size but move farther apart
    d. Molecules contract or get smaller
    e. I don't know

11. How do you think the molecules of hot water are different from the molecules of cold water? Circle all answers that you think are correct.

    a. The molecules are larger in hot water
    b. The molecules are larger in cold water
    c. The molecules move faster n hot water
    d. The molecules are warmer in hot water
    e. The molecules are the same, but there is more heat in the hot water
    f. I don't know

12. These two bottles were put into the refrigerator until they were cold. Balloons were placed over the rims of the bottles. A student took one bottle out of the refrigerator and warmed it with her hands. Which bottle did she warm? Circle your choice.

A. 

B. 

PRETEST / POSTTEST

Explain your answer.

13. You cut up an onion into small pieces. You notice the smell in a few seconds. Explain what you think the smell is made of.

Explain how it reached you. Talk about molecules, if you can.

14. Do you think the molecules are moving in windy air?

a. Yes, they are moving
b. No, they are not moving
c. I don't know

Do you think the molecules are moving in still air?

a. Yes, they are moving
b. No, they are not moving
c. I don't know

Do you think the molecules are moving in a rock?

a. Yes, they are moving
b. No, they are not moving
c. I don't know

PRETEST / POSTTEST

If you said the molecules were moving in any of the examples above, do you think they will ever stop moving? ____________

Explain.

____

____

____

15. A piece of ice is melted to liquid water. How would the weight of the water compare to the weight of ice?

    a. The water would weigh less than the ice
    b. The water would weigh the same as the ice
    c. The water would weigh more than the ice.

    Explain your answer.

    ____

    ____

    ____

16. Explain, in your own words, why heating a solid makes it melt. Explain in terms of molecules of the solid, if you can.

    ____

    ____

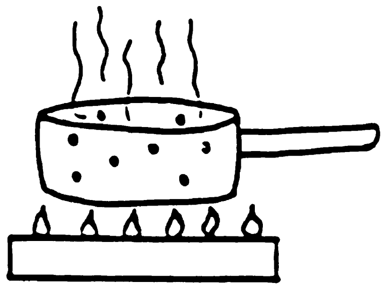
    ____

17. What happens to the molecules of water when the water freezes?

    a. Molecules of water become cold and hard
    b. Water molecules change into ice molecules
    c. Molecules of water slow down and fit together in a pattern
    d. Molecules of water get smaller
    e. I don't know

PRETEST / POSTTEST

18. When water boils, bubbles rise to the surface of the water. What do you think is inside the bubbles? ____________



Explain in your own words why heating makes the water boil. Explain in terms of molecules, if you can.

____

____

____

19. You leave a glass full of water on the counter where nobody touches it. A few days later, the water level is lower than before. Where do you think the water has gone?

____

Explain how this happens, in terms of molecules if you can.

____

____

____

20. You and a friend are sitting in a car on a cold winter day. You talk for a while, then you notice that the windows have fogged up.

What do you think the fog is?

____

PRETEST / POSTTEST

Why did the fog form on the windows instead of, say, on your face?

____

____

____

Explain how the fog formed.

____

____

____

21. You take a can of soft drink out of the refrigerator and let it stand for 15 minutes. The outside of the can becomes wet.

    Where has the water on the outside of the can come from?

    a. The water in the soft drink seeps through the can
    b. The coldness causes oxygen and hydrogen in the air to form water on the can
    c. Water in the air forms drops on the cold can
    d. The coldness comes through the can and turns into drops of water
    e. I don't know

22. When we say the air is humid, what do we mean? Explain in terms of molecules, if you can.

____

____

____

APPENDIX C

CLINICAL INTERVIEW PROTOCOL

APPENDIX C

CLINICAL INTERVIEW PROTOCOL

Task 1: Card Sort

Situation:

Provide student with a set of cards with the following words printed on each: matter, molecule, liquid, solid, gas, mixture, pure, pollution.

Materials:

Cards with one of the above words printed on each.

		Questions	Goal Conceptions
Task 1-1	0:	Look through these cards and give me back any words that you do not recognize.	
	P1:	Arrange the cards on the table so they make sense to you.	
	P2:	Explain why you have put the cards where you have.	1, 1a
	P3:	(Interviewer arranges cards in a different way: matter with solid, liquid, gas; and pure with mixture, etc.) Can you see why I might have put the cards like this?	

Task 2: Describe, contrast, and classify the three states of matter.

Situation:

Set up rock, water and plastic bag of air in front of student.

Materials:

Rock or metal, water, plastic bag of air
Cards from card sort Task 1-1
Pencil and paper for drawings

		Questions	Goal Conceptions
Task 2-1	0:	Can you tell me how these three things are different?	1,4,9
	P1:	Do you know what the three states of matter are? (If the student doesn't know) Have you ever heard of solids, States of liquids and gases?	

CLINICAL INTERVIEW PROTOCOL

Matter	P2:	What state of matter is rock?
	P3:	What state of matter is water?
	P4:	What state of matter is air?
	P5:	How do you decide whether something is a solid or a liquid?
	P6:	How do you decide whether something is a liquid or gas?
Task 2-2	0:	Can you think of any way that these three things are similar? 9,10,11,12
Molecular Constitution of Matter	P1:	Have you ever heard of molecules?
	P2:	What are they? 16,17
	P3:	How big are they? How does their size compare to the size of a speck of dust?
	P4:	Can you think of something that's <u>not</u> made of molecules?
Task 2-3	0:	What is air? 9,10,11,12
Nature of gas (air)	P1:	(If the student says there is nothing in the air) Wave your arm in the air. Do you feel anything? Is anything striking your arm? What is it? 16,17
	P2:	Suppose you are able to see air with magic eyeglasses. What is air made of? (What is in the air?)
	P3:	Draw a picture of what you would see.
	P4:	(If the student draws dots, waves, etc.) What are these dots (waves, etc.)? Are they all the same? What is between them?
	P5:	(If student mentions molecules) Is air a mixture? What does that mean? Is air made of different molecules?
Task 2-4	0:	Suppose you can see water with magic eyeglasses. What is water made of?
Nature of liquid	P1:	Draw a picture of what you see.
	P2:	(If the student draws dots, waves, etc.) What are these (water) dots, (waves, etc.)? Are they all the same? What is between them? Are they moving?
	P3:	If so, are they always moving?
Task 2-5	0:	Another student told me that a rock is made of very, very small particles or pieces that are always jiggling back and forth. What do you think of that?
Nature of	P1:	(If student agrees with and/or mentions molecules) Are the solid molecules of a rock still?
	P2:	Suppose you can see rock through magic eyeglasses. Draw a picture of what you would see.
	P3:	(If student draws dots) What are these dots? Are they all the same? Is there any space between them?

CLINICAL INTERVIEW PROTOCOL

Task 2-6	0:	Now you have drawings of air, water, and rock. What is the difference among these substances from your comparison drawings?
States of matter	P1:	(If student mentioned that there is space between. . . in the states of drawings) Is the space the same in all states? (If the student says no) Which has the largest space? Which has the smallest space?
	P2:	(If the student mentioned that they were moving) Is the movement the same in all states? (If the student says no) Which has the most movement? Which has the least movement?

<u>Task 3: Explain Changes of States of Matter</u>

<u>Situations</u>:

Melting ice: Leave ice cubes melting in a plastic cup.
Boiling water: Boil water in a beaker on a hot plate.
Condensing water: Condensation on beaker of boiling water.
Evaporating alcohol: Place drops of alcohol on a slide.
Smell of perfume: Take top off of perfume container.

		Questions	Goal Conceptions
Task 3-1	0:	What's happening to the ice cubes?	2,9,11,12
	P1:	What state of matter is ice? What state of matter is water?	
Melting ice	P2:	How does ice change into water?	14,15,17,18
	P3:	(If student has mentioned molecules) Can you explain what's happening to the molecules?	
	P4:	Does ice have to be heated to melt? Why?	
	P5:	In which state do molecules move more freely?	
	P6:	In which state are they farther apart?	
Task 3-2	0:	What's happening to the water? Describe what you see.	
	P1:	If we leave the water boiling, what happens to the amount of water in the beaker?	2,7,9 11,14,15
Boiling	P2:	Why is the amount of water lower?	17,18
	P3:	Where is the water going?	
	P4:	(If the student mentions bubbles) Is there anything inside the bubbles? What?	
	P5:	(If the student mentions "air") Do you think the air in the bubbles is the same as the air in this room?	
	or	(If the student mentions "steam") What do you mean by "steam"? What state of matter is steam?	
	P6:	How does the water change from liquid to gas?	

CLINICAL INTERVIEW PROTOCOL

	P7:	Which has more space between molecules, liquid or gas?	
	P8:	In which state do molecules move more freely?	
	P9:	In which state do molecule move farther apart?	
Task 3-3	0:	What is happening on the plate?	2,7,6,9
	P1:	Where does the water come from?	14,15,17,18
Condensing	P2:	(If student mentions "air") How does air change to water?	
	or	(If student mentions "steam") How does steam change from gas to liquid? Can you explain in terms of molecules?	
	P3:	Which state has more space between molecules, gas or liquid?	
	P4:	In which state do molecules move more freely?	
	P5:	In which state do molecule move farther apart?	
Task 3-4	0:	What do you see happening here?	2,7,9,10
	P1:	Where did the alcohol go?	11,12,17
Evaporation	P2:	Did it disappear? If so, is it gone forever? Does it still exist?	
	P3:	How does the alcohol evaporate?	
	P4:	Is alcohol made of molecules? What kind?	
	P5:	What's happening to the alcohol molecules?	
	P6:	Would anything happen differently if we heated the glass and alcohol?	
Task 3-5	0:	Can you smell the perfume?	
	P1:	What is smell made of?	
Smell	P2:	How did the smell of perfume get from the glass to your nose?	
	P3:	Can you explain in terms of molecules?	
	P4:	Molecules of what? Where did they come from?	
	P5:	If we put a top on the perfume, would you still be able to smell it? Why or why not?	

Task 4: Explain Pure Substance vs. Mixture and Process and Rate of Dissolving

Situations:

Dissolve sugar in a teabag in water.

Materials:

Sugar in teabag, Beaker of water.

CLINICAL INTERVIEW PROTOCOL

		Questions	Goal Conceptions
Task 4-1	0:	What is happening to the sugar?	2,9,10
	P1:	(If the student mentions "dissolves") What do you mean by "dissolves"?	11,12
Dissolving	P2:	How does it get out of the teabag? Can you explain in terms of molecules?	13,14
	P3:	If we leave the sugar and water sitting for one day, what will happen? Will sugar be all over, or in one place? Will sugar sink to the bottom? Why or why not? Can you explain in terms of molecules?	
	P4:	If we put a teabag of sugar in a cup of hot water and a cup of cold water, which would dissolve faster? Why? Can you explain in terms of molecules?	
	P5:	Is the sugar and water a mixture or a pure substance?	
	P6:	Can you explain why?	

Task 5: Explain Thermal Expansion of Gas and Solid

Situations:

Put the balloon on the rim of a cold bottle and warm it with hands (bottle on its side). Have the student put the ball through the ring, heat the ball, and have the student try to pull the ball back through the ring.

Materials:

Balloon, bottle, ball, ring, hot plate

		Questions	Goal Conceptions
Task 5-1	0:	What will happen to the balloon after we put our hands on the bottle?	3,9,11,12
Thermal Expansion of gas	P1:	What happens to the balloon? Why?	14,15,16
	P2:	What caused the balloon to get bigger?	
	P3:	(If the student responds "hot air rises", then turn the bottle upside down.) Can you explain why the balloon stays the same? Can you explain in terms of molecules?	
	P4:	Does the molecule motion or size change when the bottle is warmed? If so, in what way?	
	P5:	Does the number of molecules change as the bottle is warmed?	
	P6:	Is there a change in the space between molecules as the bottle is warmed?	
	P7:	Were the molecules of air in the bottle moving before we started to warm the bottle?	

CLINICAL INTERVIEW PROTOCOL

	P8:	Do molecules move faster when the bottle is cold or heated?
	P9:	Do molecule move farther apart when the bottle is cold or heated?
Task 5-2	0:	The ball goes through the ring now (unheated). What will happen if we heat the ball?
Thermal Expansion of solid	P1:	Why can't we pull the ball through the ring after heating? Can you explain in terms of molecules?
	P2:	Does the molecule motion or size change when the ball is heated?
	P3:	Does the number of molecules change as the ball is heated?
	P4:	Is there a change in the space between molecules as the ball is heated?
	P5:	Were the molecules of the ball moving before we started to heat it?
	P6:	Do molecules move faster when the ball is heated or cold?
	P7:	Do molecules move farther apart when the ball is heated or cold?

APPENDIX D

TEACHER INTERVIEW PROTOCOL

APPENDIX D

TEACHER INTERVIEW PROTOCOL

Proposed script:

I: I am happy you will be able to help me, __________. I am trying to understand how students restructure their thinking during science lessons. Understanding your approach and thinking about your teaching may help me understand more about what the students are trying to do.

Questions:

(1) What are your goals for the students' learning?

(2) How will your students best learn this?

(3) What are your plans?

(4) Do you foresee that the activities require your collaboration with students?

(5) Do you plan to expose student's alternative conceptions?

(6) Do you plan to make students aware of their own and other students' alternative conceptions?

(7) Do you plan to create conceptual conflict? How? Why?

(8) Do you plan to encourage and guide cognitive accommodation? How? Why?

(6) Do you plan to engage students in processing skills, such as predicting, hypothesizing, inferring, raising questions, analyzing, synthesizing, identifying gaps in knowledge, and confusing ideas? How? Why?

APPENDIX E

STUDENT WRITING INTERVIEW PROTOCOL

APPENDIX E

STUDENT WRITING INTERVIEW PROTOCOL

Proposed script:

I: I am happy you will be able to help me, __________. I am trying to understand how you and the other students change your thinking about science as a result of your classroom activities. Your answering these questions for me might help me begin to see how you think about your learning.

Questions:

(1) Do you write very much in your other classes?

(2) Have you written much before in your classes?

(3) Do you find it easy or hard to write?

(4) Do you like to write at school? At home?

(5) Do you like to write in your science activity book?

(6) Does writing ever help you think?

(7) Do you think there is a purpose for having you write when you are learning science? What do you think the purpose is?

STUDENT WRITING INTERVIEW PROTOCOL

Periodic and Follow-up Student Writing Interview Protocol

Proposed script:

I: I am happy you will be able to help me, __________. I am trying to understand how you and the other students thought about the Matter and Molecules lessons and how the writing you did might have helped you think about what you were learning. Your answering these questions for me might help me understand how you learned.

Questions:

(1) Are you writing very much in your other classes?

(2) Have you written much before this year in your classes?

(3) Do/Did you find it easy or hard to write about your explanations in your activity book? Why?

(4) Do/Did you find it easy or hard to write the freewriting exercises after the science lessons? Why?

(5) Do/did you like writing in your science activity book? Why or why not?

(6) Do/Did your writing ever help you think? Tell me about it.

(7) Do/Did you writing ever change <u>as you wrote</u>? Tell me about it.

(8) What do you think is the purpose for having you write about your science lessons? Why?

(9) Can you describe for me what learning science is like? (Is it "like" something else you do?)

APPENDIX F

SAMPLE SUMMARY OBSERVATION FORM

APPENDIX F

SAMPLE SUMMARY OBSERVATION FORM

Observation Summary Form

Date: 9-90 Teacher: M. Davis Lesson cluster: Soc/P Lesson: 'Broken Circles' Observer: M. Fellows

Time	Activity	Back Camera	Front Camera
8:25 ± to 8:45	Intro—explaining the game, rules	focused on Mary, pan for responses used 'bullet' mike.	front group used 'bullet' mike
8:45	into groups—working in activity	focused on back target group	focused on front target group first group completed activity
8:55	finishing up	"help" for last group to finish from other group members. turned off bullet mike @ 1:15 on counter—(how did it pick up sound?)	
9:00 – 9:10.	Discussion about what happened		

APPENDIX G

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

APPENDIX G

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

<u>Artie</u> - Semantic Node-Link Networks for Pretest and Posttest

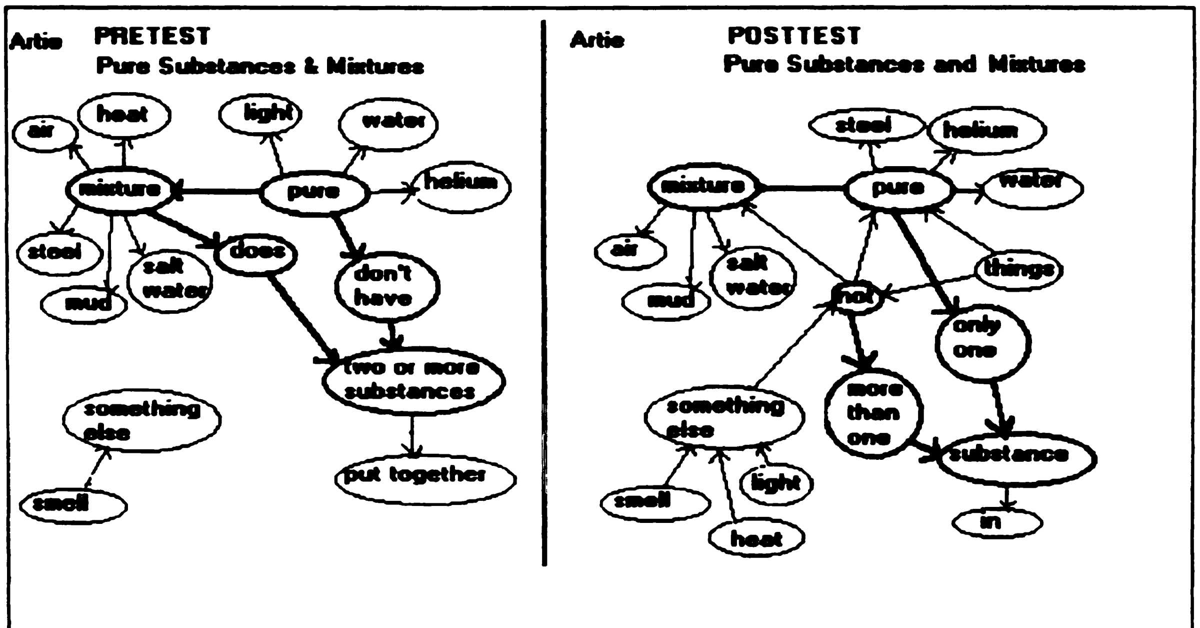


Figure H.1 Artie's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

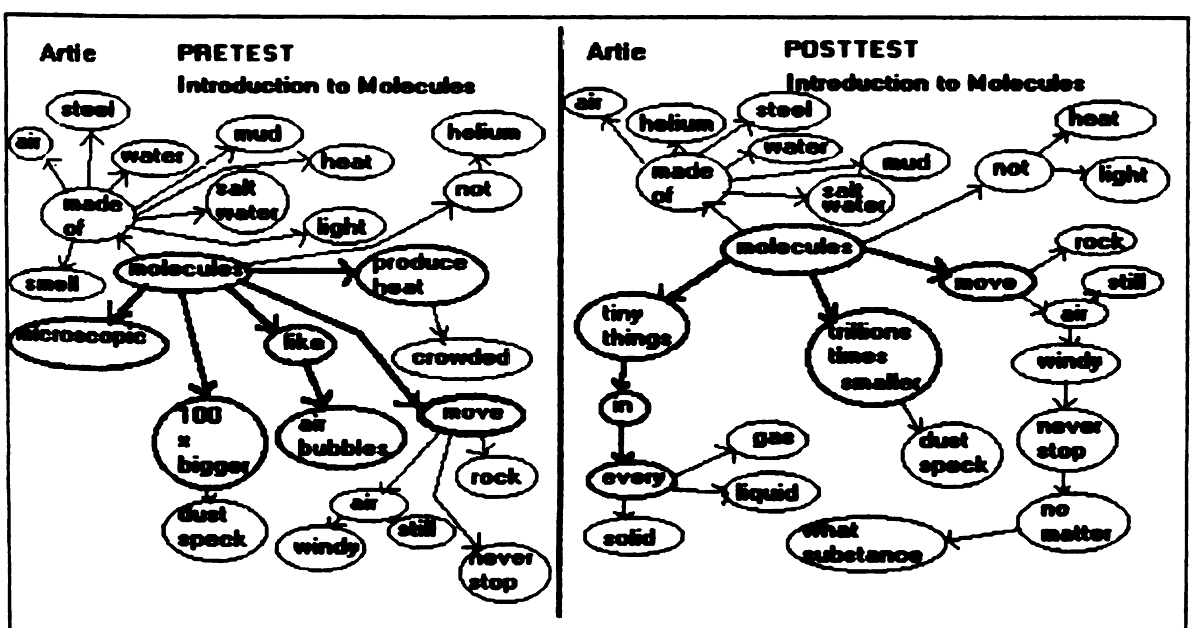


Figure H.2 Artie's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

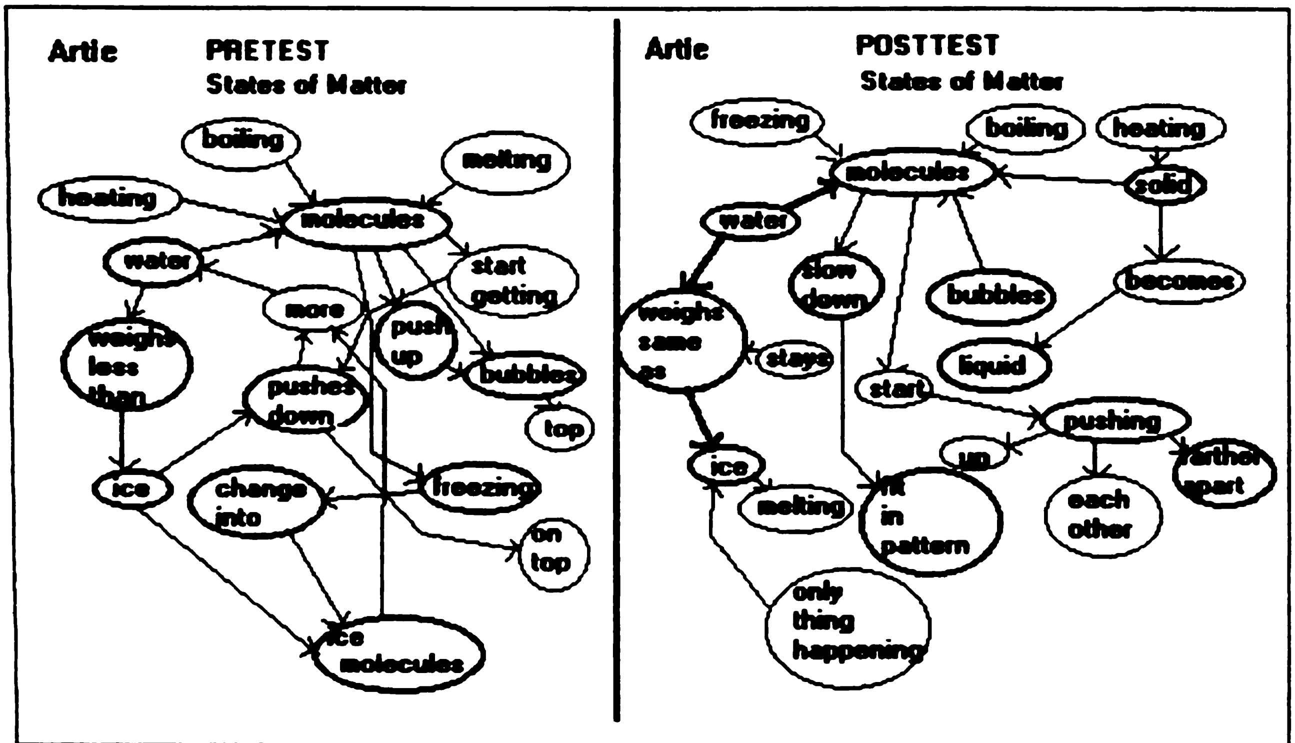


Figure H.3 Artie's semantic node-link networks for States of Matter pretest and posttest written statements.

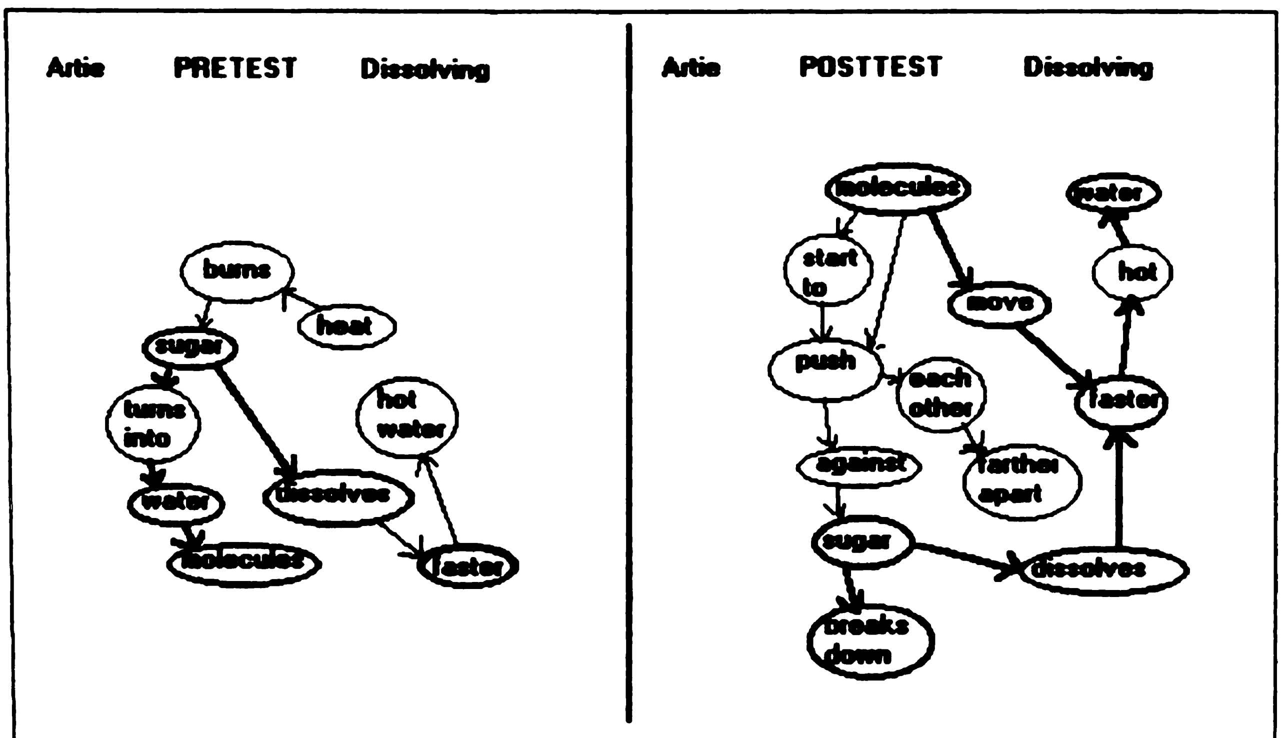


Figure H.4 Artie's semantic node-link networks for Dissolving pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

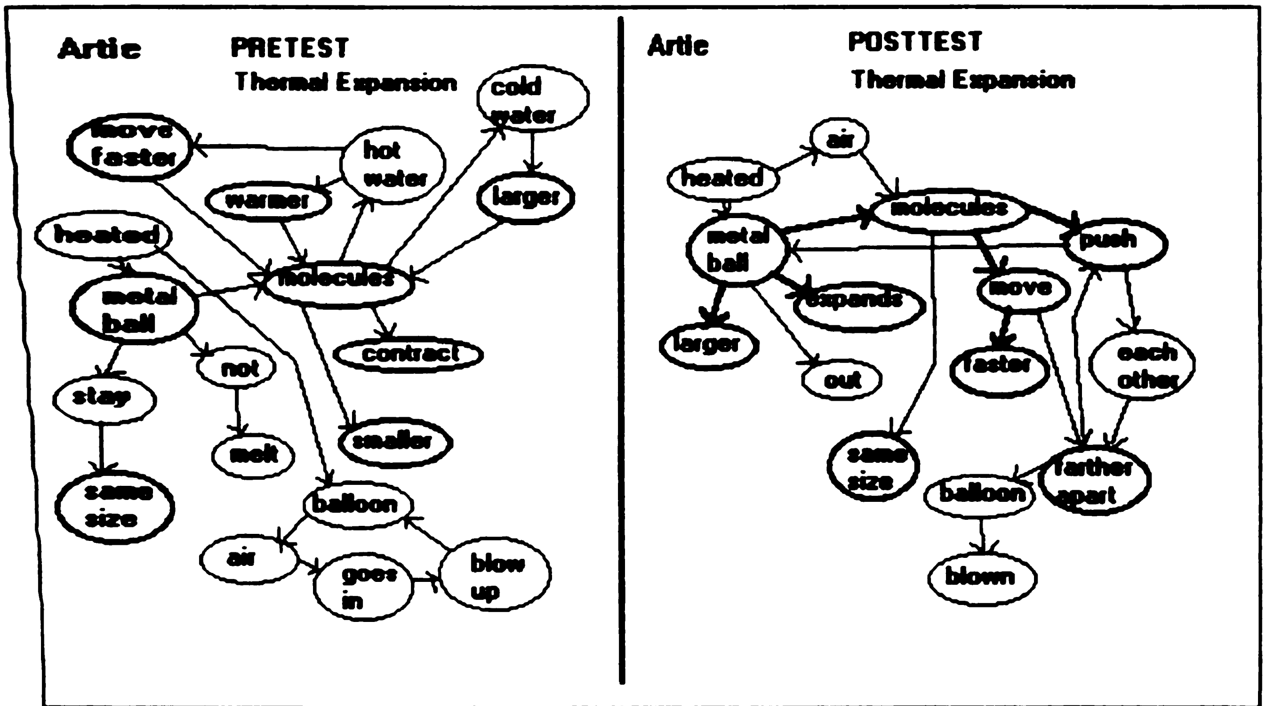


Figure H.5 Artie's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

Kenny - Semantic Node-Link Networks for Pretest and Posttest

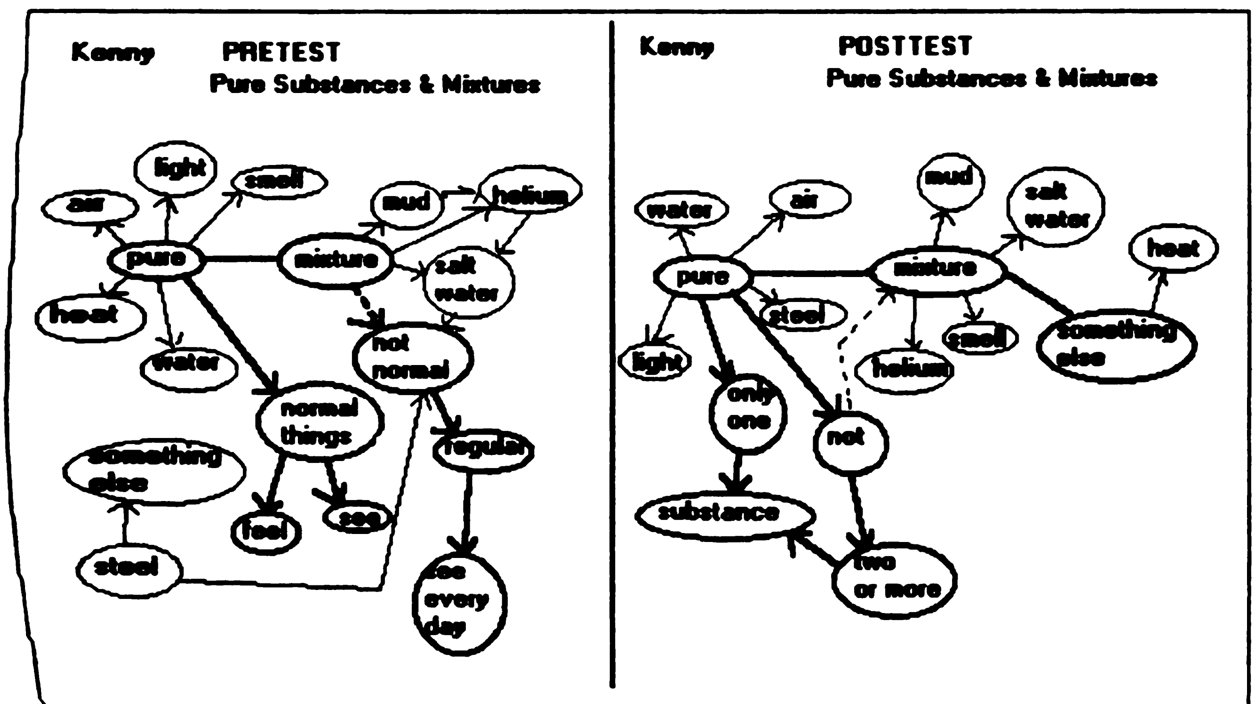


Figure H.6 Kenny's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

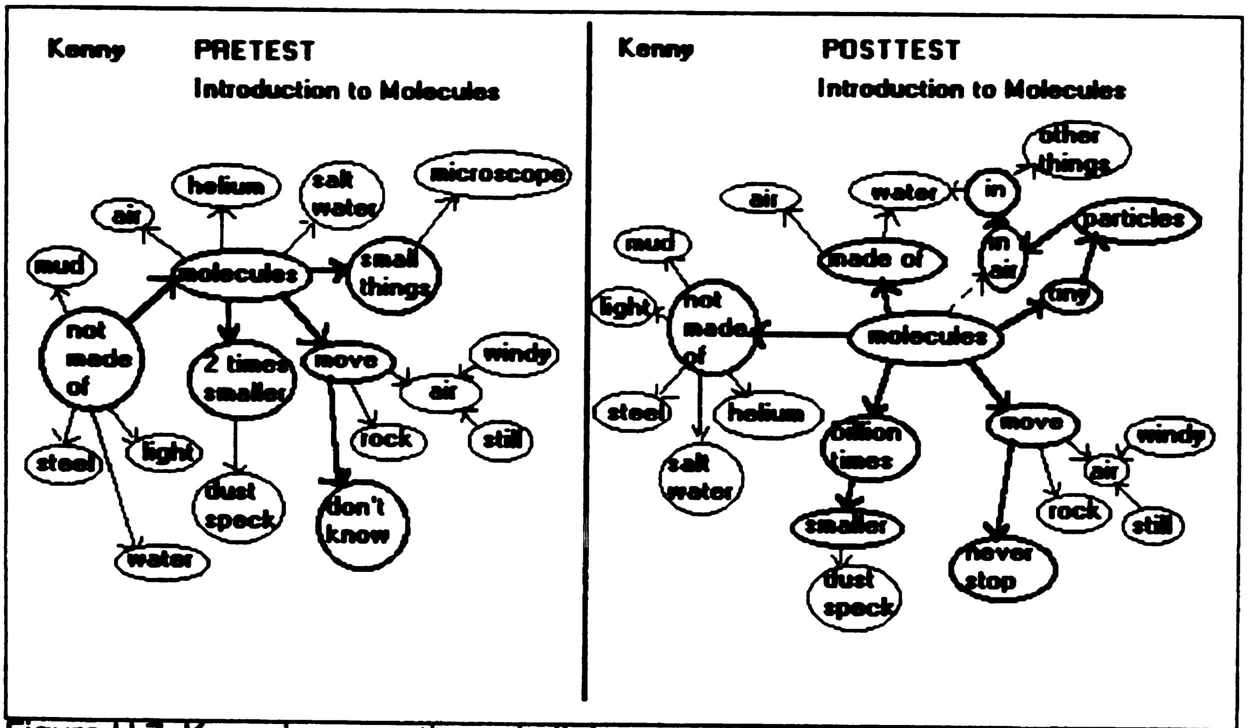


Figure H.7 Kenny's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

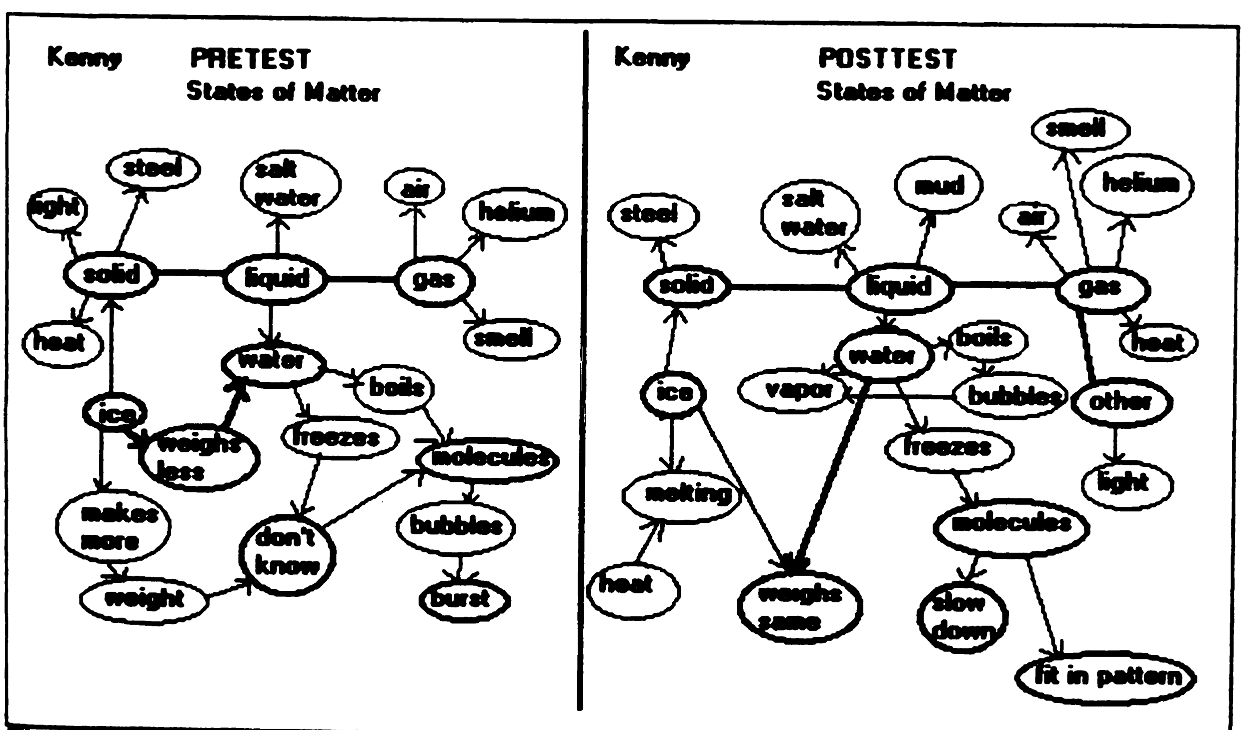


Figure H.8 Kenny's semantic node-link networks for States of Matter pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

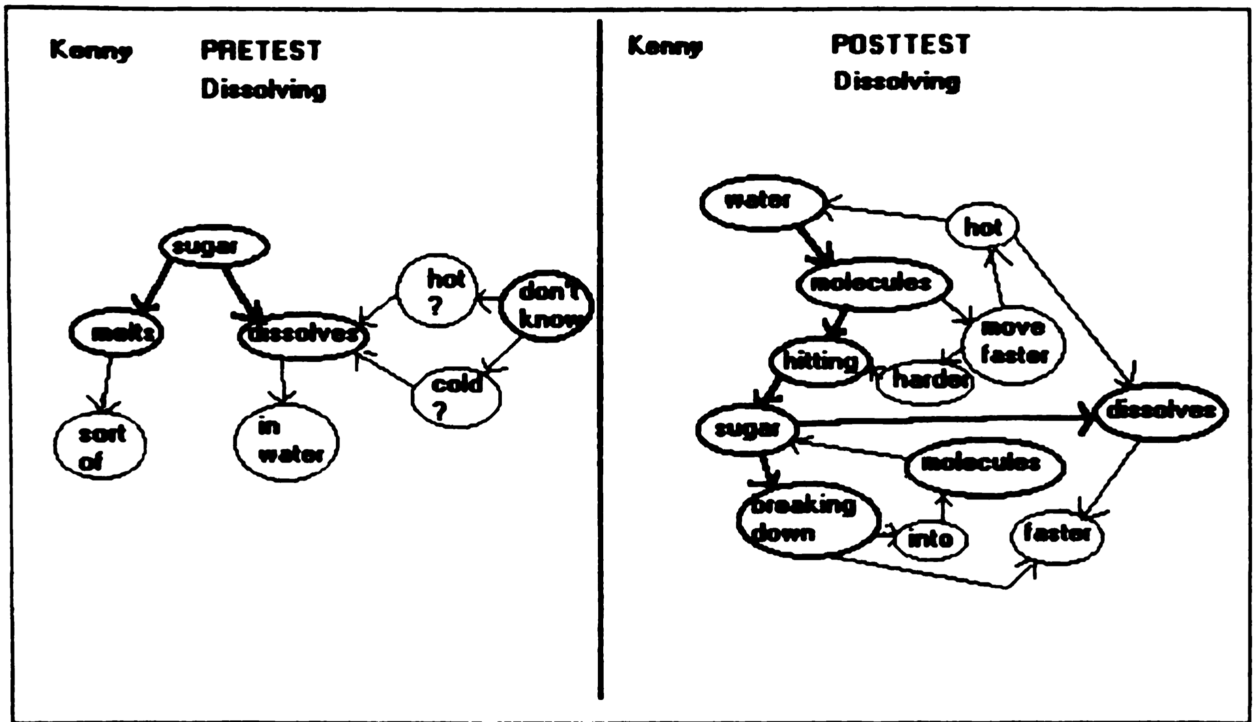


Figure H.9 Kenny's semantic node-link networks for Dissolving pretest and posttest written statements.

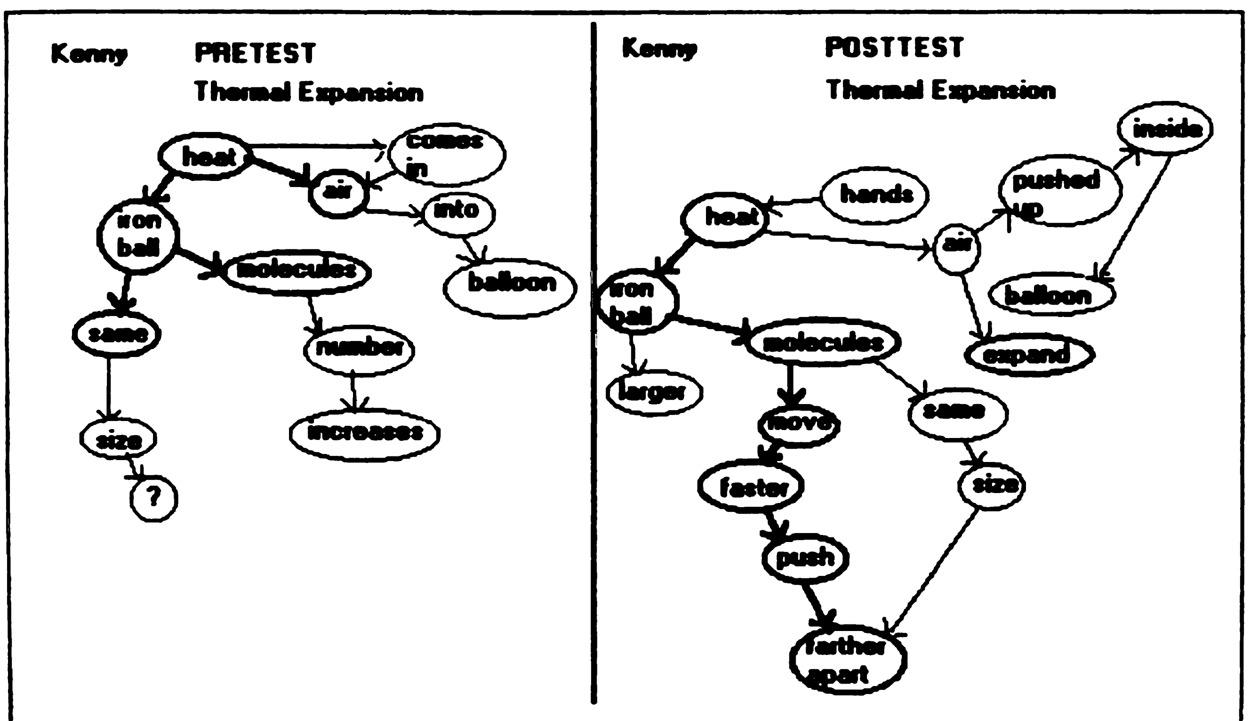


Figure H.10 Kenny's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

Carol - Semantic Node-Link Networks for Pretest and Posttest

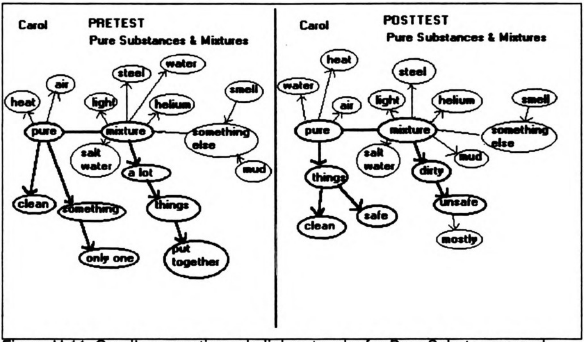


Figure H.11 Carol's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

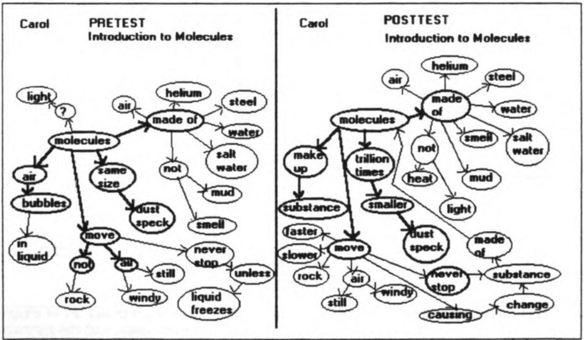


Figure H.12 Carol's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

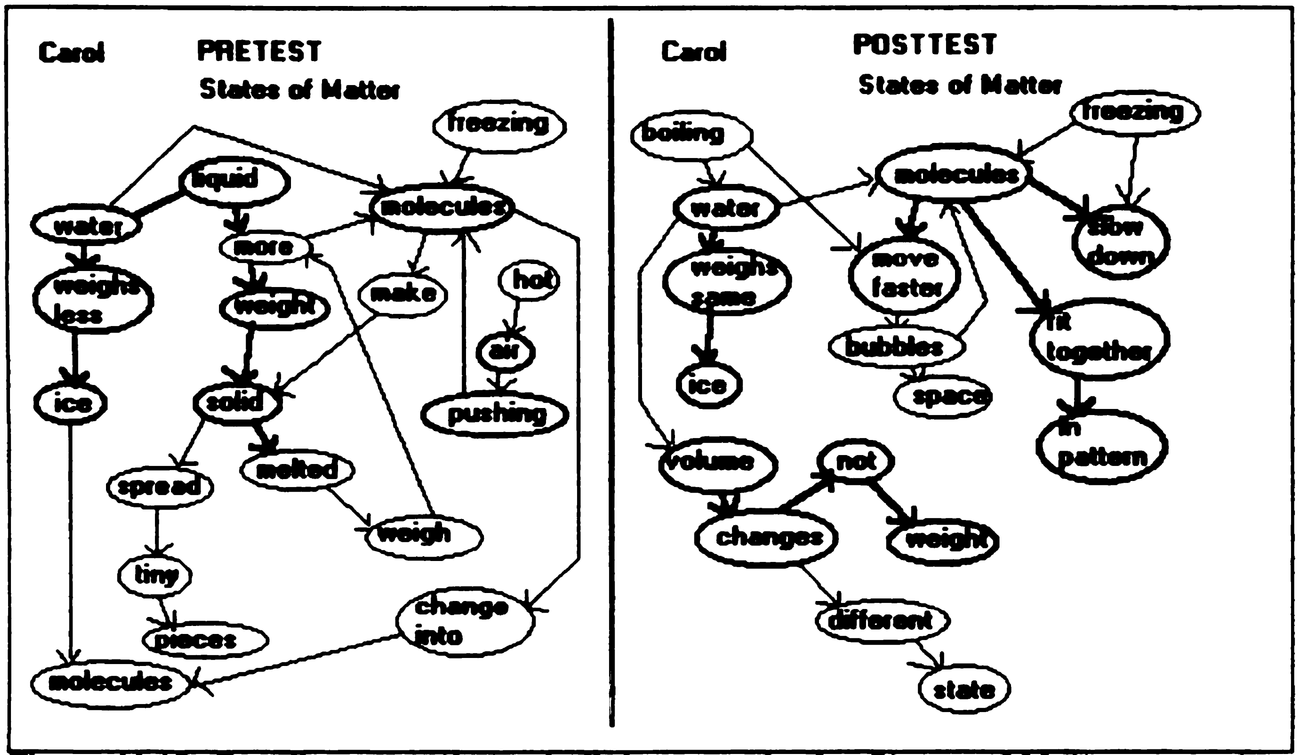


Figure H.13 Carol's semantic node-link networks for States of Matter pretest and posttest written statements.

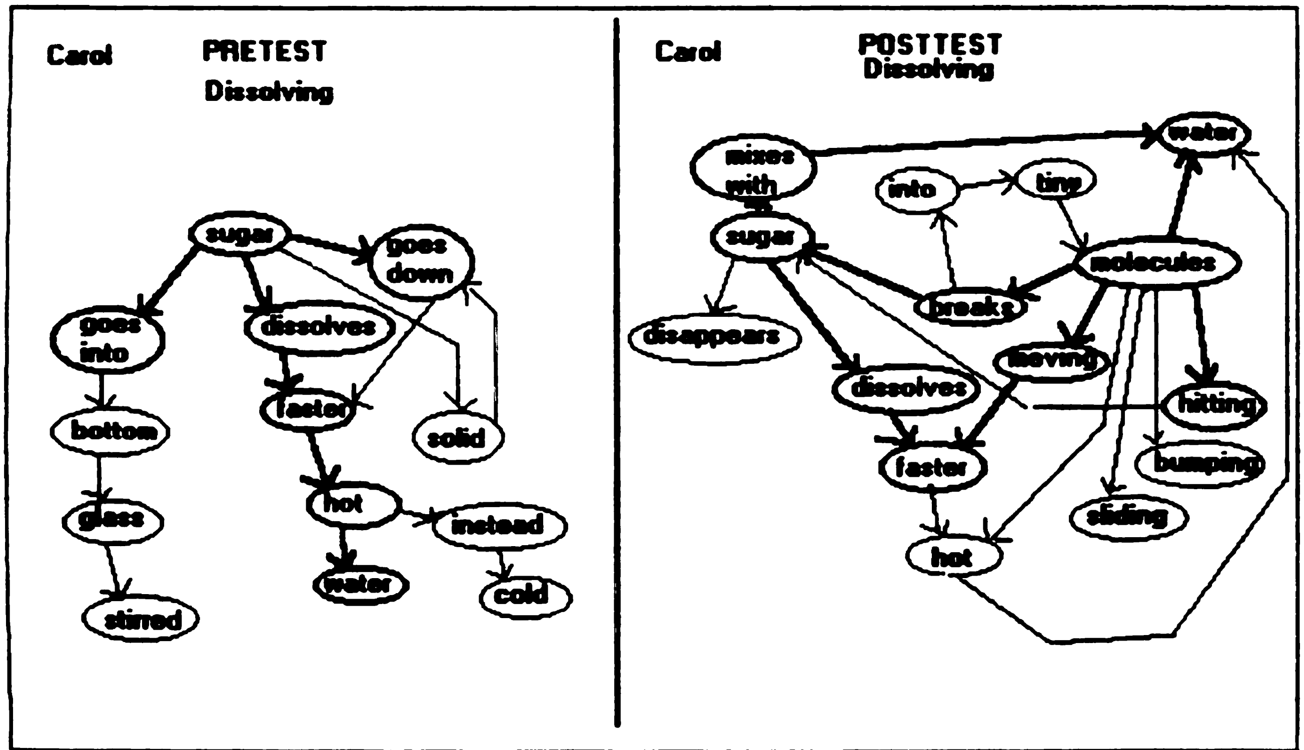


Figure H.14 Carol's semantic node-link networks for Dissolving pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

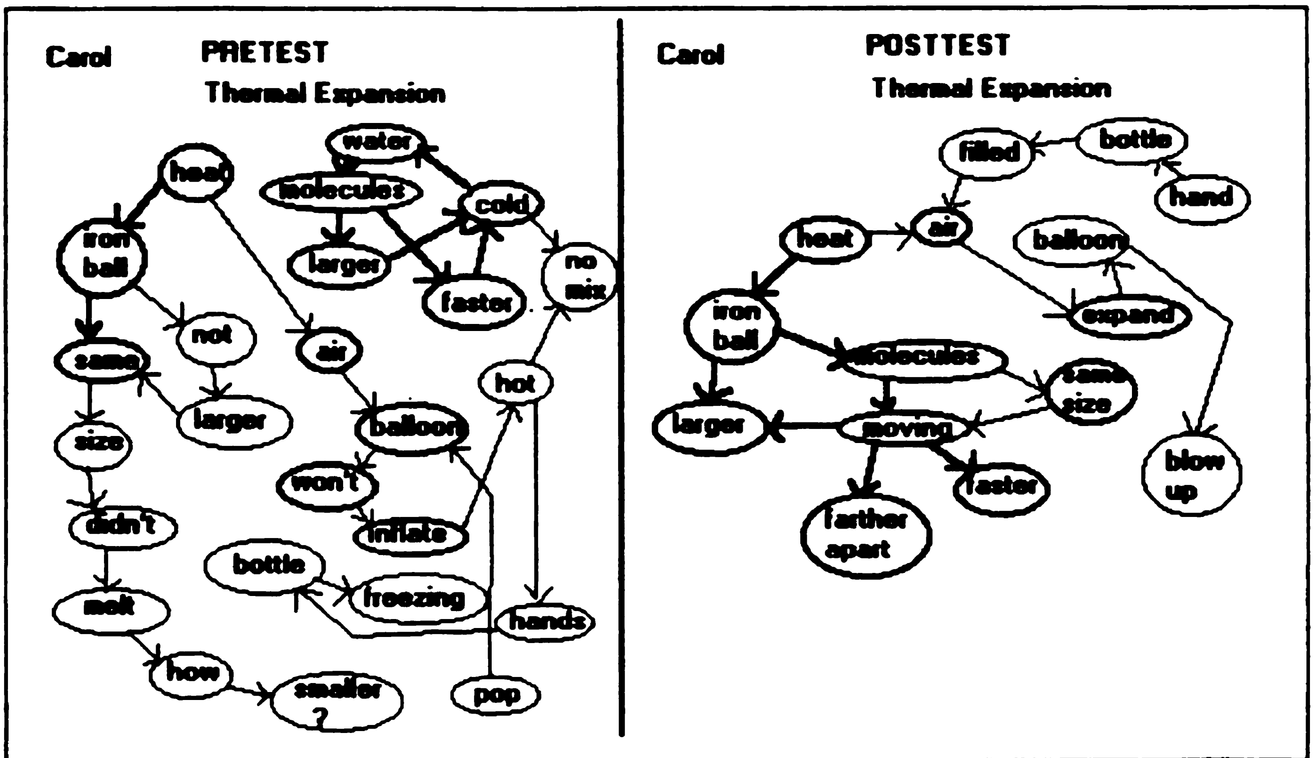


Figure H.15 Carol's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

<u>Melinda</u> - **Semantic Node-Link Networks for Pretest and Posttest**

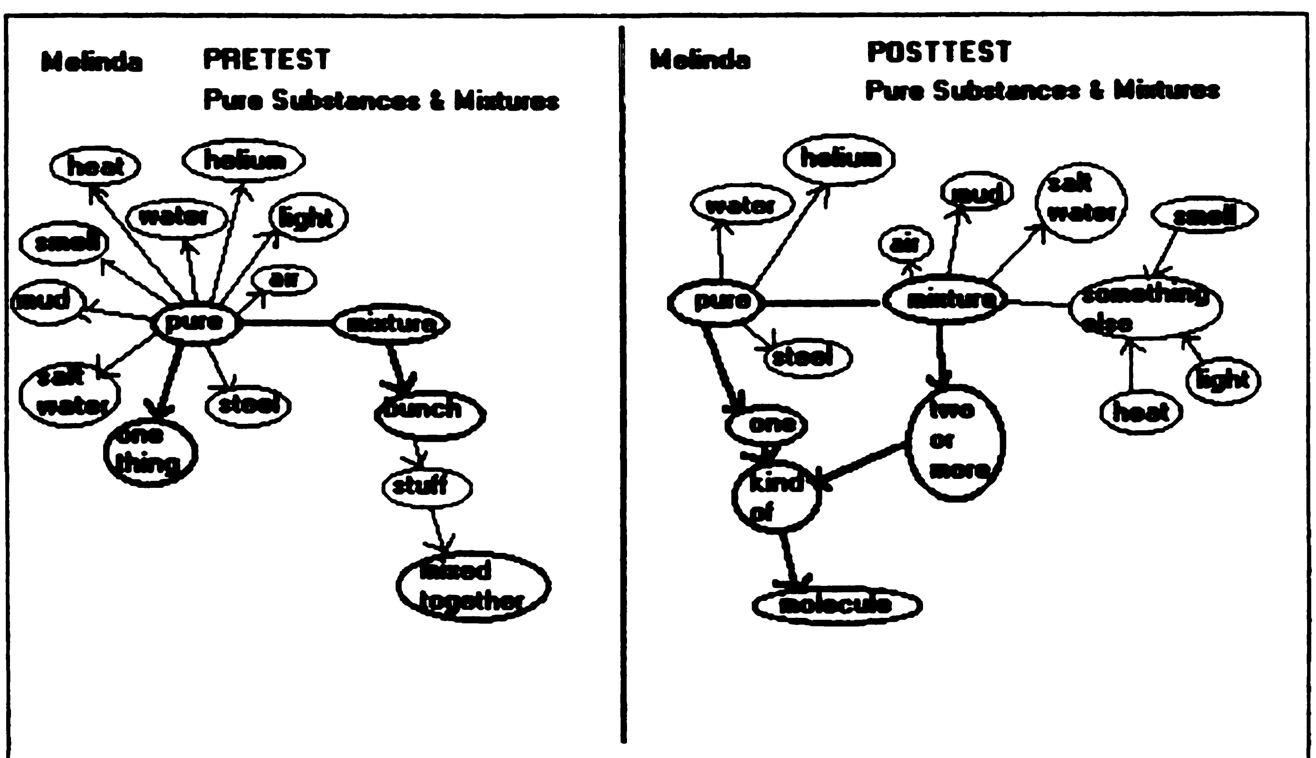


Figure H.16 Melinda's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

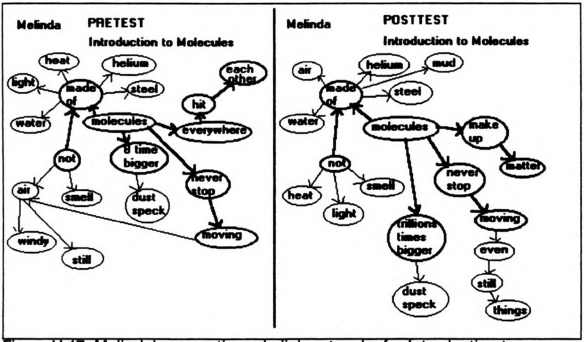


Figure H.17 Melinda's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

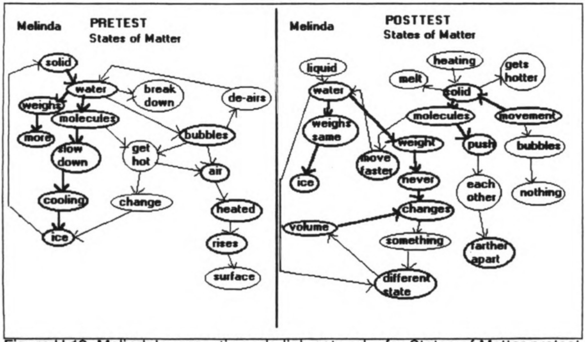


Figure H.18 Melinda's semantic node-link networks for States of Matter pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

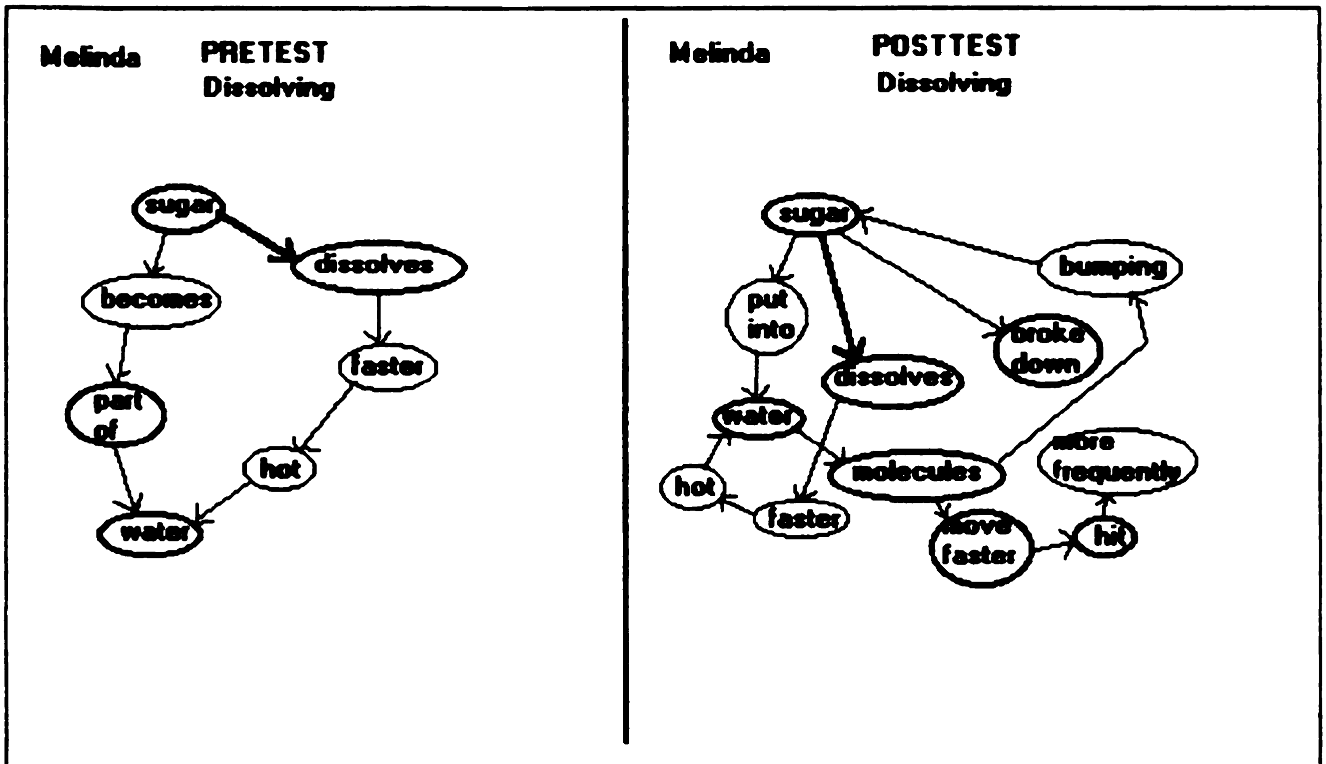


Figure H.19 Melinda's semantic node-link networks for Dissolving pretest and posttest written statements.

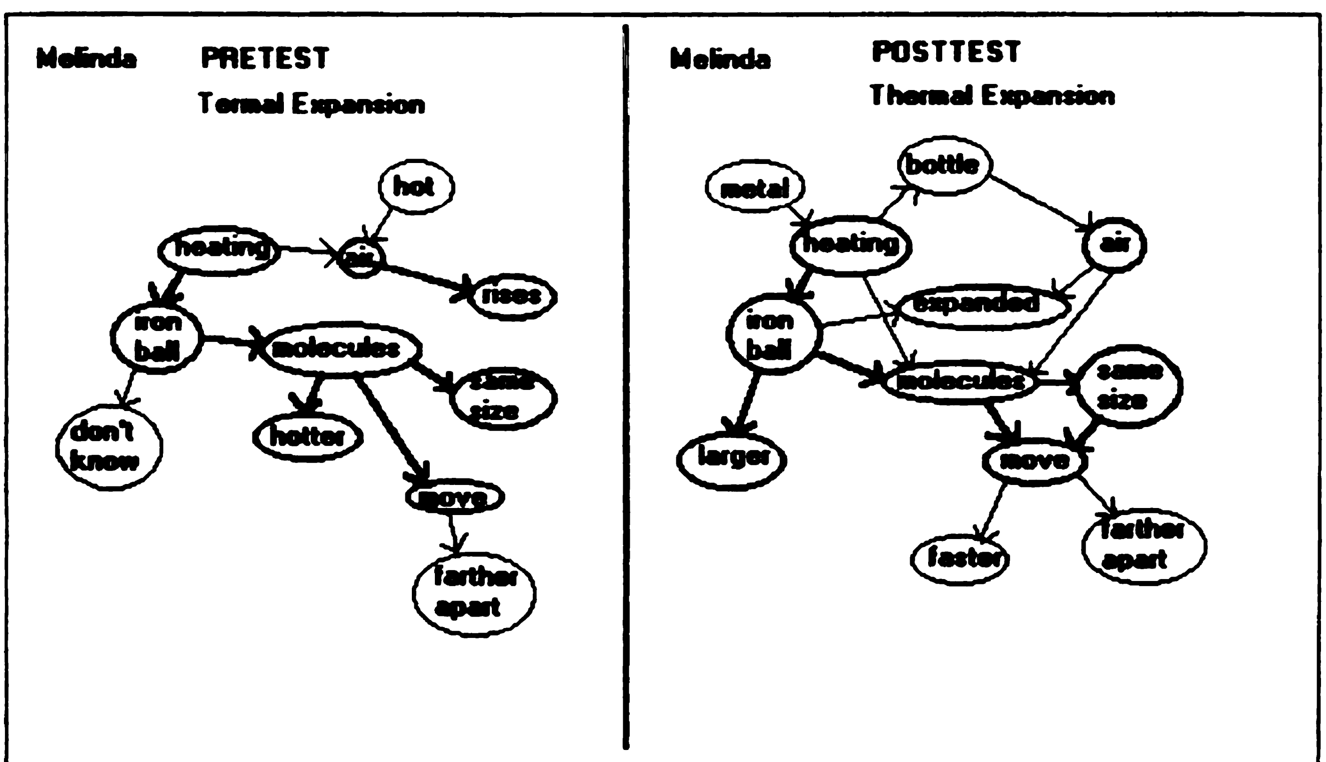


Figure H.20 Melinda's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

Antoine - Semantic Node-Link Networks for Pretest and Posttest

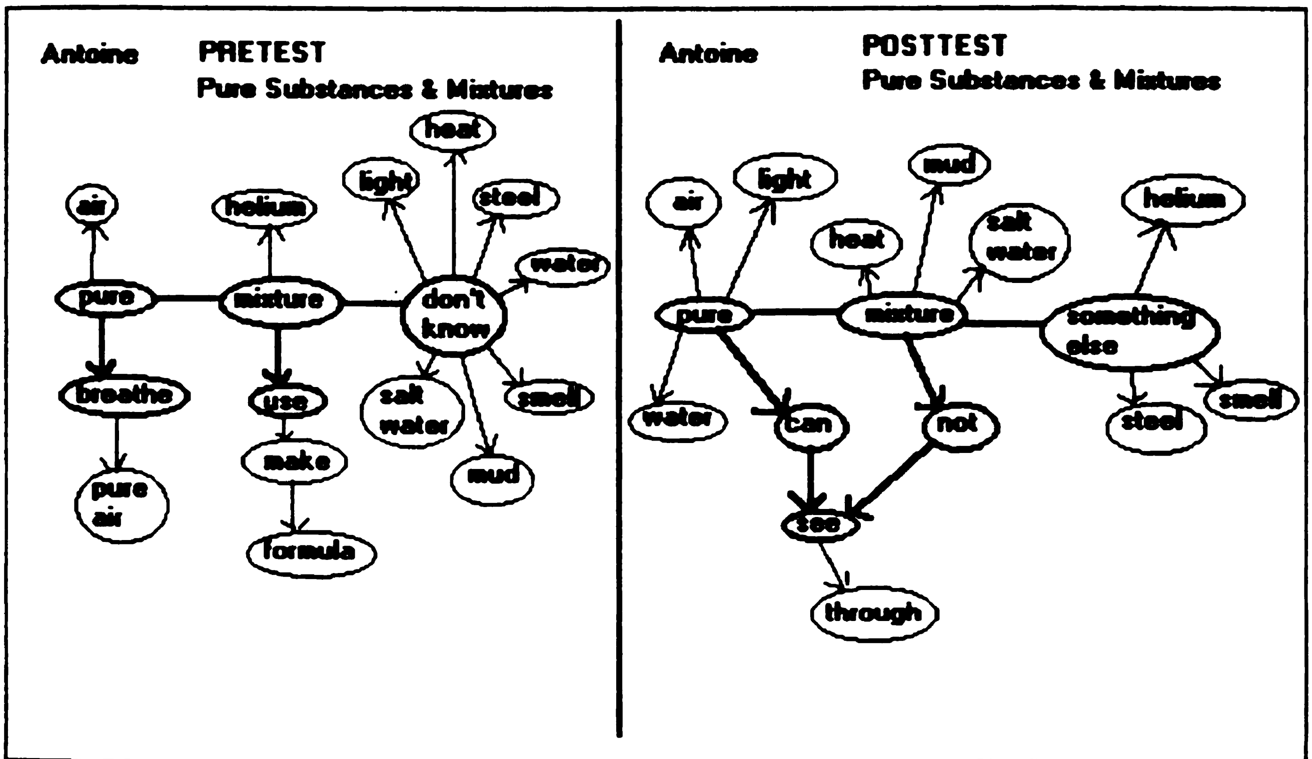


Figure H.21 Antoine's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

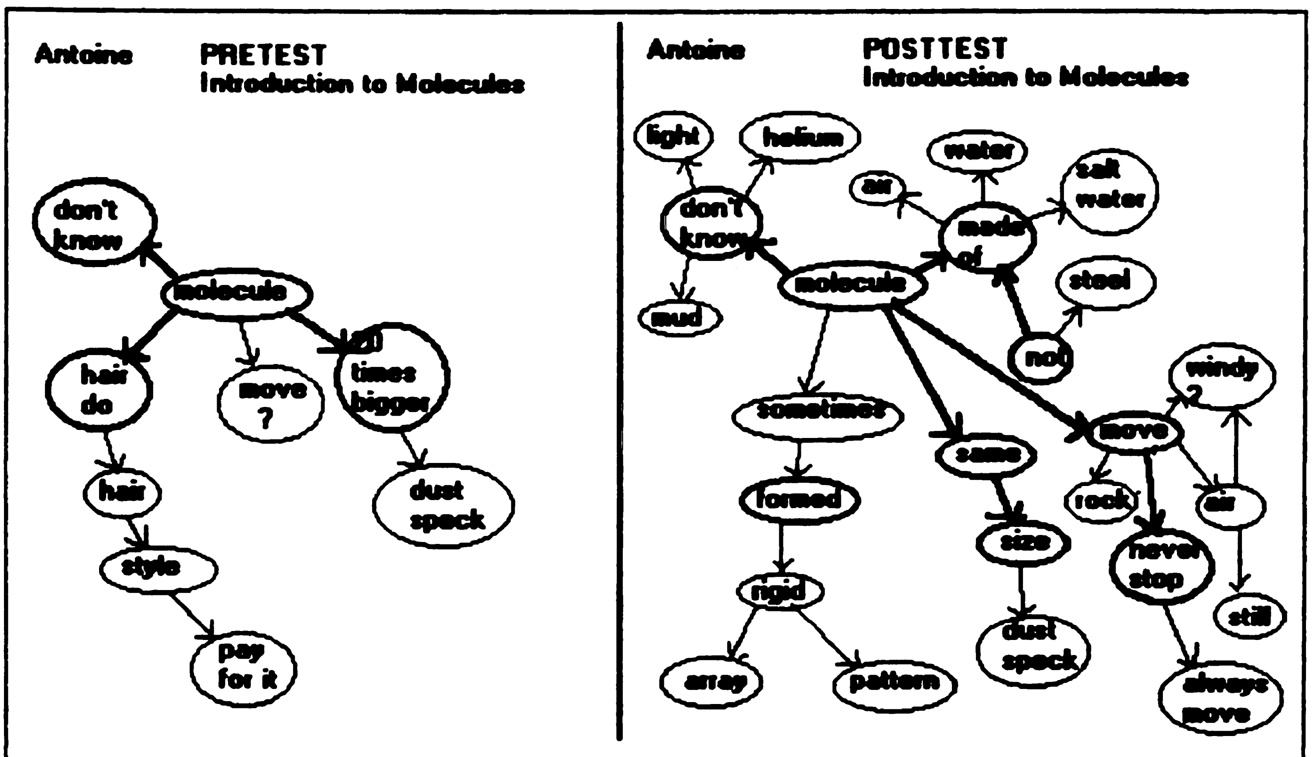


Figure H.22 Antoine's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

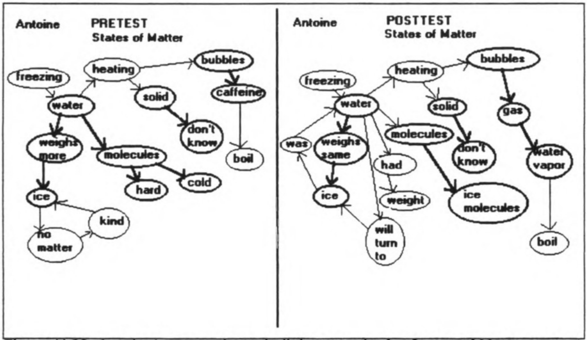


Figure H.23 Antoine's semantic node-link networks for States of Matter pretest and posttest written statements.

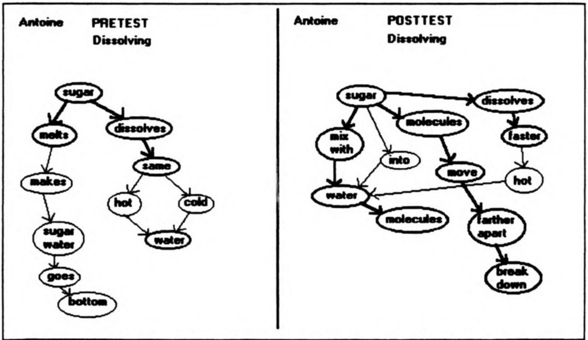


Figure H.24 Antoine's semantic node-link networks for Dissolving pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

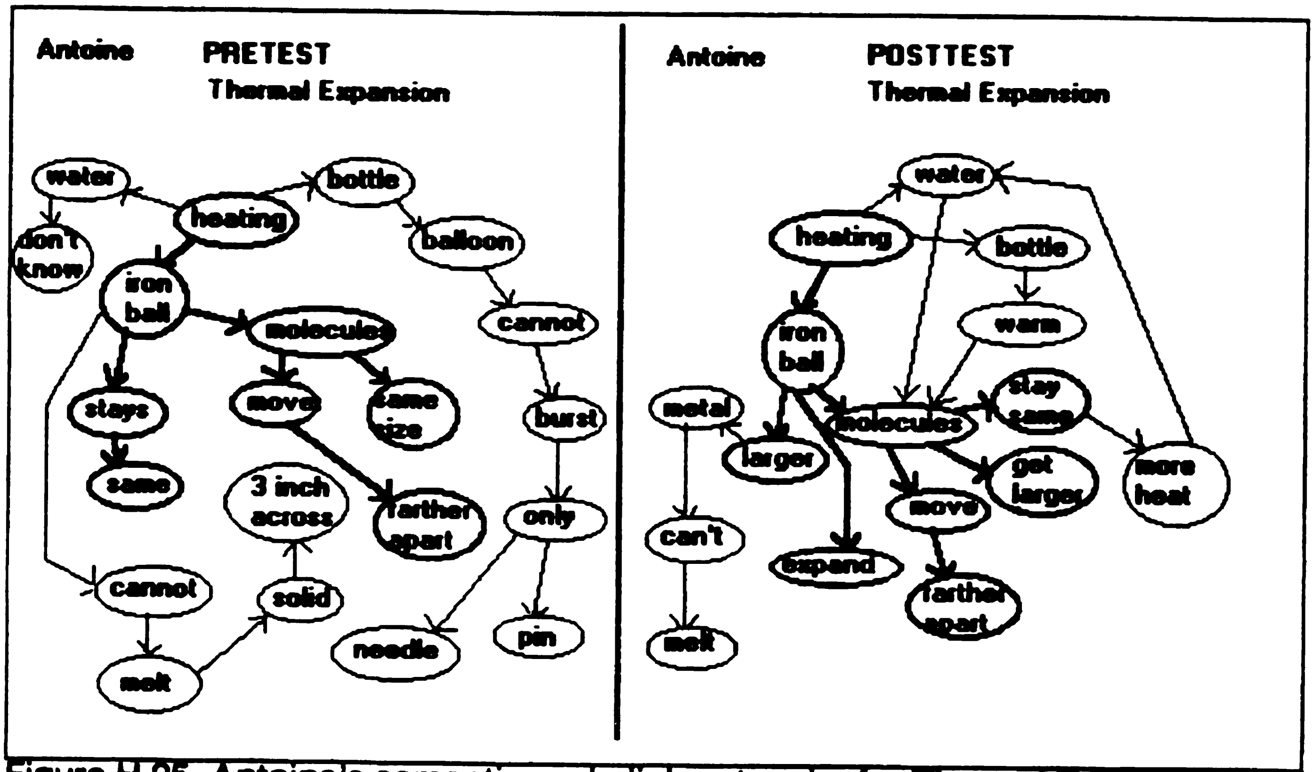


Figure H.25 Antoine's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

Jose - Semantic Node-Link Networks for Pretest and Posttest

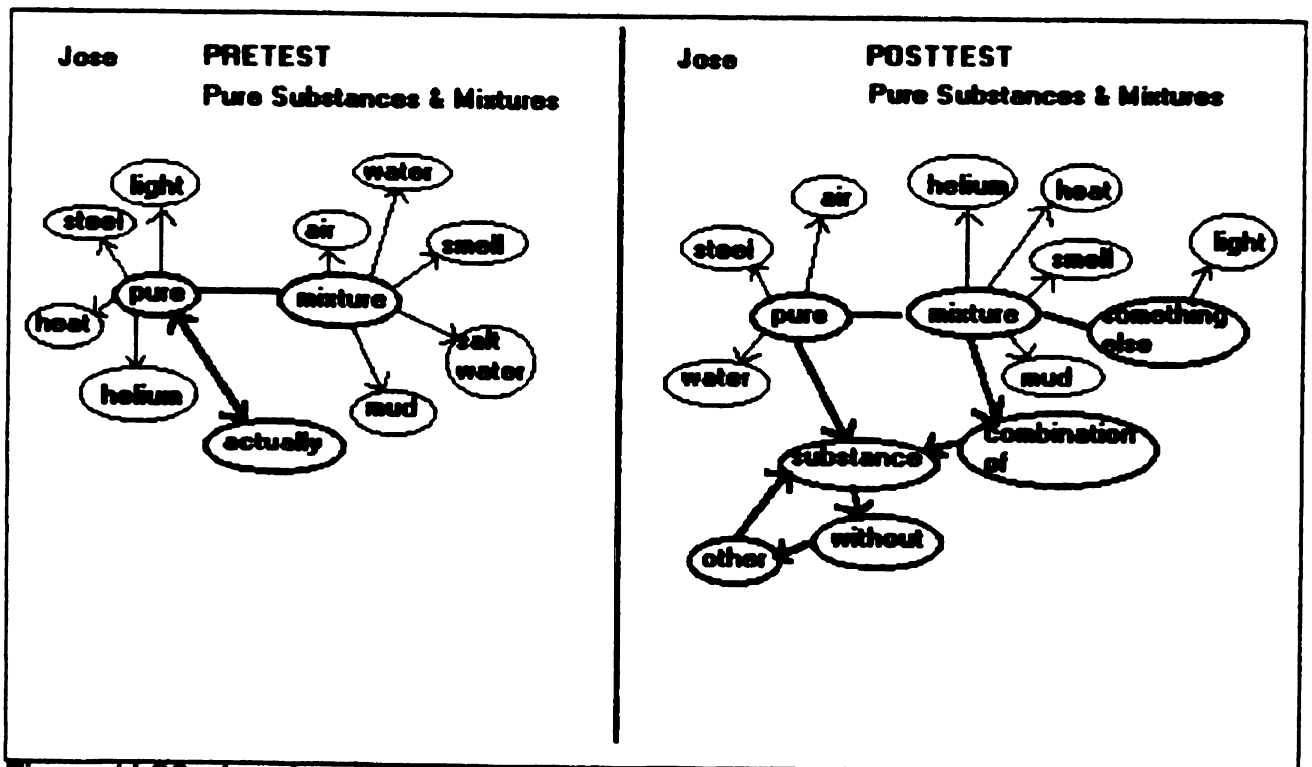


Figure H.26 Jose's semantic node-link networks for Pure Substances and Mixtures pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

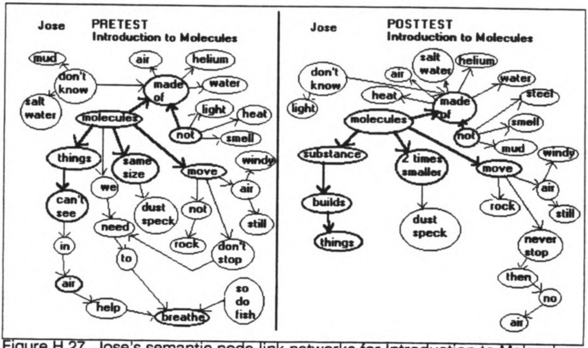


Figure H.27 Jose's semantic node-link networks for Introduction to Molecules pretest and posttest written statements.

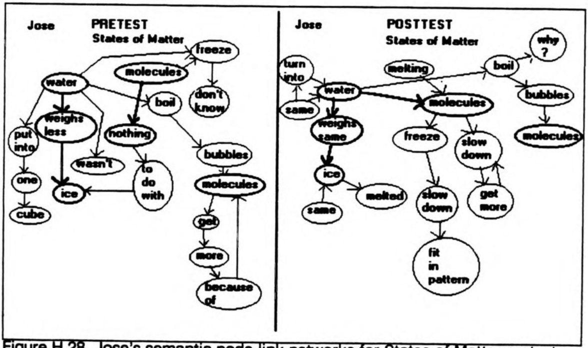


Figure H.28 Jose's semantic node-link networks for States of Matter pretest and posttest written statements.

TARGET STUDENTS' SEMANTIC NODE-LINK NETWORKS

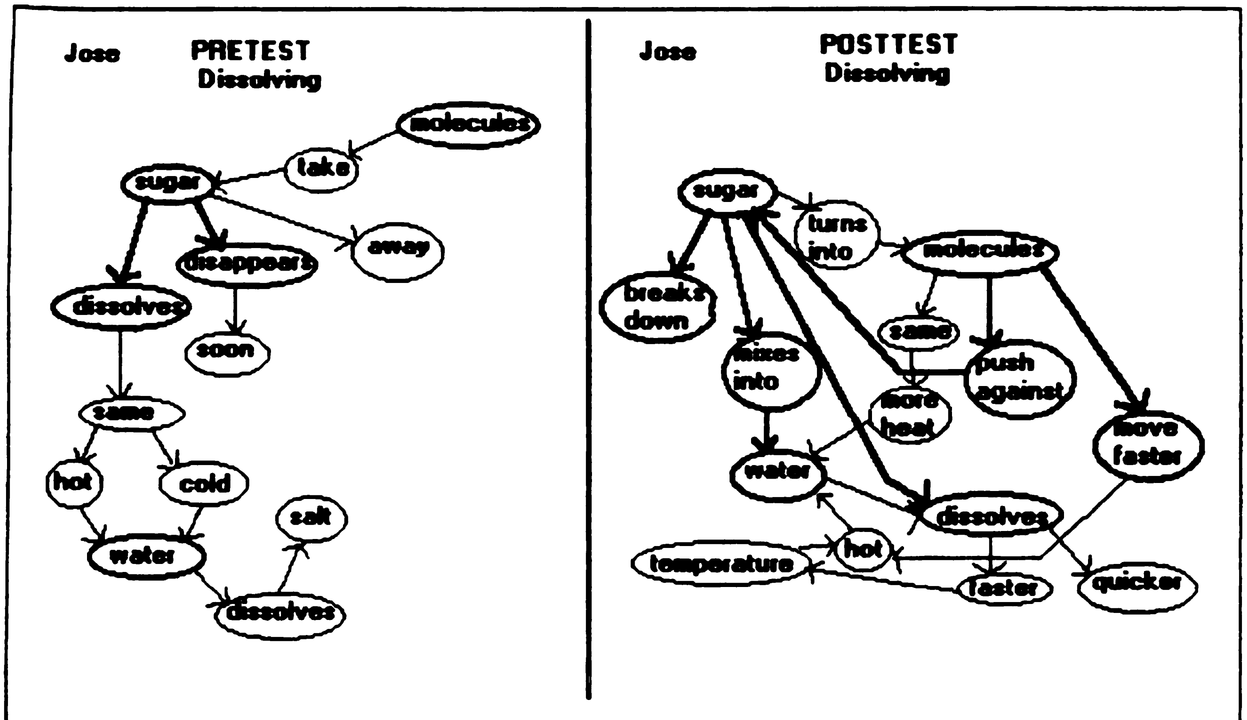


Figure H.29 Jose's semantic node-link networks for Dissolving pretest and posttest written statements.

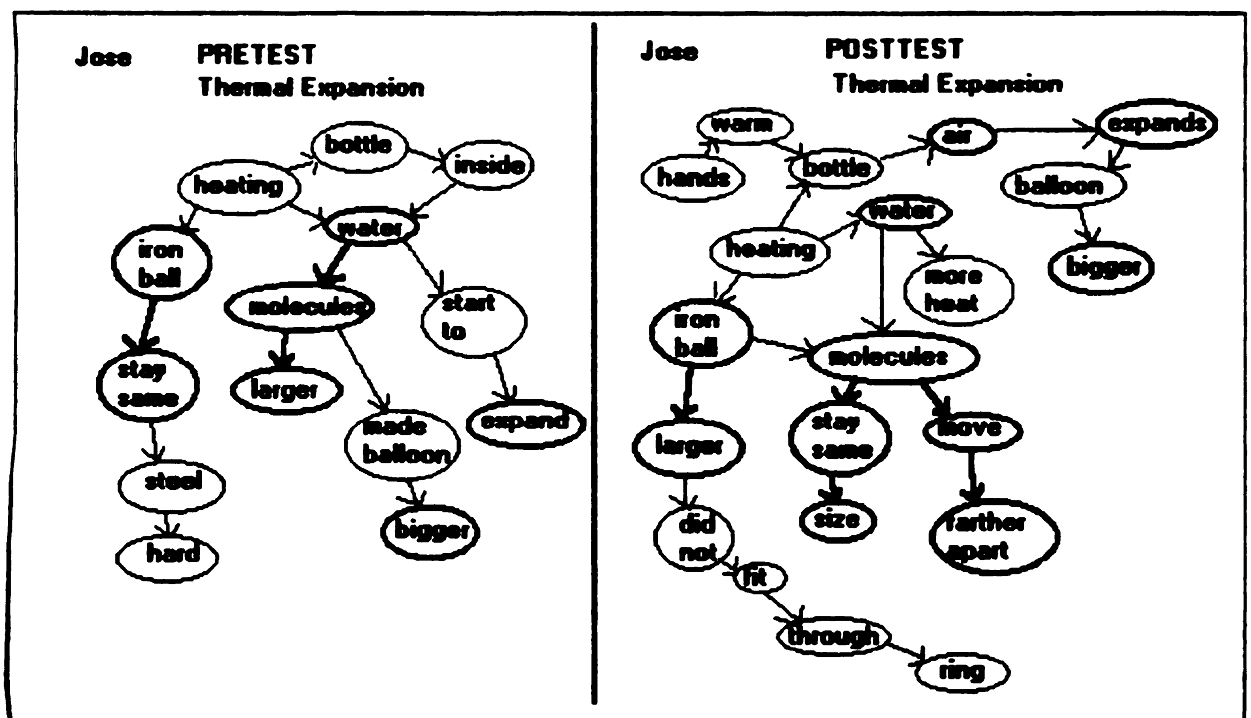


Figure H.30 Jose's semantic node-link networks for Thermal Expansion pretest and posttest written statements.

APPENDIX H

GOAL CONCEPTIONS FOR THE MATTER AND MOLECULES UNIT

APPENDIX H

GOAL CONCEPTIONS FOR THE MATTER AND MOLECULES UNIT

Issue	Goal Conception	Typical Alternative Conception
Macroscopic level: Conceptions about observable substances and phenomena		
1. Definition of Matter	1a. Solids, liquids, and gases are matter, other things (e.g., light, heat) are not.	1a. Gases and non-matter often incorrectly classified.
2. Conservation of Matter	2. Matter is conserved in all physical changes.	2. Matter not always conserved especially in changes involving gases. Words like "dissolve" and "evaporate" sometimes used as synonyms for "disappear".
3. Thermal Expansion	3. Substances expand when heated.	3. Substances may "shrivel up" when heated; expansion of gases explained in terms of movement of air.
4. Nature of Smells	4. Smells are gases, therefore matter, made of molecules, etc.	4. Smells considered ephemeral, not really matter.
5. Distribution of gases in space	5. Gases spread evenly through the spaces they occupy.	5. Distribution of gases is uneven befor or after expansion or compression.
7. Water vapor in air	7. Air contains invisible water vapor (humidity).	7. Water n air is visible (e.g., fog, "steam").
8. Condensation	8. Water vapor in air condenses on cold objects.	8. Condensate is "fog" or "breath"; or is formed by a reaction between heat and cold.
Molecular level: Conceptions about molecules and their nature		
9. Molecular constitution of matter	9. All matter is made of molecules, non-matter is not.	9. Material substances not described as molecular; non-matter described as molecules (e.g., "heat molecules"); molecules are <u>in</u> substances.

GOAL CONCEPTIONS FOR THE MATTER AND MOLECULES UNIT

10. Size of molecules	10. Molecules are too small to see, even with a microscope.	10. Molecules may be comparable in size to cells, dust specks, etc.
11. Constant motion	11. All molecules are constantly moving.	11. Molecules may sometimes be still, especially in solids.
12. Visibility of molecular motion.	12. Molecular motion continues independently of observable movement.	12. Molecules simply share in observable movements of substances (e.g., convection currents); molecules move in gases and liquids, not in solids
13. Molecular explanation of dissolving	13. Molecules of solute break away and mix with molecules of solvent.	13. Focus on observable substances or molecules themselves "dissolve".
14. Effects of heat on molecular motion	14. The only effect of heat on substances is to make its molecules move faster.	14. Molecules themselves can be hot or cold.
15. Molecular explanation of thermal expansion	15. Increased motion moves molecules farther apart.	15. Molecules themselves expand.
17. Molecular explanation of states of matter	17. States of matter are due to different arrangements and motions of molecules: -solids: vibrate in rigid array -liquids: random motion within liquid -gases: random motion, no limits	17. States of matter described only in terms of observable properties or properties of the state attributed to individual molecules (e.g., solid molecules are hard, liquid molecules are in drops, etc.)
18. Molecular explanation of changes of state	18. Heating and cooling cause changes of state by making molecules move faster or slower.	18. Heating and cooling make molecules "melt", "evaporate", etc.; or molecules begin to move when heated.

APPENDIX I

CODING SCHEME FOR PRETEST / POSTTEST

APPENDIX I

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 1a
1a1 Matter vs Non-matter (ignore smell)	1	All correct for both matter & non-matter All except light & heat marked as either pure or mixture. Light & heat marked as something else	+ 2
	2	All correct for matter, 1 or both incorrect for non matter: All except light & heat marked as either pure or mixture. Light and/or heat marked as substances (pure and/or mixture).	0
	3	1 or more incorrect for matter, both correct for non-matter.	0
	4	1 or more incorrect for both matter and non-matter.	-1
	5		
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	
1a2 Smell of popcorn	1	Smell as mixture	+ 1
	2	Smell as pure	0
	3	Smell as something else	- 1
	4		
	5		
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 1a
1b1 Pure vs. Mixture: Visible distinction (mud & saltwater only)	1	Mud and saltwater as mixtures	+ 1
	2	Mud and/or saltwater as pure and/or something else	- 1
	3		
	4		
	5		
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	
1c1 Pure Subst: Molecular distinction (ignore smell,mud & saltwater)	1	*All correct:helium & water ONLY	+ 2
	2	Partially correct: helium Or water ONLY	+ 1
	3	Partially correct: helium & water & anything else	0
	4	Partially correct: helium OR water & anything else	0
	5	Incorrect: neither helium nor water	- 1
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	
1c2 Mixture Molecular distinction (ignore smell, mud, & saltwater)	1	All correct: steel & air ONLY	2
	2	Partially correct: steel OR air ONLY	+ 1
	3	Partially correct: steel & air & anything else	0
	4	Partially correct: steel OR air and anything else	0
	5	Incorrect: neither steel nor air	- 1
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 1a
2a1 Explain pure vs. Mixture	1	-Correct molecular explanation: Pure = substance made of only one kind molecule. Mixture = substance made of 2 or more kinds of molecule	+2
	2	Correct macroscopic explanation: Pure = substance made of only one kind of matter/thing Mixture = substance made of 2 or more kinds of matter/things mixed together	+ 1
	3	Naive macroscopic explanation: Pure = clean, clear, natural, light or smooth, solids, can be touched, real Mixture = unclean, dirty, made of chemicals or by humans, liquids or gases, fake artificial	- 1
	4	Incomplete macroscopic answer	
	5	Incomplete microscopic answer	
	6		
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 1a,4
3a1	1	Circles only steel	+1, *
	2	Circles steel and anything else as solid except mud.	0,*
SOLID			
	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	-1, *
	9	No Response	
	0	Missing data	
3b1	1	Circles water & saltwater as liquid ONLY	+1, *
	2	Circles water, saltwater and anything else	0,*
LIQUIDS	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	-1, *
	9	No Response	
	0	Missing data	
3c1	1	Circles air, helium, & smell of popcorn ONLY	+2, +2
	2	Circles only air and helium	+1, *
GAS	3	Circles air OR helium only	0, *
	4	Does not circle air, helium, or smell of popcorn as gases	-1, *
	5	Circles air, helium, smell of popcorn and light, and/or heat	-1, *
	6	Circles air, helium, and light and/or heat	-1, *
	7	Other	-1, *
	8	I don't know	
	9	No response	
	0	Missing Data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 1a,4
3d1	1	Circles only light and heat	+2,*
	2	Circles only light	+1,*
	3	Circles only heat	+1,*
OTHER	4	Circles only light, heat, and smell of popcorn	0,-1
	5	Does not circle heat and light (circles something else)	-1,*
	6	None circled	-1,*
	7	Other	-1,*
	8	I don't know	0,*
	9	No response	
	0	Missing Data	
3e1	1	Circles solid or liquid	+1,*
	2	Circles both solid and liquid	+1,*
MUD	3	Circles Other	0,*
	4	Circles gas	-1,*
	5		
	6		
	7	Other	
	8	I don't know	-1,*
	9	No Response	
	0	Missing data	

C

Coding Variable (Item)	code
4a1	1
	2
	3
	4
	5
	6
	7
	8
	9
	0
4b1	1
molecules	2
	3
	4
	5
	6
	7
	[illegible]
	[illegible]
	[illegible]
4b2	
	[illegible]
	3
	4
	5
	6
	7
	8
	9
	0

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 9,10
4a1	1	Yes	0,*
	2	NO	0,*
	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
4b1	1	Scientific explanation: all matter is made of molecules (solids, liquids, or gases)	+2,*
molecules	2	Ambiguous: everything is made of molecules	0,*
	3	Molecules are pieces OF things	+1,*
	4	Molecules are pieces IN things	-1,*
	5	Ambiguous: little things, little pieces	0,*
	6	Not relevant (refer only to size)	0,*
	7	Other	-1,*
	8	I don't know	
	9	No Response	
	0	Missing data	
4b2	1	Too small to be seen even with a microscope	*,+2
	2	Microscopic	*,+1
	3	Ambiguous: too small to be seen; tiny, small, little	*,0
	4		
	5		
	6		
	7	Other	*,-1
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 9,4
5a1	1	Correct scientific conception: circles yes for both air & helium	+1,*
air & helium ONLY	2	Naive conception: circle yes for helium only	-1,*
	3	Naive conception: circle yes for air only	-1,*
	4	Naive conception: circles NO for BOTH	-2,*
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
5a2	1	Correct scientific conception: circles yes for both steel, water, and saltwater	+1,*
Steel and waters	2	Naive conception: circles yes for water & saltwater, NO for steel	-1,*
	3	Naive conception: circles NO for BOTH	-1,*
	4	Naive conception: circles yes for waters and IDK for steel	-2,*
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
5a3	1	Correct Scientific conception 1a: circles no for light and heat	+1,*
light and heat only	2	Naive conception: circles no for light ONLY	-1,*
	3	Naive conception: circles no for heat ONLY	-1,*
	4	Circles yes for BOTH	-2,*
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 9,4
5a4	1	Circles YES	*, +1
	2	Circles NO	*, -1
smell only	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
5a5	1	Circles YES	+1, *
	2	Circles NO	-1, *
mud only	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	-1, *
	9	No Response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 10
6a1	1	Circles a conception 10	-1
	2	Circles b	-1
molecular size	3	Circles c- 2 to 1000 times bigger	+1
	4	Circles c - more than 1000 times bigger or a lot	+2
	5	Circles c - no response or IDK for size	+1
	6		
	7	Other	
	8	I don't know	-1
	9	No Response	
	0	Missing data	

Coding Variable (Item)
7a1 What happens to sugar use both responses to code 8a1,8a2

Coding Variable (Item)
8a1 circles a

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 2,4,13
7a1	1	Correct molecular explanation: water breaks away the sugar molecules which <u>mix with the water</u>.	+2, 0,+2
What happens to sugar	2	Correct macroscopic explanation: sugar mixes with water.	+2, +2, 0
	3	Ambiguous molecular explanation: not clear what happens to sugar molecules	0,0,0
use both responses to code 8a1,8a2	4	Ambiguous macroscopic explanation: sugar evaporates, disappears, turns invisible, breaks down, melts, dissolves	0,0,0
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 11,13,14
8a1	1	Correct microscopic explanation: water molecules move faster when heated and break away sugar molecules faster	+1,+2,+2
circles a	2	Incomplete correct microscopic explanation: molecules move faster when heated but not clear what happens to sugar	+1,0,+2
	3	Naive microscopic explanation: Molecules start to move when heated; cold molecules do not move	-1,0,*
	4	Ambiguous macroscopic explanation: water moves faster when heated (convection); no mention of molecules.	0,0,0
	5	Macroscopic explanation about melting: hot water melts sugar; heat causes faster melting	0,0,*
	6	Not relevant; answers B, or C	0,0,0
	7	Other	
	8	I don't know	*,*,-1
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

8a2	1	Circles b	0,0,-1
	2	Circles c	-1,0,-1
circles	3		
b,c,or d	4		
	5		
	6	Not relavant, circles a	0,0,0
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 2,3,14,15
9a1	1	Circles a: correct molecular explanation: heat causes molecules to move faster and therefore farther apart	*,2,2,2
thermal expansion	2	Circles a: correct macroscopic explanation: heat expands the ball	*,2,0,0
	3	Circles a: naive molecular explanation for expansion: <u>molecules expand</u> or increase so ball becomes larger	*,2,0,-1
	4	Circles b: gives naive explanation for contraction: heat makes ball shrink; molecules shrink or leave the ball, ball melts	*, -1,0,0
	5	Circles c: heat has no effect: ball is a solid and solids don't change form unless they melt	*,-1,-1,0
	6	Circles c: some correct answer	
	7	Other	*,-1,-1,*
	8	I don't know	
	9	No Response	
	0	Missing data	
10a1	1	Circles a	-1,0,*,0
	2	Circles b	0,1,*,-2
choices heating metal	3	Circles c	0,1,*,1
	4	Circles d	0,-1,*,-1
	5		
	6		
	7	Other	
	8	I don't know	*,-1,-1,*
	9	No Response	
	0	Missing data	

11a1

hot vs. cold water

Coding Variable (Item)

12a1

circles a

CODING SCHEME FOR PRETEST / POSTTEST

11a1	1	Circles c ONLY	*,*,+1,*
	2	Circles a and c	*,*,+1,-2
hot vs.	3	Circles a ONLY	*,*,0,-2
cold	4	Circles d ONLY	*,*,-2,*
water	5	Circles e ONLY	*,*,-1,*
	6	Circles c and e	*,*,+1,*
	7	Other (except f)	*,*,-1,-1
	8	I don't know	*,*,-1,*
	9	No response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 3,14,15
12a1	1	Naive macroscopic explanation: heat shrinks things	-1,0,0
circles a	2	Ambiguous macroscopic explanation: the balloon will pop or deflate	-1,0,0
	3	Ambiguous microscopic explanation: molecules will escape, or shrink, or "fatigue" etc.	-1,-1,0
	4		
	5		
	6	Not relevant circles b	
	7	Other	-1,*,*
	8	I don't know	-1,*,*
	9	No Response	
	0	Missing data	

CODING SCHEMÉ FOR PRETEST / POSTTEST

12b1 circles b	1	Correct microscopic explanation: molecules of a substance move faster and farther apart when a substance is heated	2,2,2
	2	Correct macroscopic explanation: molecules move farther apart (no mention of speed)	2,0,2
	3	Correct macroscopic explanation: heat causes air in the bottle to expand and inflate the balloon	2,0,0
	4	Naive microscopic explanation: molecules themselves expand	
	5	Naive macroscopic explanation: Talks of movement of air from bottle up into balloon-- more air pushes up balloon, not air rises, not air chases cold air, heat rises	-1,0,0
	6	Not relevant (circles a)	
	7	Other	-1,*,*
	8	I don't know	-1,*,*
	9	No response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 4,5
13a1 smell	1	Scientific explanation: molecules or particles of onion: onion gas	2,*
	2	Non-specific scientific explanation: molecules or gas	1,*
	3	Correct macroscopic explanation: something in the onion (eg. chemicals, spicy liquid)	0,*
	4	Non-matter explanation: odor, smell, not- matter	-1,*
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 11,12
13b1	1	Diffusion of molecules or gas through air (molecules move from onion to nose)	*,2
	2	Convection of gas (gas or molecules move with the air)	*,1
movement	3	Convection of ambiguous substance (air pushed it; smell floats, smell spreads out through room; smell sticks to air molecules)	*,0
	4	No explanation of motion (smell "leaks out" or "gets out" of onion)	*,-1
	5		
	6		
	7	Other (you just smelled it, it reached you)	
	8	I don't know	
	9	No Response	
	0	Missing data	
14a1	1	Circles a,a,a,	1,1
	2	Circles a,a,b	-1,1
choices	3	Circles a,b,b or a,c,b	-1,-1
	4	Circles a,a,c	0,1
molecular movement	5	Circles a,b,c	0,-1
	6		
	7	Other	
	8	I don't know	-1,-1
	9	No Response	
	0	Missing data	
14b1	1	Answers yes	-1,*
	2	Answers no	+1,*
stop moving	3		
	4		
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

14b2

explain

Coding Variable (Item)

15a1

weight

15b1

CODING SCHEME FOR PRETEST / POSTTEST

14b2	1	Scientific conception: molecules are in constant motion	2,2
explain	2	Naive conception 12: molecules move with the substance. Air keeps things moving; when wind stops, molecules stop	-1,-1
	3	Answers focus on states of matter: molecules do not move in solids	-1 -1
	4	Molecules are alive: they will stop moving when they die.	-1,0
	5		
	6		
	7	Other	
	8	I don't know	-1,-1
	9	No Response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 2
15a1	1	Circles a	- 2
	2	Circles b	+ 1
weight	3	Circles c	- 2
	4		
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
15b1	1	Explains conservation of matter (circles b)	2
	2	Gives reasons for non-conservation (weighing more/less): no longer a solid, ice is larger than water	- 1
	3	Avoids conservation: some evaporates	0
	4		
	5	Non- explanation: repeats answer to 15a1: volume changes, weight stays the same.	0
	6		
	7	Other	
	8	I don't know	- 1
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 11,17,18,15
16a1	1	Goal: heat makes molecules move faster (and farther apart)	*,*,2,*
motion of molecules	2	No motion in solids; heat makes molecules begin to move	-1,0,0,*
	3	Macroscopic movement: the solid begins to move, drip, or flow	0,0,-1,*
	4		
	5		
	6	Not relevant: mentions only structure	
	7	Other	-1,-1,0,*
	8	I don't know	
	9	No Response	
	0	Missing data	
16a2	1	Goal: heat makes molecules break out of array, or out of their pattern, or move past each other.	0,2,0,*
structure	2	Attributes macroscopic properties to molecules: molecules turn into a liquid heat breaks down or melts molecules	0,-1,-1,*
	3	Macroscopic description: heat makes things melt or solid turns into liquid	0,0,0,*
	4	Molecules move farther apart.	0,1,0,*
	5		
	6	Not relevant: mentions only motion of molecules	
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
17a1	1	Circles c ONLY	*1,1,*
freezing	2	Circles a or b	*,-2,0,*
	3	Circles d	*,0,0,-1
	4	Circles c and a and/or b	*,-1,0,*
	5		
	6		
	7	Other	
	8	I don't know (circles e)	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 18
18a1	1	Water vapor, steam	
	2	Air, oxygen, gases	
bubbles	3	Nothing, heat	
	4	Molecules	
	5	Water	
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
18b1	1	Correct molecular explanation: molecules move faster and farther apart when heated, thus causing boiling	2
explain boiling	2	Correct macroscopic explanation: water changes to steam, or heat pushes water up into bubbles	1
	3	Incomplete molecular explanation	1
	4	Attributes physical changes to molecules: molecules grow or degrade; molecules get hotter	- 1
	5	Refers to air: heat releases air or changes water to air or air pushes up	
	6	Macroscopic description: heat makes the water boil, the temperature rises, becomes hotter so it boils, the gas flame causes boiling, heat erupts in bubbles, (molecules) bubble up	0
	7	Other	- 1
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Conception Scores 2,19,18
19a1	1	-Water has gone (or evaporated) into the air	2,*,*
	2	Water goes into the clouds	1,*,*
evapor-ation	3	Evaporated	0,*,*
	4	Dissolved, disappeared	-1,*,*
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
19a2	1	Scientific explanation: faster-moving molecules escape from liquid, go into air	*,2,*
explain	2	Naive microscopic explanation: water turns into molecules and goes into air, molecules evaporate	*,0,*
	3	Macroscopic explanation with conservation: water goes into air	*,0,*
	4	Ambiguous macroscopic explanation: water evaporates or turns into air	*,0,*
	5	Requires heat	
	6	Incomplete microscopic explanation	*,1,*
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

Coding Variable (Item)	code	Response Features	Scores 7,8
20a1	1	Water, moisture, steam, ice	*, 1
	2	Air, oxygen, gases	
what is	3	Breath or air you breathed out	*, 0
fog?	4	Heat or cold	
	5	Molecules	*, 0
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	
20b1	1	Explanation refers to relative temperature of substances: windows are cold, face is	
temp.		hot; warm (air or water) hits cold windows	
	2	Ambiguous about what is warm and cold: hot and cold mix to form fog	*, -2
use	3	Only hot or cold mentioned: heat from your	
responses		body, fog forms on cold windows	
together	4		
to code	5		
20b1,b2,b3	6	Not relevant (no mention of temperature)	
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

CODING SCHEME FOR PRETEST / POSTTEST

20b2 change of state	1	Change of state of water: water vapor (or steam, moisture) changes to water drops (or liquid)	+2,+2
	2	Change in one substance to another: air changes to water, hot breath changes to water, air changes to fog	
	3	No change of state; the person's breath caused the fog, or the air caused the fog, or breath or steam or heat cannot escape through windows; breath etc. can be seen on windows or sticks to windows	*,-1
	4		
	5		
	6		
	7	Other	
	8	I don't know	
	9	No Response	
	0	Missing data	

Coding Variable (Item)	code	Response Features	Conception Scores 17,7,18,14,8
20b3 molecular explanation	1	Scientific molecular explanation: when cooled molecules slow down and move closer together	1,1,2,*,*
	2	Naive molecular explanation: molecules degrade grow smaller, or somehow change to form a liquid	*,0,-2,*
	3	Ambiguous: Molecules themselves become cold	*,0,-1,-1
	4		
	5		
	6	Not relevant (no mention of molecules)	
	7	Other	*,0,-1,-1
	8	I don't know	
	9	No Response	
	0	Missing data	
21a1 condensation	1	Circles a	*,-1,*,*,-2
	2	Circles b	*,-1,*,*,-2
	3	Circles c	*,1,*,*,1
	4	Circles d	*,-1,*,*,-2
	5	Circles b & c	*,0,*,*,0
	6		
	7	Other	*,*,*,*,-1
	8	I don't know	*,*,*,*,-1
	9	No Response	
	0	Missing data	