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DAVID CLAIR EICHINGER

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Charles W. Anderson
Major professor

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ANALYSES OF MIDDLE SCHOOL STUDENTS' SCIENTIFIC ARGUMENTS IN COLLABORATIVE PROBLEM SOLVING CONTEXTS

By

David Clair Eichinger

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ABSTRACT

ANALYSES OF MIDDLE SCHOOL STUDENTS' SCIENTIFIC ARGUMENTS IN COLLABORATIVE PROBLEM SOLVING CONTEXTS

by

David Clair Eichinger

This study examined how individuals and groups of students constructed scientific arguments as they engaged in a series of collaborative problem solving activities. The study was based on research traditions in conceptual change, social semiotics, and argumentation.

Two research questions were investigated: a) What is the nature of students' scientific arguments and how do they approximate or fail to approximate scientists' arguments for relatively complex scientific problems?; and b) Does the nature of students' arguments and argumentation processes change over time, and if so, in what ways?

Two target groups of four students each were videotaped during three months of instruction in a sixth grade science classroom in a midwestern urban school district. Data analyses focused primarily on an examination of students' small group discussions of four collaborative activities that addressed aspects of the kinetic molecular theory.

In general, the results show much variability in the degree of scientific and logical sophistication that students developed in their individual and group arguments during their study of the curriculum unit. While a few students demonstrated significant progress in their understanding and application of scientific forms of argumentation, the majority of students continued to approach and solve these problems in much less complex and sophisticated ways.

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CHAPTER ONE

INTRODUCTION

Statement of the Problem

Understanding science means more than simply memorizing facts, formulas, and vocabulary terms. Developing meaningful understandings of science involves at least two key components: a) linking scientific concepts amongst themselves and with one's own personal knowledge of how the world works; and b) using scientific knowledge to describe, explain, predict, and control the world around us in a variety of contexts, both in and out of school (Anderson & Roth, 1989; Smith, 1991). In order to develop this kind of scientific literacy, students need to acquire an understanding of the principles and theories of science, their relationships, and their applications (AAAS, 1989). Equally important is the development of fluency in the use of the language and the cognitive tools of the discipline of science (Heath, 1983; Lemke, 1990; Michaels & O'Connor, 1990).

Clearly, however, many students do not develop meaningful understandings of science. Results of recent national science achievement testing (NAEP 1990) show that American students have made little progress in their science performance over the last twenty years. In general, students' basic knowledge of science stagnates by eighth grade, and relatively few students develop their science knowledge further (Education Department, 1992). Comparisons of science achievement between American students and those in 14 other countries show that U.S. students rank near the bottom in math and science performance (IAEP, 1991).

While the results of these national and international achievement tests are compelling, even more disconcerting are the findings of research on students' scientific understanding and problem solving which show that many students do not develop either structural or functional literacy in science (Anderson & Roth, 1989; Driver, Guesne, &

Tiberghien,1985; Pines & West, 1986). That is, they are unable to make meaningful links between their personal knowledge of the world and scientific knowledge. In addition, they are unable to use this scientific knowledge to solve problems, provide explanations, make predictions or design ways of testing their ideas.

Several research traditions have addressed various aspects of these problems by examining what it means to "understand" science, how students learn science, and what the important components of meaningful scientific understanding are. These research traditions are described below.

Research Traditions

Much of the recent research in science education has focused on examining students' existing knowledge of various scientific concepts and the ways in which they develop progressively richer and more sophisticated understandings of a particular body of scientific knowledge. One research tradition that has studied these issues is conceptual change research. Researchers supporting this perspective claim that, in order to achieve meaningful understanding, students need to undergo a process of conceptual change. This involves integrating scientific concepts and strategies with students' own "conceptual ecologies", or their personal concepts and learning strategies (Posner, Strike, Hewson, & Gertzog, 1982). Recent research in conceptual change teaching and learning has shown that teaching strategies and curriculum materials that are designed to help students integrate elements of scientific knowledge with their own personal knowledge are more successful in helping students develop meaningful understandings of science (Anderson & Roth, 1989; Berkheimer, Anderson, & Blakeslee, 1990; Driver & Brook, 1987; Minstrel, 1984; Linn & Songer, 1988). In other words, students using the conceptual change curriculum materials are able to develop scientific knowledge that is better integrated and more useful in helping them solve problems than the knowledge that is gained by students using more traditional science curricula (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, in press).

One limitation of this tradition is that much of the conceptual change research has focused primarily on whether and how individual learners develop scientific content knowledge. In part, this focus on the individual learner is due to a reliance on data from individually administered instruments such as written tests and clinical interviews. In large part, however, the individual focus is due to traditional assumptions about the nature of learning and cognitive development that have prevailed for several decades. This focus on learning as an individual activity contrasts with current views of cognition proposed by a second research tradition which characterizes learning in general and the development of scientific understanding in particular as a social, rather than an individual, process. According to the social constructivist perspective, knowledge growth occurs as a result of personal interactions in social contexts and the eventual internalization of this socially constructed knowledge (Brown, Collins, & Duguid, 1989; Brown & Campione, 1990; Vygotsky, 1978; Wertsch, 1985). Rather than being a process of accumulating knowledge or accommodating new theories with one's personal knowledge, learning is viewed as a process of acculturation in which learners become members of particular disciplinary communities (Collins, Brown, & Newman, 1989; Rogoff, 1990). Thus, learning science becomes a process of appropriating the concepts, the cognitive tools, and the discourse of the scientific community while interacting with more scientifically literate people (Edwards & Mercer, 1988; Heath, 1983, 1986; Lemke, 1990; Michaels & O'Connor, 1990; Roseberry, Warren, & Conant, 1990; Warren, Roseberry, & Conant, 1989).

In science, part of learning these ways of talking and thinking scientifically involves being able to use the ideas of science to construct reasoned arguments about how the world around us works. The ability to solve problems, give explanations, make predictions and devise plans to control the world around us all depend on being able to develop scientific arguments that explain and justify our problem solutions. The norms for constructing arguments in the scientific community are not necessarily the same as those found in other disciplinary communities. Scientific norms include relating explicitly stated theories and specific evidence to explain an event or phenomenon, and a dependence on syllogistic reasoning and a distrust of narrative or anecdotal data or emotion (Keller, 1985; Toulmin, 1958).

Thus, a third research tradition related to this study concerns argumentation by children and adults. Some researchers have proposed frameworks for describing and analyzing the structure of scientific arguments (Toulmin, 1958). Others have investigated the kinds of arguments used by children and the kinds of argumentation processes they use while working together to solve a problem (Miller, 1987). Still others have studied the kinds of explanations and arguments given by science students, and their research has shown that students' explanations and arguments differ from scientists' in terms of their scientific content, syntax, and explanatory ideals (Hesse & Anderson, 1992; Solomon, 1985).

Thus, the ability to develop scientific arguments is considered to be a critical component of scientific literacy, and studying the content and nature of students' arguments and argumentation processes provides a means for examining the nature of their scientific understanding. In light of current conceptions of the learning process as a social activity, it is important to look at students working in collaborative groups as they solve problems that include messy, real-world problem situations. These kinds of problems allow students to use their own personal ideas about how the world works as well as the scientific concepts they are taught in the classroom, and they thus provide a means for investigating the extent to which students are integrating their own ideas with the scientific ideas. In addition, by looking at collaborative problem solving situations, it is possible to study the relationship between the development of collective and individual scientific understanding. By comparing the students' arguments and argumentation with the ideal arguments and argumentation processes that would likely be developed by a group of scientifically literate members, it is possible to examine the extent to which students internalize the concepts, the cognitive tools, and the discourse of the scientific community. Finally, by examining students' arguments and their collaborative interactions during a series of problem solving situations, it is possible to study the extent to which their understanding of the scientific content, their understanding of the nature of scientific arguments, and their argumentation processes change over time.

Objectives and Research Questions

This study investigated the development of middle school students' scientific arguments in collaborative problem solving situations. In particular, the study examined how individuals and groups of students developed their understanding of a particular body of science content (the kinetic molecular theory) and how they used this content knowledge to construct arguments explaining and defending their solutions to a series of relatively complex and "messy" science problems. The research questions addressed by this study were as follows:

1. What is the nature (in terms of science content and logical structure) of the scientific arguments and the argumentation processes developed by sixth grade students? How do these arguments and processes approximate or fail to approximate scientists' arguments and argumentation for relatively complex science problems?

2. Do the content and logical structure of students' arguments and the argumentation processes they use change over time? If so, in what ways?

Overview of Research Design

The study followed two target groups of four students each over a three month period as they were taught a conceptual change unit on matter and molecules. The unit was taught by the classroom teacher and instruction took place in an urban, multicultural school setting. Data in the form of videotapes of whole class and small group classroom observations, copies of students' written work, and individual pre- and post-instruction clinical interviews and tests were analyzed to study whether and how individual students and small groups socially constructed and used the the knowledge, cognitive tools, and discourse of the scientific community.

The study included multiple occasions on which the students, individually or in small groups, solved two different types of problems. Explanation problems involved describing and making sense of phenomena that the students encountered, either through hands-on experimentation, demonstrations, or through other means. Design problems involved planning, and in some cases carrying out, strategies to achieve some practical goal. Analysis frameworks based on the work of Miller (1987) and Toulmin (1958) were developed to analyze how students decided on a set of collectively validated statements as their solution to a science problem and the criteria they used for judging the validity, the relevance, and the completeness of possible solutions to the problem.

Methodological Limitations

This study was very limited in scope. It involved only eight students from a single classroom taught by one teacher. In order to conduct in-depth analyses of students' arguments and interactions over time, it was necessary to limit the number of students involved in the study. Thus, the generalizability of the findings to other classrooms is necessarily limited.

In addition, due to limited resources and time, all of the analyses were carried out by the researcher himself. This raises potential questions concerning the reliability of the findings. Further research in a variety of settings is needed to ensure the validity and reliability of the research methods and findings.

CHAPTER TWO

REVIEW OF THE LITERATURE

This chapter presents a review of the literature relevant to this study. The chapter includes a discussion of previous research related to the three research traditions described in Chapter 1: 1) conceptual change research, 2) social constructivism and social semiotics, and 3) arguments and argumentation. The literature review for each of the first two research traditions examines important ideas related to the nature of students' scientific understanding or scientific literacy. The review of the literature for the third research tradition examines the nature of scientific arguments and argumentation and collective validation processes, and previous research on students' explanations and arguments is discussed. The chapter also includes a discussion of why the research questions presented in this study are important and relevant for shedding new light on issues concerning the nature of students' scientific understanding, and how the findings from previous research are included in the design of the present study.

Part I: Conceptual Change

One research perspective that has provided important insight on the nature of students' scientific understanding is the conceptual change research tradition. Researchers in this tradition have developed explanations for what it means to understand science and how the learning of science occurs (Anderson, 1987; Anderson & Smith, 1987; Brook, Driver,& Johnston, 1988; Carey, 1986; Driver, 1989; Nickerson, 1985; Nussbaum & Novick, 1982; Pines & West, 1986; Posner, Strike, Hewson & Gertzog, 1982; Smith, 1991; Strike & Posner, 1985; Toulmin, 1972; Vosniadou & Brewer, 1987, Wittrock, 1985). Researchers supporting this perspective agree that, in order to achieve meaningful understanding of science, learners must undergo a process of conceptual change involving the integration of canonical scientific concepts and strategies with their own personal concepts and learning strategies, what Posner et al. (1982) refer to as the learner's "conceptual ecology."

Based on this assumption that learning results from a process of conceptual change, Anderson & Roth (1989) proposed a definition of scientific understanding that includes two major components: a structural component and a functional component. The structural component of meaningful scientific understanding involves the development of linkages between students' prior, everyday explanations of how the world works and scientific explanations of natural phenomena. In addition, learners must develop knowledge that includes conceptual coherence among scientific concepts themselves. The functional component of scientific understanding includes the ability to use this knowledge to perform the essential scientific activities of describing, explaining, predicting, and controlling the world around us. As Anderson and Roth (1989) point out, the structural and functional components of scientific understanding are interdependent, since any one of the scientific activities may require the integration of several concepts, and any particular concept can be used for more than one function. Thus, the process of conceptual change that results in meaningful scientific understanding involves the development of conceptually coherent knowledge that is integrated with one's personal knowledge, and the ability to use this knowledge to perform the basic scientific functions.

Research has shown that the conceptual change process is long and gradual, since it requires students to modify or restructure their prior knowledge that conflicts with scientific knowledge. Recent studies have shown that the difficulties that students experience during this process are common across subject areas and across grade levels (Anderson & E. Smith, 1983; Hesse & Anderson, 1992; Lee et al., in press; Minstrell, 1984; Nussbaum & Novak, 1976; D. Smith, 1987). But as Posner et al. (1982) and

Toulmin (1972) point out, conceptual change learning requires more than simply changing one's prior knowledge of a particular body of content. Other aspects of students' conceptual ecologies must also be modified, such as the analogies and metaphors they use to explain phenomena, and their epistemological beliefs, including their beliefs about the nature of scientific knowledge and their criteria for what they consider to be a complete and convincing scientific explanation. Given the scope of the changes that are required for knowledge restructuring to occur, it is not surprising that students' misconceptions and prior knowledge structures are so resistant to change (Anderson, Sheldon, & Dubay, 1990; Bishop & Anderson, 1990; Lee et al., in press; Roth, 1985). However, studies have demonstrated that when students receive support in the form of conceptual change curriculum materials and instructional techniques, they are more successful in developing meaningful understandings of science than when they study science using traditional curriculum materials and techniques (Anderson & Roth, 1989; Berkheimer, Anderson, & Blakeslee, 1990; Driver & Brook, 1987; Lee et al., in press; Linn & Songer, 1988; Minstrel, 1984).

Part II: Social Constructivism and Social Semiotics

Two important limitations of the conceptual change research tradition become apparent based on the review of the above mentioned literature. First, contrary to the original characterization of scientific understanding as an individual as well as a collective phenomenon by Posner et al. (1982) and Toulmin (1972), conceptual change research has focused primarily on the development of scientific knowledge in individual learners. This individual focus is due in large part to traditional American educational research assumptions about the nature of cognitive development that have been strongly influenced by such ideas as the Piagetian theories of individual development (Rogoff, 1990). More recent views of cognition, however, characterize learning as a social process and portray learners as active participants in social contexts who learn as a result of their social interactions. As Rogoff (1990) points out, learners are viewed as:

> apprentices in thinking, active in their efforts to learn from observing and participating with peers and more skilled members of their society, developing skills to handle culturally defined problems with available tools, and building from these givens to construct new solutions within the context of sociocultural activity. (p. 7)

Learning, according to the social constructivist perspective, is seen as a process of acculturation which results in membership in particular disciplinary communities, rather than as a process of accumulating new knowledge and accommodating new ideas with individual prior knowledge (Brown, Collins, & Duguid, 1989; Brown & Campione, 1990; Vygotsky, 1978; Wertsch, 1985). Learning "is embedded in the context of social relationships and sociocultural tools and practices" (Rogoff, 1990, p. 8).

Given this social constructivist perspective, a second major limitation of the conceptual change research tradition becomes apparent. Until very recently, much of the conceptual change research has focused primarily on the study of the nature of individual students' scientific content knowledge, with much less attention paid to other aspects of students' conceptual ecologies, to the tools needed to successfully participate in the knowledge community, or to the social context in which learning typically occurs (Resnick, 1987). Research in social semiotics has examined these issues as they relate to teaching and learning in general and, in particular, to the teaching and learning of science (Edwards & Mercer, 1988; Heath, 1983, 1986; Lemke, 1990; Michaels & Bruce, 1989; Michaels & O'Connor, 1990; Warren, Roseberry, & Conant, 1989). A general definition of scientific understanding or literacy shared by researchers in this tradition is that literacy involves the ability to understand and participate in the discourse and activities of a variety of knowledge communities in a variety of social contexts. The knowledge, skills, language, norms, and values of each community are shared among its members, and are internalized by individuals as they participate in and contribute to these communities. Researchers sharing this perspective study the teaching and learning of science by examining students' patterns of language and activity and the extent to which they prepare students to participate in communities of scientifically literate members.

With this primary focus on the social nature of learning, it is clear that the social status of learners can influence their ability and their opportunities to equally participate in knowledge communities and, ultimately, to develop scientific understanding or literacy. In her research, Elizabeth Cohen (1986) found that among the educational disadvantages of dominance and inequality in collaborative learning contexts are the impairment of learning of low status students, the reinforcement of stereotypes and prejudices, and a decrease in the overall intellectual quality of group performance.

Part III: Scientific Arguments and Argumentation

Based on the literature discussed above, it is clear that one possible means of studying students' scientific understanding would be to investigate their ability to apply their scientific knowledge in collaborative problem solving contexts. These problem solving tasks require students to develop solutions to a problem and to provide explanations that support their particular solution. These tasks also require students to work individually and as a group to develop collective answers and reasons. These answers and reasons could be studied to examine the extent to which students appear to be integrating scientific knowledge with their personal ideas about how the world works. In addition, the collaborative problem solving activities would permit researchers to study the nature of the social interactions between students and the ways in which these interactions influence the development of individual as well as collective knowledge.

Thus, a third research tradition related to this study involves the analysis of scientific arguments and collaborative argumentation processes. Researchers have proposed frameworks for examining the components and structure of scientific arguments as well as for studying the nature of the argumentation processes that are used by groups engaged in collective problem solving activities. In addition, recent research has begun to investigate the nature of students' explanations and identify components of scientists' and students' explanations that are both similar and different.

Stephen Toulmin (1958) proposed a framework for analyzing the logical structure of scientific arguments which described complete scientific arguments as including particular components related in prescribed ways. In constructing their arguments, scientists are typically given a certain amount of data (D) with which they are expected to make a claim or reach a conclusion (C). They are expected to defend their conclusions with warrants (W), and these warrants generally have backing (B) based on theoretical explanations. Warrants and backing can be in the form of canonical scientific knowledge or some other form of communally held knowledge (e.g., for students it might be referring to another activity in class) and they represent a search for cognitive consistency and relations between other phenomena and problems and the particular one being considered.

Depending on the nature of the problem and the data provided, it may be necessary to specify additional qualifiers (Q) or assumptions, that is, the particular conditions under which the conclusion would be valid. Finally, a complete scientific argument would also consider and take into account any potential rebuttals (R) that opponents to the argument might raise. According to Toulmin (1958), an argument would be treated as incomplete without all of these these components, even though all components would not necessarily have to be explicitly stated at all times.

Given this analytical framework, it is possible to construct a model scientific argument that identifies the components and their respective relationships for each problem solving activity selected for analysis. This model argument can then serve as a comparative template for analyzing the arguments proposed by students who are faced with the same problems or questions. Thus, the Toulmin (1958) framework is useful for examining the products of students' arguments, but it is not very appropriate for analyzing group problem solving sessions, especially in terms of capturing the dynamic process of developing scientific arguments in collaborative groups. Thus, an additional analysis framework is needed that, in concert with the Toulmin framework described above, allows for the examination of both the processes and the products of students' collaborative problem solving sessions.

The work of Max Miller (1987) provides a useful basis for thinking about how to analyze arguments developed in collaborative contexts. Although his ideas were originally applied to the analysis of children's collaborative moral arguments, I believe that the underlying framework is equally applicable to the analysis of collaborative scientific arguments. Miller characterizes collaborative argumentation as a collective validation process in which "the primary goal is to develop a joint argument which gives an answer to a disputed question, the 'quaestio'" (p. 231). In order to obtain this answer, participants suggest possible solutions to the problem, react to or ignore these ideas, and eventually reach consensus on a group answer and reasons. As Miller points out:

> The essential difficulty for the participants of a collective argumentation stems from the fact that they must coordinate their contributions in such a way that they can find and agree on a *set of collectively valid statements* that need not be questioned any more within the context of a given argumentation, and on the basis of which one of the possible answers to a "quaestio" can be converted into a

> collectively valid statement, i.e., a statement accepted by all participants at least for the time being. (p. 232)

Miller (1987) recognized that, in studying collective argumentation, it is necessary to distinguish between argument (product) and argumentation (process). Not only are the final products (arguments) of a collaborative problem solving session of interest, Miller argued, but equally important is the process (argumentation) by which the participants reach consensus on their solution to the problem. In order to understand this process, Miller asserted, it is necessary to examine "those formal conditions or rules on which the participants rely or to which they (implicitly) refer if they try to evaluate the legitimacy (or rationality) of an answer to a 'quaestio' " (p. 232).

In summary, Miller's (1987) framework addresses a groups' attempts to reach consensus on a solution to the problem. As various group members suggest ideas, other members could either ignore the ideas, agree with them, or challenge them. For the statements that are not immediately rejected or ignored, Miller suggests that the ideas would be subjected to a collective validation process, and judgements would be made concerning the completeness of the supporting arguments using a set of standards or criteria. Toulmin's (1958) analysis framework provides one such set of standards for judging the completeness of an argument that a group of scientifically literate members would likely use. Miller (1987) also suggests that ideas or arguments that are challenged by other group members would be judged on the basis of their tenability and their relevance to the problem under consideration.

These two analysis frameworks (Toulmin and Miller) provide potentially valuable tools for analyzing the arguments and the argumentation processes that are developed by individuals and groups. In fact, they form the basis of the analyses included in this dissertation study, and both are discussed in more detail in the data analysis section of Chapter 4. In addition to these frameworks, other research has examined the nature of students' and adults' explanations and arguments, and the results of these studies provide additional information on the products and processes of argumentation.

In his own research, Miller (1987) analyzed the moral argumentation of groups of children of various ages, and his results revealed a number of developmental patterns. One of these patterns involved differences in the nature of the kinds of statements used by younger versus older children as they developed their moral arguments. Older children seemed to understand that complete arguments must include factual statements as well as statements about moral principles, and that the different kinds of statements must be judged using different criteria. Thus, the older students implicitly recognized the need for more complete and sophisticated moral arguments.

Solomon (1985) analyzed the scientific explanations of high school students and found that students use a variety of modes of explanation, from simple redescription and reiteration to the use of metaphors and similies to the use of theoretical scientific explanations. Her findings help increase our understanding of scientific argumentation by providing descriptions of various types of explanations and the difficulties involved in helping students develop more scientifically sophisticated explanations.

Hesse and Anderson (1992) also examined the explanations given by high school students to a variety of chemical phenomena. Their findings support those of Solomon (1985) in many ways and they also reveal that, in addition to using a variety of explanatory modes, students also differ in terms of their explanatory ideals. That is, different students use different sets of criteria for deciding what constitutes a complete and adequate scientific explanation. While most students preferred to use everyday analogies to explain chemical phenomena such as rusting and oxidation, only a few demonstrated a preference for explanations based on chemical theories. Thus, meaningful understanding of chemical change involves three aspects of students' conceptual ecologies:

> (a) *chemical knowledge*, including specific facts and theories associated with the change being described, (b) an understanding of how *conservation of matter* applies to chemical changes, and (c) an understanding of chemists' *explanatory ideals* for chemical change. (p. 278, original emphasis)

In addition to factors such as modes of explanation and explanatory ideals that influence the nature of scientific explanations given by students, researchers have also identified other elements that have an impact of students' thinking as they engage in problem solving activities. In particular, Schauble and Glaser (1990) point out that among the variables that affect both children's and adults' reasoning and problem solving abilities (and thus their explanations and arguments) are their "familiarity or practice with the activity, content knowledge about the domain, and the demands of the task" (p. 21). In addition, they note that:

> the kind of search or reasoning that people employ will vary with their interpretation of the goal state. The implication is that in addition to concentrating on the scientific reasoning strategies that individuals do or do not display, it is important to attend to their interpretation of the task, and to ask how that develops as well. (p. 25)

Thus, these results confirm once again that studying scientific understanding requires attention to and consideration of many aspects besides changes in students' scientific content knowledge.

Implications for This Study

The literature reviewed above provides a background and rationale for this dissertation study. The research questions addressed in this study are based on the findings of previous studies and represent attempts at going beyond the limitations of earlier research. First, the study deliberately focuses on the individual as well as the social nature of students' learning of the kinetic molecular theory as they engage in collaborative problem solving activities. This dual focus allows for the investigation of the development of personal as well as collaborative scientific understanding, and the ways in which social interactions affect and contribute to science learning. The study also examines the nature of students' scientific arguments and argumentation processes as they attempt to solve a variety of problem types over an extended period of time. This allows for the investigation of the ways in which students' arguments and problem solving techniques approximate or fail to approximate scientists' arguments and techniques. Finally, this study provides opportunities to investigate a variety of components of students' conceptual ecologies that influence the development of personal and collective scientific understanding.

CHAPTER THREE

BACKGROUND FOR THIS STUDY

This chapter presents a brief description of the research, curriculum materials, and instruction that provided a basis for the current study. First, the Matter and Molecules unit is presented as an example of recent efforts in conceptual change research to improve curriculum materials and instructional strategies in order to promote scientific understanding for students. Then, special features of the collaborative problem solving (CPS) curriculum materials are discussed and compared with traditional curriculum materials and the Matter and Molecules unit. Finally, information is provided on the nature of the classroom instruction that was observed during this study and how this instruction affected the students' group problem-solving activities.

The Matter and Molecules Curriculum Unit

Several recent research efforts have focused on the development of curriculum materials that promote conceptual change and scientific understanding for students (Anderson & Smith, 1983; Berkheimer, Anderson, & Blakeslee, 1990; Nussbaum & Novick, 1982; Roth, 1985). These materials have proven to be more effective than traditional curriculum materials in helping students develop meaningful understandings of a variety of science topics. All of these materials differ from traditional materials in two important ways: they incorporate extensive knowledge about students' personal knowledge or "misconceptions," and they emphasize the application of the scientific concepts for explaining and understanding a variety of real-world phenomena.

One such unit based on the conceptual change approach to curriculum development is the Matter and Molecules unit developed by the Science Achievement Project funded by the National Science Foundation (Berkheimer, Anderson, & Blakeslee, 1988; Berkheimer, Anderson, Lee, & Blakeslee, 1988). Matter and Molecules, a revision of the commercially available unit entitled "Models of Matter" in the Houghton Mifflin Science textbook (Berger, Berkheimer, Lewis, & Neuberger, 1979), was written for sixth-grade science classrooms. The unit teaches students the basic principles of the kinetic molecular theory (in short, that all substances are made of molecules which are constantly moving) and to use these ideas to explain the three states of matter and several physical changes of matter including expansion and compression of gases, dissolving, thermal expansion and contraction, and changes of states of matter such as melting and freezing, boiling, evaporation, and condensation. An important part of the unit involves having students write on a regular basis to give them practice in developing their own descriptions and explanations of the natural phenomena being studied. In general, the activities in Matter and Molecules were designed to be completed on an individual basis, with occasional opportunities for students to work together to compare and discuss their answers.

Comparisons of student achievement for the two sets of curriculum materials revealed that students using the Matter and Molecules materials mastered about 50% of the scientific goal conceptions, while students using the Houghton Mifflin Science materials demonstrated understanding of only 25% of the scientific goal conceptions (Lee et al., in press). Thus, the research provided evidence that student achievement could be substantially improved by using curriculum materials that were developed using the conceptual change approach.

CPS Curriculum Materials

The curriculum materials that were used during this study are revised versions of the Matter and Molecules unit. The collaborative problem solving (CPS) curriculum materials are very similar to Matter and Molecules in some important ways, but there are also some fundamental differences between these two units, as well as between the two conceptual change units and the Houghton Mifflin Science unit. Table 3.1 below summarizes the similarities and differences between the three sets of curriculum materials.

Curriculum development approach

The Houghton Mifflin Science text uses a traditional curriculum development approach that is common to many commercially available textbooks. The primary knowledge base used to write the "Models of Matter" unit consists of canonical scientific knowledge about the kinetic molecular theory (e.g., All matter is made up of particles; Particles of matter are very small; Particles of matter are in constant motion; etc.). In contrast, both the Matter and Molecules and the CPS units are based on a conceptual change approach to curriculum development. In this approach, the knowledge base used for writing the unit consists of canonical scientific knowledge about the kinetic molecular theory and knowledge of students' prior conceptions about the nature of matter and of physical changes in matter. As noted earlier, the conceptual change approach to learning assumes that, rather than simply adding new knowledge about a topic into existing knowledge schemes, learners gradually change their prior conceptions about a topic to be more congruent with scientific conceptions. In essence, students need to be convinced that the scientific conceptions

Table 3.1 - Comparison of <u>Houghton Mifflin Science</u>, <u>Matter and Molecules</u>, and CPS Curriculum Materials

	<u>Houghton Mifflin Science</u>	<u>Matter and Molecules</u>	CPS
Curriculum development approach	Traditional Primary knowledge base consists of canonical scientific knowledge Students' pprior conceptions play no role in curriculum development or instruction	Conceptual change Canonical scientific knowledge <u>and</u> students' prior conceptions play key roles in curriculum development and instruction	Conceptual change and collaborative Canonical scientific knowledge, social norms, arguments, and students' prior conceptions play key roles in curriculum development and instruction
Content focus	Kinetic molecular theory and explanations of everyday phenomena Molecular conceptions only	Kinetic molecular theory and explanations of everyday phenomena Macroscopic and molecular conceptions	Kinetic molecular theory and explanations of everyday phenomena Macroscopic and molecular conceptions
Social norms	Not included	Not included	Explicit instruction of norms via a series of five "social activities" followed by discussion of norms during content-based activities throughout the unit
Nature of activities	Individual Individual students present their ideas and answers to rest of class Emphasis on scientific processes (e.g., observing & describing, investigating and manipulating, organizing and quantifying, generalizing and applying)	Cooperative Occasional opportunities for students to compare and discuss questions and answers to problems. Individual students present their ideas and answers to rest of class Emphasis on application of scientific conceptions (e.g., describing, explaining, predicting, and controlling the world around us) Primarily explanation activities.	Collaborative All content-based and most social activities include individual planning and/or explanations, followed by small group planning and explaining to reach group consensus. Each group member accountable for presenting group's plan and explanation to rest of class Emphasis on application of scientific conceptions (e.g., describing, explaining, predicting, and controlling the world around us) Explanation and practical/design activities
Explanation heuristic	Not included	A complete explanation includes: - statement about substances and how they are changing - statement about molecules	Two kinds of activities identified: 1.Explanation activities include: - observations and assumptions - statement about substances - statement about molecules 2. Practical/design problems include: - proposed plan of action or solution - explanation (see #1 above)

of the unit are more powerful and more accurate for predicting and explaining natural phenomena than their prior conceptions developed during everyday observations of and interactions with the world around them. Therefore, conceptual change curriculum materials and instructional strategies need to first recognize where students are in their understanding of a topic prior to instruction and to take students' prior conceptions into account while helping them develop more scientific understandings of the world.

An additional component of the curriculum development approach used for the CPS unit is the emphasis on collaborative approaches to learning and the incorporation of explicit instruction on social norms throughout the unit. (More will be said about the social norms below.) This emphasis on collaborative problem solving influences not only the content of the unit but also the instructional techniques used by the teachers(discussed below in The Nature of the Classroom Instruction).

Content focus

While all three sets of curriculum materials share a common content focus, there are some important differences between the three units. All of the units focus on teaching about the kinetic molecular theory and having students use their knowledge of the molecular nature of matter to explain a number of common natural phenomena involving changes of states of matter and thermal contraction and expansion. However, an important difference exists between the "Models of Matter" unit and the two conceptual change units in terms of the nature of the conceptions that are taught. In "Models of Matter" the students learn only about the molecular conceptions of the kinetic molecular theory, focusing on the existence of molecules and their properties. In the Matter and Molecules and the CPS units, students learn both molecular and macroscopic conceptions , which focus on the nature of substances and how they are affected by physical changes.

Social norms

Of the three units, only the CPS unit includes explicit instruction of social norms. This instruction begins with a series of five "social activities" that are taught prior to instruction of the science content. These activities, similar to activities discussed in Cohen (1986), are designed to introduce and reinforce the following four social norms which have been chosen by the researchers as important for successful collaborative problem solving:

1. We contribute and help others to contribute to the group's work.
2. We support ideas by giving reasons.
3. We work to understand others' ideas.
4. We build on one another's ideas.

These norms are introduced in the social activities and are subsequently discussed during the content-based activities throughout the unit.

Nature of activities

In general, the activities included in the Houghton Mifflin unit are designed to reinforce the content presented in the text and to emphasize some general scientific processes, such as observing and describing, investigating and manipulating, organizing and quantifying, and generalizing and applying. While the activities may be carried out by groups of students, the questions that accompany the activities are meant to be answered by individual students.

The activities included in the Matter and Molecules unit are cooperative in nature, in that they are meant to be completed by groups of students and the questions that accompany the activities provide opportunities for students to discuss the questions and compare their answers to the problems. After completing the activities, individual students report their answers to the rest of the class during large group discussions. Unlike the Houghton Mifflin activities that emphasize general science processes, the Matter and Molecules activities emphasize the application of the scientific concepts presented in the text and provide opportunities for students to describe, explain, predict, and control the world around them while using these science concepts.

The activities in the CPS unit are collaborative in nature, designed to provide opportunities for students to use the science content to answer "messy," real-world questions. All of the content-based and most of the social activities are first completed by individual students. Tasks typically require students to develop written plans of action or to give answers and reasons on an individual basis before meeting in small groups to reach consensus on group plans or explanations. Finally, each group reports its plan or explanation to the rest of the class, with each individual group member accountable for presenting the group's solution to the whole class. Like the activities in Matter and Molecules, the CPS activities emphasize the application of science content by presenting problems that require students to describe, explain, predict, and control the world around them. However, the activities are somewhat different in that they include a combination of questions that ask students to either explain natural phenomena or to design experiments or procedures that could be used to answers questions posed in the unit.

Explanation heuristics

Finally, only the Matter and Molecules and the CPS units include explicit heuristics on the nature of "good" or complete scientific explanations. In Matter and Molecules, students are taught that a complete explanation includes macroscopic and molecular components: statements about which substances are changing and how, and statements about how the motion and arrangement of the molecules of these substances are changing. In the CPS unit, the explanation heuristics are more developed and are different for each of the two types of activities. For the explanation activities, students learn that complete scientific explanations include observations and assumptions, statements about substances, and statements about molecules. For the practical or design problems, complete arguments include a proposed plan of action as well as the three components included in the explanation activities. In both the CPS and the Matter and Molecules units, the explanation heuristics are first modelled in the text and by the teacher, and students are then given repeated opportunities to apply these heuristics in activities that include scaffolding in the form of questions and worksheets to be completed.

The Nature of the Classroom Instruction

Although the primary focus of this study is on the collaborative problem solving activities of the target students, it is important to remember that these activities took place within and were shaped by the larger context of the science classroom. Therefore, before examining the students' scientific arguments and argumentation processes in detail, it is necessary to provide some general background information on the role of the instruction and how it affected what was observed in the collaborative problem solving groups.

The classroom in which this dissertation study was conducted was one of several sixth grade science classrooms involved in the larger CPS research project. The teacher is a former elementary school teacher who moved to the middle school level when the school district switched from a junior high school system. He had worked as a collaborating teacher with the previous Matter and Molecules research project and, as a result, was familiar with the science content on the kinetic molecular theory and the conceptual change approach that was included in the CPS unit. He also participated in the pilot testing of the CPS curriculum materials in the spring of 1990 and, as a result, he was familiar with the project's research goals, curriculum materials, and instructional approaches.

Several aspects of the teacher's instruction were important elements in terms of their potential impact on the students' small group problem solving activities. First, throughout his instruction of the unit, the teacher regularly reminded the students to be thinking about the social activities they had completed at the beginning of the unit and about their relevance to the problem solving activities. Students were reminded of the four social norms emphasized in the unit and of their importance in facilitating effective group work. The teacher also discussed with students the importance of developing explanations that included all of the components of complete scientific arguments (observations, statements about the substances, and statements about molecules). These comments were made during the teacher's introduction of each of the collaborative problem solving activities as well as during the whole class discussions that were conducted after each activity. These comments and discussions served as regular reminders to the students that, in addition to thinking about the science content of each activity, they also needed to be thinking about their social interactions and the nature of their argumentation processes and products.

Another important aspect of the teacher's instruction involved the nature of his interaction with the students as they worked in their collaborative groups. During the small group activities, the teacher would circulate among all of the groups to ensure that the students were on-task, had the necessary materials for completion of the activities, and were working in ways that resulted in effective and equitable social interactions. His comments to the groups often included procedural suggestions for ensuring equal participation of all group members and completion of all parts of the activity. Most importantly, whenever students approached him with questions concerning the science content or with requests to validate one student's answer in lieu of another's, the teacher would not directly or immediately answer their questions. Instead, he would refer the students to other sources of information (e.g., their texts or the results of previous activities or demonstrations) and encourage them to find the answers themselves. Thus, he generally avoided the role of the outside authority to whom students could turn for resolutions to their disputes over content questions, preferring instead to encourage students to discuss their ideas and reasons and reach consensus among themselves.

While it is not possible to determine the exact influence of the teacher's instruction on each small group, it is clear that various groups responded to and made use of the teacher's instruction in very different ways, as shown in the data analyses in Chapter 5 below. Some groups (and, in particular, some individuals within groups) appeared to be more receptive to his comments and suggestions and were able to demonstrate progress in their ability to understand the science content, to work effectively as a group, and to develop more complete and sophisticated scientific arguments. Other students and groups showed very little progress in these areas, despite regular assistance from the teacher throughout the instruction of the unit. These results help to demonstrate that the teacher's instruction is only one of many important elements that affect the overall process of student learning.

CHAPTER FOUR

METHODS

This dissertation study was part of a larger research project (herein referred to as the Collaborative Problem Solving, or CPS project) funded by the National Science Foundation (#MDR-8950308) and co-directed by Drs. Andy Anderson and Annemarie Palincsar. The main goals of that on-going research project are to: 1) study children's collaborative problem solving in order to better understand substantive and social aspects of the development of children's scientific reasoning, and 2) investigate the potential of collaborative problem solving as an effective instructional tool (Anderson & Palincsar, 1991). While the larger project examines a variety of both social and substantive aspects of classroom life, this dissertation study focused specifically on the scientific arguments developed by individual students and by peer groups as they engaged in a series of collaborative problem solving activities included in a curriculum unit on matter and molecules.

In order to analyze students' scientific arguments, it was necessary to collect data on the nature and quality of the arguments and explanations they provided during the collaborative problem solving sessions as well as on students' understanding of the main concepts of the kinetic molecular theory presented in the curriculum materials. The following section describes the subjects and curriculum materials involved in this study as well as the data collection and analysis procedures that were used.

Subjects and Setting

All of the students involved in this study attended sixth grade in an urban middle school in the Midwest. The student body of the school was heterogeneous in terms of its ethnic and socioeconomic composition. The classroom selected for this study was one of five classes participating in the larger research project, and was judged to be a typical sixth grade science class in terms of the range of student ability and achievement levels.

During the instruction of the unit, students regularly worked in small groups of four or, rarely, five members. These groups were formed by having the science teachers first divide their classes into four categories (high, middle high, middle low, and low) based on their perceptions of each student's overall ability. Small groups were then formed by randomly selecting one student from each of the four ability levels while at the same time trying to maintain ethnic and gender diversity and taking into account individual personality factors. Two target groups were identified in the classroom chosen for this study, with each target group composed of four students. Group 1 was composed of two male and two female students, (Jason, Nate, Mary, and Jamie) with one African American student, one Asian American student, and two white students. (Another male student, Marvin, started the unit as a member of Group 1 and completed one of the collaborative activities with this group. He left this classroom two weeks into the unit, and was replaced by Nate.) Group 2 consisted of three females and one male, (Sheronda, Anna, Jennifer, and Brett), with one African American student and three white students. Thus, a total of eight target students were identified for this study. In order to minimize the need for moving video equipment during filming and potentially disrupting classroom instruction, the target groups were chosen based on their proximity to the two video cameras used for recording the instruction of the unit. (See Figure 4.2 below.)

The classroom teacher involved in this dissertation study had worked as a collaborating teacher with an earlier study of the nature and extent of students' conceptual change while using the specially designed Matter and Molecules curriculum materials (Berkheimer, Anderson, & Blakeslee, 1988; Berkheimer, Anderson, Lee, & Blakeslee, 1988). Based on his past experience with the Matter and Molecules project, the teacher was familiar with the conceptual change approach to teaching and learning used in those curriculum materials as well as in the modified version of the unit used in this study. He had used some group work in his teaching prior to becoming involved with the CPS study. However, he pointed out that groupwork was used infrequently, and the tasks and group structures were rarely designed for collaborative problem solving activities. This teacher also took part in the pilot testing of the CPS curriculum materials in the spring of 1990, so he was familiar with the project's research goals, curriculum materials, and pedagogical approaches.

Curriculum and Instruction

The curriculum unit used during this study was described in detail in Chapter 3 above. Briefly, the unit consisted of a series of five Lesson Clusters focusing on aspects of the molecular nature of matter, the three states of matter, and changes of states of matter. Each Lesson Cluster included a series of lessons providing instruction on the basic concepts of the particulate nature of matter, and at least one collaborative problem solving activity. Two types of problems were included in these activities, **explanation** and **design** problems, each requiring students to perform different kinds of tasks and to provide different components of scientific arguments. Explanation problems involved describing and making sense of phenomena that the students encountered, either through hands-on experimentation, demonstrations, or through other means. This sense-making required students to provide reasons or, more specifically, warrants and backing to supplement the data and claims provided by the problem itself. Design problems involved planning and, in some cases, carrying out strategies to achieve some practical goal. In order to develop complete scientific arguments for these activities, students were required to furnish claims, warrants, backing, and occasionally qualifiers to supplement the data provided in the problem. Four of these activities were selected as the foci for this study, and they represented a mixture of explanation and design activities. These activities are described briefly later in this chapter and in detail in Chapter 5.

Data Collection Procedures

Data were collected for this study using the following data sources:

1. Classroom observations of whole class instruction and small group problem solving, consisting of daily videotaping of each lesson in the unit, written field notes, and copies of students' written work;
2. Pre- and post-instruction clinical interviews; and
3. Pre- and post- instruction tests.

The data collection procedures began in October, 1990, and ended in January, 1991. The following timeline illustrates the sequence of data collection:

Pre-Instruction 10/5/90 to 10/26/90	Instruction of CPS Unit 10/09/90 to 01/17/91	Post-Instruction 01/22/91 to 01/30/91
Pre-test Clinical Interviews	Daily Classroom Observations Videotaping lessons Written field notes Copies of students' written work	Post-test Clinical Interviews

Figure 4.1: Timeline of Data Collection Sequence

Data collection procedures for each of these data sources are discussed below.

1. Classroom observations

Instruction of the entire unit, including both the whole class and the small group portions, was videotaped using two 8 mm. video cameras in the classroom. One camera was placed in a back corner of the room to film the teacher during whole class instruction and discussions. A second camera was placed in a front corner of the room to film as many of the target students as possible during whole class discussions. During large group instruction, on-camera microphones were used to record the discussions of the entire class. During small group activities, each camera filmed the nearest target group (the front camera focused on Group 1 and the back camera on Group 2), using table-top microphones to record the small group discussions. (See Figure 4.2 below for a sketch of the classroom, small group locations, and camera placements.) Transcripts of selected class sessions and small group discussions were made for subsequent analysis of students' scientific explanations and arguments and their argumentation processes.

In addition to videotaping each lesson, the researcher also took written observation notes on classroom observation forms. In general, these forms were used to record a summary of events that occurred during each videotaped lesson including: the starting and ending times for each activity, the nature and content of each activity (whole class or small group discussions, teacher demonstrations, etc.), and notes of what was filmed by the front and back video cameras. Additional notes were recorded for the individual target students' activities during all phases of the lessons. (See Appendix 4-A).

The development of students' scientific arguments was also traced by examining copies of their written work. Each activity in the unit, with the exception of the supplemental questions on weight and volume changes, required students to write their individual explanations and proposed plans as well as their group's plans and explanations on worksheets, and these documents were collected and examined.

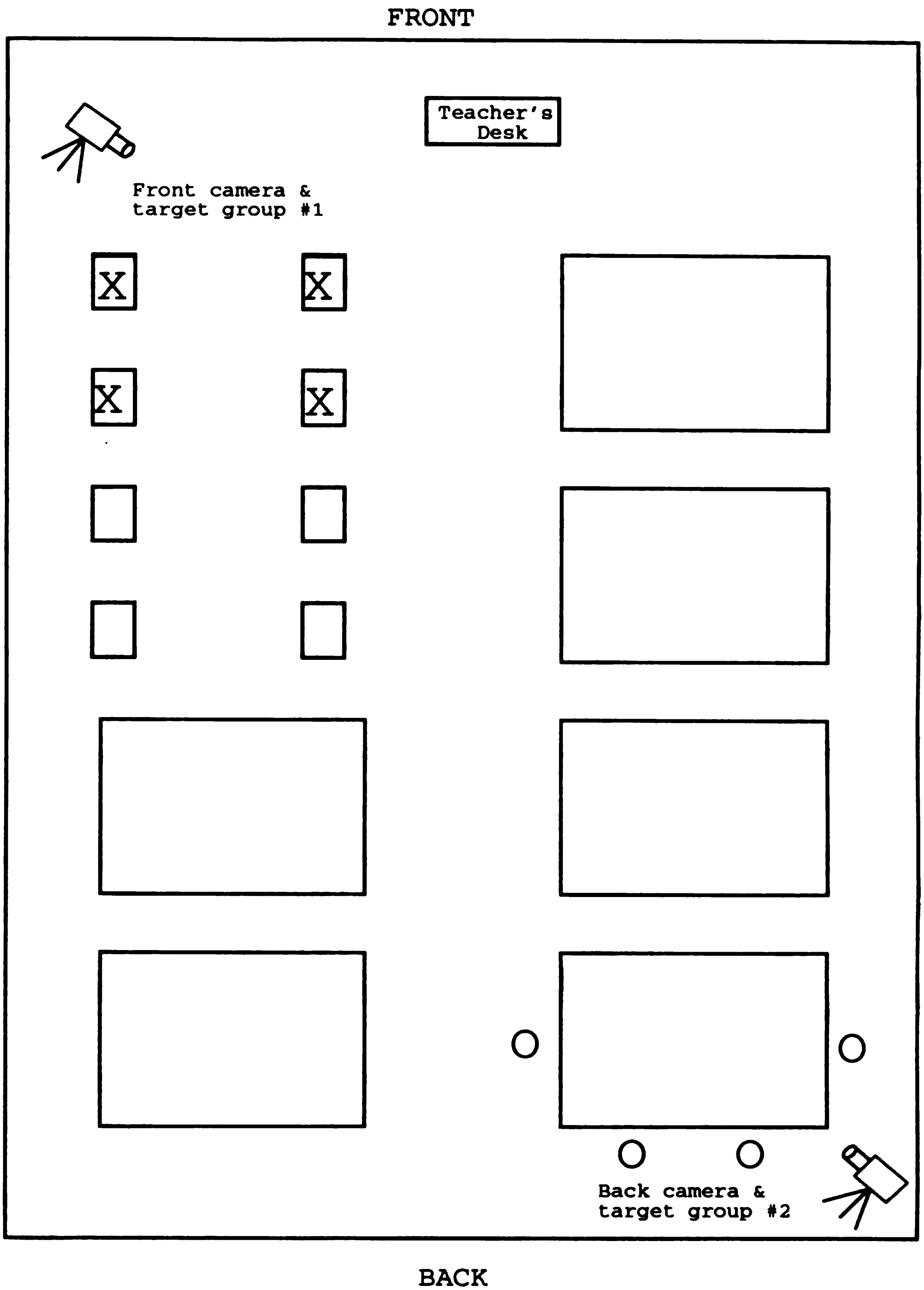


Figure 4.2: Sketch of classroom

2. Pre- and post-instruction clinical interviews

Clinical interviews were conducted with six of the eight target students prior to instruction of the unit and again after the instruction had been completed. Due to the limited amount of time available for interviewing purposes, the middle high and middle low groups of students were combined and one student from each of the high, middle, and low ability levels was selected for interviewing from each target group. The clinical interviews used in this study provided supplemental information on students' conceptual understanding of the kinetic molecular theory as well as their views on scientific arguments. The standard interview protocol was composed of a series of five hands-on tasks that required students to describe, predict, and explain various aspects of the phenomena under study, and a series of probe questions for each task (See Appendix 4-B). The five tasks included the following topics: pure substances versus mixtures; the three states of matter; changes of states of matter (melting,freezing, boiling, condensing, and evaporation); dissolving; and thermal expansion of solids and gases.

In addition to the five content-based tasks mentioned above, the clinical interviews also included questions designed to investigate students' ideas about and understandings of the components of scientific explanations and arguments. (See Appendices 4-C & 4-D) These questions were designed to probe students' ideas of what distinguishes a "good" from a "not-so-good" explanation in science and to try to get them to identify and apply the necessary components, either as defined by the students themselves or as they were defined and taught by the curriculum materials, of a "good" or complete scientific argument. (More specific information about these questions is given in the data analysis section below.) The clinical interviews were videotaped and normally took approximately fifty minutes to complete.

3) Pre- and post-instruction tests

The test was designed to assess students' understanding of a number of key conceptions of the kinetic molecular theory and the application of these conceptions to common physical phenomena. (See Appendix 4-E) The test included twenty-two questions in multiple choice and short essay formats and was designed to test students' understanding at both a macroscopic level (concerning the nature of substances and their properties) and at a molecular level (concerning molecules and their properties). Some of the questions on the test asked about "knowledge" (e.g., "Have you ever heard of molecules? If you answered yes, what do you think molecules are?"), but the majority of the questions asked for explanations of physical phenomena (e.g., "Explain, in your own words, why heating a solid makes it melt. Explain in terms of molecules of the solid, if you can"). The test was administered during a 45-50 minute class period.

Data Analysis Procedures

The discussion of the data analysis procedures, like the data collection discussion above, is organized by data source and describes how each source provided information concerning each of the research questions being addressed. The data sources are discussed in the order of their importance for this study; the classroom observations and students' written work served as the primary data sources, with the clinical interviews and pre/post-tests providing additional support.

Classroom Observation Videotapes

As mentioned in the data collection procedures above, all instruction of the CPS unit was videotaped, including both the whole class and small group portions. Since the primary goal of this study was to examine students' development of scientific arguments in collaborative problem solving contexts, the data analyses were focused on videotapes of small group activities in which the students were engaged. Due to the large number of these activities included in the curriculum unit, it was necessary to select a subsample for in-depth analysis. The selection of the four activities chosen for this study was based on the following criteria: include a mixture of the two activity types, explanation and design, in order to study the nature of students' scientific arguments for activities requiring different argument components (claims and warrants for explanation activities; claims, warrants, backing, and/or qualifiers for design problems); include activities spanning the length of the unit in order to provide information on the development of students' arguments over time; and include activities whose conceptual content coincided with the scientific concepts examined in the tasks of the clinical interviews. The following chart shows each of the four activities selected for the study, whether it was an explanation or design activity, and the Lesson Cluster in which the activity was presented.

Activity Name	Activity Type	Lesson Cluster
#1: Pure substances vs. mixtures	Explanation	Lesson Cluster 1
#2: Weight and mass changes	Explanation	Lesson Cluster 3
#3: Water on the spaceship	Design	Lesson Cluster 3
#4: Dissolving races	Design	Lesson Cluster 4

Figure 4.3: Descriptions of Selected Collaborative Activities

The videotapes for each of these collaborative problem solving activities were transcribed to produce transcripts that were as close to verbatim as possible. The transcripts were numerically labelled in terms of moves, with each person's contribution to the discussion counted as a separate move.

Discussion Flow Graphs

The next step in the analysis procedure was the development of what I have termed a **discussion flow graph** (DFG) for each of these transcripts. Working from the numbered transcripts of the small group discussions, each move was classified into one or more of the following categories: off-task, procedural, answers, or reasons. The characteristics of each category are described below.

Off-task: This category was used for statements judged to be irrelevant to the procedural or cognitive completion of a particular activity.

Procedural: These statements were judged to be related to one of three possible interpretations of the procedural aspects of an activity. The first involved the completion of the administrative or logistical aspects of an activity or worksheet, such as whose turn it was to read, who should get the materials for the activity, what the rules were for completing the activities or worksheets, which question the group was on, and so forth. A second type of procedural statement involved students' attempts to reach consensus on the purpose of a question or activity (Miller's collective validation of the question, discussed below). These included statements which related to questions such as, what does this question that we're working on really mean, and how are we supposed to answer it? Finally, a third group of procedural statements involved students' comments on the social aspects of group conduct, such as the need for all group members to participate in the discussion, the need to combine aspects of individual student answers to arrive at a group answer, and the need to be willing to change one's ideas for the benefit of the entire group.

Answers: These statements provided possible solutions to the problems or the questions included in the activity. These statements would correspond to Toulmin's claims in his argument analysis structure.

Reasons: These statements provided justification for the answers given in the category above. These reasons would correspond to Toulmin's warrants and backing.

Finally, in order to indicate the degree of uptake of particular statements and concepts by various group members, symbols were used to indicate direct, immediate uptake (solid line arrows, →), indirect uptake (broken line arrows, -->), or lack of uptake (inverted T-shape, ⊥) for each move. (For the purposes of this study, the term "uptake" has a common-sense meaning that refers to the degree of individual or group follow-up or response to a particular statement or idea.) These symbols served as a visual means for diagramming the collective validation process used by the small group members. Discussion flow graphs of problem solving sessions that included extended and well developed discussions of ideas were characterized by complex patterns of symbols that linked successive moves and categories of statements. The ideal DFG for a group of scientists would likely show patterns of connections between the groups' answers and two or three kinds of reasons (Warrants, Backing, Data, and possibly Qualifiers). Occasional side trips would be expected to the procedural column if the group was having trouble getting organized or if they were experiencing difficulty in reaching agreement or in getting their answer written down. If, on the other hand, the arguments made by students were incomplete or limited in extent, the discussion flow graphs showed very little linkage between moves and between categories.

These discussion flow graphs were developed as an integral part of the analysis framework used to answer the primary research questions of this study. Specifically, the graphs and these particular categories served several purposes. First, working from a group discussion transcript, I was able to diagram the categories of statements made by group members in order to compare the relative proportions of off-task, procedural, answer, and reason statements for a variety of small group tasks for the two target groups. These categories and relative proportions provided a first indication of the overall distribution of the group's efforts to solve a given problem. Second, the answers and reasons categories in the discussion flow graphs facilitated the analysis of individual statements or chains of statements by allowing me to examine the arguments in terms of a) their components and logical structure using Toulmin's categories and analysis framework and b) the nature of the scientific concepts used by students and whether they were canonical or non-canonical. Third, as mentioned above, these graphs allowed me to examine the degree of uptake for individual ideas or topics between group members, and to trace the "history" of possible problem solutions as they were proposed and as a particular solution was developed over the course of the group discussion. Using the system of symbols, it was possible to demonstrate whether an answer or idea was rejected, put in limbo, scrutinized, or accepted as is with little or no further discussion by the group members. Thus, they served as a visual means for applying Miller's analysis framework for the collective validation process.

Finally, the discussion flow graphs allowed me to examine the relative proportions of participation by each group member in each small group discussion. By calculating the number of moves attributed to a particular student out of the total number of moves for an activity, the percentage student participation rates were determined for each activity and compared over the entire period of instruction.

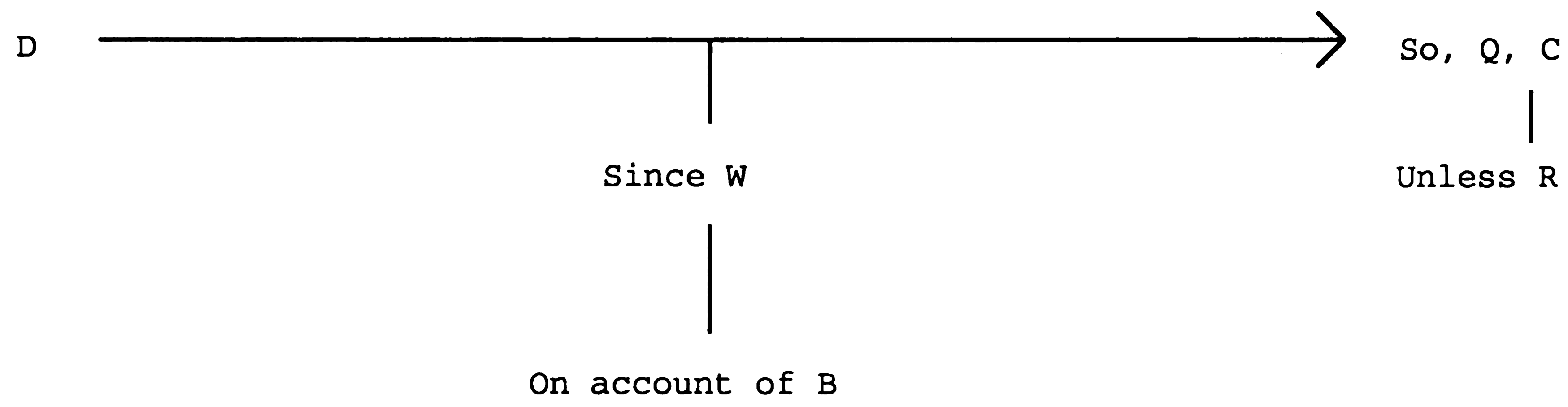
Argument Analysis Frameworks

The analyses of students' scientific arguments were based on analysis frameworks proposed by Toulmin (1958) and Miller (1987) and were similar in some respects to the analyses of students' discourse presented in a recent AERA paper by Eichinger et al. (1991). Each of these frameworks is discussed in detail below.

Stephen Toulmin (1958) proposed a framework for analyzing the logical structure of scientific arguments which described complete scientific arguments as including particular components related in prescribed ways (See Figure 4.4 below). In constructing their arguments, scientists are typically given a certain amount of data (D) with which they are expected to make a claim or reach a conclusion (C). They are expected to defend their conclusions with warrants (W), and these warrants generally have backing (B) based on theoretical explanations. Warrants and backing can be in the form of canonical scientific knowledge or some other form of communally held knowledge (e.g., for students it might be referring to another activity in class) and they represent a search for cognitive consistency and relations between other phenomena and problems and the particular one being considered.

Depending on the nature of the problem and the data provided, it may be necessary to specify additional qualifiers (Q) or assumptions, that is, the particular conditions under which the conclusion would be valid. Finally, a complete scientific argument would also consider and take into account any potential rebuttals (R) that opponents to the argument might raise. According to Toulmin, an argument would be treated as incomplete without all of these these components, even though all components would not necessarily have to be explicitly stated at all times.

Given this analytical framework, it was possible to construct a model scientific argument that identified the components and their respective relationships for each of the four collaborative problem solving activities selected for analysis. These model arguments then served as comparative templates for analyzing the arguments proposed by students who were faced with the same problems or questions. Thus, this framework was useful for examining the products of students' arguments, but it was not very appropriate for analyzing the group problem solving sessions, especially in terms of capturing the dynamic process of developing scientific arguments in collaborative groups. Since much of what made this research project different and interesting was the collaborative nature of the problem solving situations in which the students were



B = Backing
C = Claim
D = Data
Q = Qualification
R = Rebuttal
W = Warrant

Figure 4.4: Toulmin's Argument Analysis Framework

engaged, the analyses of these collaborative problem solving sessions need to describe and examine the interactive, social nature of the progressive development of the students' scientific arguments as well as their scientific content and logical structure. Thus, an additional analysis framework was needed that, in concert with the Toulmin framework described above, would allow me to examine both the processes and the products of students' collaborative problem solving sessions.

The work of Max Miller (1987) provided a useful basis for thinking about how to analyze arguments developed in collaborative contexts. Although his ideas were originally applied to the analysis of children's collaborative moral arguments, I believe that the underlying framework is equally applicable to the analysis of collaborative scientific arguments. Miller characterized collaborative argumentation as a collective validation process in which "the primary goal is to develop a joint argument which gives an answer to a disputed question, the 'quaestio'" (p. 231). In order to obtain this answer, participants suggest possible solutions to the problem, react to or ignore these ideas, and eventually reach consensus on a group answer and reasons. As Miller points out:

> The essential difficulty for the participants of a collective argumentation stems from the fact that they must coordinate their contributions in such a way that they can find and agree on a *set of collectively valid statements* that need not be questioned any more within the context of a given argumentation, and on the basis of which one of the possible answers to a "quaestio" can be converted into a collectively valid statement, i.e., a statement accepted by all participants at least for the time being. (p. 232)

Miller (1987) recognized that, in studying collective argumentation, it was necessary to distinguish between argument (product) and argumentation (process). Not only are the final products (arguments) of a collaborative problem solving session of interest, Miller argued, but equally important is the process (argumentation) by which the participants reach consensus on their solution to the problem. In order to understand this process, Miller asserted, it is necessary to examine "those formal conditions or rules on which the participants rely or to which they (implicitly) refer if they try to evaluate the legitimacy (or rationality) of an answer to a 'quaestio' " (p. 232). I propose that Toulmin's analysis framework can serve as one possible set of conditions or rules that a group of scientifically literate adults would use during their collective argumentation. A primary goal of this study was to investigate the extent to which groups of sixth grade students used these or alternative sets of rules and conditions in their own collective argumentation activities.

Miller's analysis framework assumed that all of the participants agreed from the outset on the question to be answered. In my interpretation of his framework, I did not assume consensus on the question. In fact, I think some of the more interesting aspects of the problem solving sessions that were videotaped are the questions of whether and how the students reached consensus on the nature of the tasks they were asked to complete. Thus, for the purposes of this study, I suggest that collective argumentation includes the process of developing a collectively validated interpretation of the question as well as a collectively validated solution to the problem.

The interpretation of the Miller analysis framework used in this study can be summarized as follows. (See also Figure 4.5 below) Given a particular problem or question, the groups of students were faced with a number of alternative courses of action. The members could first attempt to reach consensus on the definition of the question, or begin working directly on the problem solution. In the first case, potential sources of information would be provided by the problem statement itself as well as by individual student interpretations of the task. These statements could undergo a collective validation process, resulting in a mutually validated question which the group could then attempt to answer. One analysis question for this study was whether this validation process occurred, and if so, how it took place. For a group of scientifically literate members, this collective validation process would likely involve steps such as

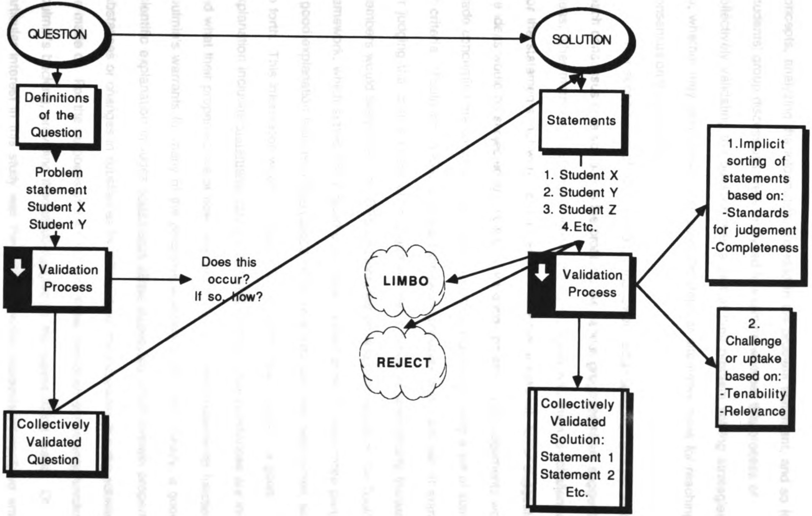


Figure 4.5: Miller's Argument Analysis Framework

identifying and prioritizing the relevant variables, clarifying unknown terms and concepts, analyzing the information provided in the problem statement, and so forth. Students' group discussions were analyzed to examine whether this process of collectively validating the question was a part of their problem solving strategies and, if so, whether they used these same scientific steps or alternative ones for reaching consensus on the question.

The second part of Miller's (1987) framework addressed the groups' attempts to reach consensus on a solution to the problem. As various group members suggested ideas, other members could either ignore the ideas, agree with them, or challenge them. For the statements that were not immediately rejected or ignored, Miller suggested that the ideas would be subjected to a collective validation process, and judgements would be made concerning the completeness of the supporting arguments using a set of standards or criteria. Toulmin's (1958) analysis framework provides one such set of standards for judging the completeness of an argument that a group of scientifically literate members would likely use. The CPS unit included an adapted version of the Toulmin framework, which stated that a good or complete explanation includes three parts. First, a good explanation includes observations telling what you can see, hear, smell, feel, and so forth. This information would correspond to Toulmin's data. Second, a good explanation includes statements about substances, telling what substances are involved and what their properties are or how they are changing. These statements functioned as Toulmin's warrants for many of the problems included in the unit. Finally, a good scientific explanation includes statements about molecules which explain properties of substances or changes in substances by telling about the molecules that the substances are made of. For the purposes of the CPS unit, these molecular statements functioned as Toulmin's backing, providing theoretical support for the claims being made. Of particular interest in this study was the extent to which students internalized and applied the curricular version of these standards or used alternative criteria for judging their own and others' arguments. The students' own validation procedures could have nothing to do with the logical nature or the scientific content, being based instead on such factors as a dominant group member , majority rule, or the unyielding persistence of an individual student in support of his or her idea.

Miller (1987) also suggested that ideas or arguments that were challenged by other group members would be judged on the basis of their tenability and their relevance to the problem under consideration. In the analysis of students' problem solving discussions in this study, particular attention was paid to students' answers and reasons that were challenged or elaborated to try to identify what distinguished them from answers and reasons that were automatically accepted.

Using these frameworks as guidelines, the next step in the analysis of the discussion flow graphs was the segmentation of the discussion into "chunks" or portions of discourse that provided information on potential patterns that existed in students' attempts to reach consensus on their answers and reasons. These patterns were then used to characterize the group argumentation processes for each of the activities, allowing comparisons to be made with the likely scientific argumentation, between the groups, and over time.

Thus, the combination of the Toulmin and Miller analysis frameworks allowed me to develop case studies of the target groups and their individual members as they worked through each of the four selected activities in the CPS unit. Using these frameworks and the format of the discussion flow graphs, it was then possible to take the information obtained from these analyses to begin to reach some conclusions about the overall nature of students' scientific arguments, using the following questions as general guidelines:

1) To what extent did students demonstrate that the questions being asked or the problems being posed were meaningful and/or relevant to them and therefore worth paying attention to?

2) If students did answer the questions, did they correctly classify a particular task or problem as an example of a more general phenomenon (e.g., thermal expansion or a change of state) and did they identify and isolate relevant variables for the particular task or problem?

3) Did students provide reasons for their answers , and were these reasons provided with or without prompting by the teacher, a fellow student, or the worksheet?

4) If reasons were given, what was the nature of the reasons? Did students' arguments include the three components of scientific explanation taught in the unit (observations, statements about substances, statements about molecules) ? If so, what was the nature of these components and how were they structured in the students' arguments?

Once this information was obtained for each activity, it was possible to begin answering Research Question #2 concerning changes in students' scientific arguments over time. By comparing the patterns of student interactions and the arguments developed by the students with those that would likely be developed by scientists, it was possible to evaluate the effectiveness of these curriculum materials in helping students appropriate and apply the ideas, cognitive tools, and discourse of the scientific community. In particular, the analyses of students' scientific arguments provided information on the effectiveness of the unit in helping students from different ability levels learn to develop scientific arguments in a variety of task environments.

Clinical Interviews

As mentioned briefly in the data collection section above, the clinical interviews consisted of two main parts. The first was a series of five hands-on tasks designed to provide additional information on students' understanding of the science content presented in the unit. (See Appendix 4-B) In general, students' responses to these content questions were judged as representing one of four categories: a) scientific goal conception; b) partial understanding of a scientific conception; c) naive conception; or d) ambiguous response. These judgements were made by comparing students' responses with a chart of scientific and naive conceptions developed for the Matter and Molecules project (See Appendix 4-F). The second portion of the interview consisted of two sets of argument questions. The first set (See Appendix 4-C) was designed to look at the role of technical terms (Question #1), intended audience (Question #2), and the necessary components for a "good" explanation (Question #3). These categories were selected based on work by Hesse & Anderson (1992) on students' explanations of chemical change which suggested that these were important components of students' ideas about scientific arguments. These questions were administered during the pre- and the post-instruction interviews, and were designed to provide information on changes in students' ideas about scientific arguments over time. The second set of questions (See Appendix 4-D), administered during the post-instruction interview only, asked students to provide their own explanations for a series of questions involving real-world situations. Students were asked to identify the three argument components (observations, statements about substances, and statements about molecules) in either their own explanations or, in cases where they had difficulty in providing their own explanations, by using notecards with possible pieces of an explanation that were provided by the interviewer. This second set of questions provided additional opportunities for students to develop arguments and explanations for science topics that corresponded to those covered in the CPS curriculum unit.

As mentioned above, the primary data source for this study was the students' arguments that were developed during their collaborative problem solving discussions. The information obtained from the clinical interviews on the students' conceptual understanding as well as the nature and content of their explanations and arguments was used to supplement the analyses of the discussion flow graphs.

Pre- and Post-Instruction Tests

Like the clinical interviews, the pre- and post-instruction tests provided supplemental data for investigating students' understanding of the scientific concepts covered in the CPS curriculum materials. Students' responses to the test questions were coded using the same four general categories used for the clinical interviews: scientific goal conception, partial understanding, naive conception, or ambiguous response, using the same goal conception-naive conception chart (See Appendix 4-F). Students' answers to the test questions were used to supplement the analyses of the discussion flow graphs and to provide further evidence supporting the conclusions made concerning the nature of students' scientific arguments.

CHAPTER FIVE

FINDINGS AND DISCUSSION

This chapter presents the findings for the research questions addressed by this study. For research question #1 concerning the nature of students' scientific arguments, results are presented for each of the four group tasks described in Chapter 4. Each task was analyzed in terms of a) the logical structure and scientific content of scientific arguments and b) the collective validation process. Both of these components were examined from an ideal, scientifically literate perspective and from the students' perspective. For research question #2 concerning changes in students' scientific arguments over time, each of the group's arguments for the four tasks are discussed in terms of changes in the group's argument structures and its collective validation processes over the course of the unit. Research question #3, concerning factors that affect students' scientific arguments, will be discussed in Chapter 6: Summary, Conclusions, and Implications.

Activity #1: Pure Substance vs. Mixture

A goal of this task was to have students apply what they had learned in previous lessons about matter, non-matter, pure substances and mixtures to the classification of eight unknown samples. In this activity, the students were given unlabeled vials containing water, air, salt water, salt and sand, sand and iron filings, mud, sand and sawdust, as well as a picture of a candle flame. They were asked to first decide on a name for each of the substances, then to determine if each was matter or non-matter, a pure substance or a mixture, and whether they were sure or unsure of their classifications. For each substance, students were told that they must provide reasons to support their conclusions. The teacher modeled the procedure for the entire class by thinking aloud while going through the decision-making process for a sample substance. Students were given time to work on this task on an individual basis first, and then they met in small groups to reach consensus on their group answers and reasons. They were told by their teacher and by the instructions on their worksheets that they could use the equipment provided (beakers, magnifying glasses, test tubes, and other containers) to collect evidence that might help them arrive at and defend their answers.

Earlier lessons stressed the following scientific concepts: matter includes all solids, liquids, and gases that make up the world; non-matter are those things that are not solids, liquids, or gases; pure substances are substances that contain only one kind of matter; and mixtures are substances containing two or more different substances mixed together.

Logical structure/scientific content

Scientifically literate version

In order to identify an unknown substance under the conditions set out in this activity, most scientists would probably first make a decision based on a visual examination of the substance. Additional testing using simple techniques discussed below could be done to verify an initial identification or, in cases where the initial identification was uncertain, to obtain further information concerning the unknown substance. For example, with a substance that looked like water, scientists could evaporate a small sample of the liquid and check for a precipitate, indicating that another substance had been added to the water. Or, for a substance that contained a mixture of small white grains or crystals, a magnifying glass could be used to try to visually distinguish between the different grains, or the mixture could be mixed with water to see if any of the grains dissolved. Thus, various tests (evaporating, smelling, examining with a magnifying glass, dissolving, tasting, etc.) could be performed to determine the identity of the unknown substance. This empirical evidence would play an important role in the identification of the substance and, as will be discussed shortly, in determining whether the unknown was a pure substance or a mixture.

The decision of whether a substance was matter or non-matter would be fairly straightforward, based on: the canonical definitions given in the preceding lessons; an understanding of the distinguishing characteristics of each of the three states of matter; and observational data that matched or failed to match these distinguishing characteristics. Substances that were found to be either a solid, liquid, or gas would be examples of matter, while anything that was not an example of one of these three states of matter would be classified as non-matter.

If a substance was identified as an example of matter, it could then be classified as either a pure substance or a mixture. As noted above, the basic tests and the kinds of empirical evidence used to determine the identity of the substance (evaporating, smelling, dissolving, etc.) could also be used to determine whether the sample consisted of only one substance (a pure substance) or more than one substance (a mixture).

Finally, the decision of whether a group of scientists was sure or not sure about their classifications would likely depend on the level of confidence they had in their answers concerning the identity of the substance and whether it was pure or mixture. In other words, this decision would be based primarily on the kinds of empirical evidence the group was able to gather, and the nature of the qualifiers or the assumptions that were deemed important for this activity.

It is clear that for a group of scientists completing the worksheet accompanying this activity, the answers to each of the cells in a row (name of substance, matter or non-matter, pure or mixture, sure or not sure) for a particular substance would be closely linked. That is, the answer given for one cell would provide useful and necessary information for determining the possible answers to the other cells for the same substance. For example, if a sample was classified as non-matter, then it could be neither pure nor mixture, based on the canonical definitions of matter and non-matter. It is also clear that the arguments developed by a group of scientifically literate members would be based on a mixture of empirical evidence (the data they gathered for each of the unknown substances) and theoretical warrants and backing (in this case, the canonical definitions for the scientific concepts).

With this description of the ideal, scientific approach to completing this task serving as a sort of comparative template, it is possible to examine the nature of the target students' answers and arguments.

Student version - Group 1

Table 5.1 below presents a summary of the answers and the reasons that the Group 1 students developed on an individual basis prior to their group discussion, as well as a summary of their final group answers and reasons. The portions of the table in

Table 5.1: Summary of Group 1 Worksheet Entries - Activity #1

Student	Answers	Reasons
Jason	Air - matter, mixture Salt - matter, pure	*No reason given* Tastes like salt
Jamie	Air - matter, mixture Salt - *nothing written on paper*	*No reason given*
Mary	Air - (non)matter, pure Salt - non-matter, pure	Because there's nothing to mix in it Because there's chemicals only on
Marvin	Air - matter, mixture Ground salt - (non)matter, mixture	Because it has gas I didn't test it
Group	Air - matter, mixture Salt - matter, pure	Because you can't smell air Because we tasted it

parentheses indicate parts of students' answers that were erased during the course of the group discussion. Appendix 5-A includes copies of students' worksheets and discussion flow graphs for each small group discussion.

Group 1, consisting of Mary, Jason, Jamie, and Marvin, completed the identification and classification of two substances during the group discussion period, which lasted approximately twenty minutes. The first unknown substance the group examined was a vial of air. Classification decisions concerning air had to be made based primarily on canonical knowledge, since there was limited empirical evidence that could be collected for this substance to aid in determining the group's answers and reasons. In fact, Group 1 relied rather heavily on canonical definitions in deciding that air is an example of matter and that it is a mixture. Mary began the group discussion with the claim that air is non-matter because it was not an example of any of the three states of matter, but Marvin and Jason pointed out that air is in fact a gas and, therefore, an example of matter.

7	Mary:	You guys ain't even paying attention. I said air, non-matter ...
8	Marvin:	Air is pure.
9	Mary:	... because it's not a liquid, solid, or ...
10	Jason:	Air is a gas!
11	Marvin:	It's a gas. It's a matter.
12	Jason:	Matter.

In a similar fashion, Jamie and Marvin used the canonical definition of a mixture (two or more different substances mixed together) to claim that air is a mixture (23-24), contrary to Mary's claim that air is pure "because nothing's mixed in with it." (3)

While trying to decide on a group reason for their claim of mixture, the students in Group 1 proposed several alternatives, but very few of these elicited much extended discussion. One exception was Mary's claim that "we can smell air." (72) All of the other group members objected strongly to her suggestion, arguing that you can't smell air. Several students used sarcastic remarks to strengthen their objections.

68	Mary:	Because we can smell it.
69	Marvin:	Because it's mixed with lots of gases.
70	Jason:	No, I don't think so.
71	Marvin:	(To Jason) Yes, it is.
72	Mary:	You can smell it.
73	Jason:	(To Marvin) Fine.
74	Marvin:	(To Mary) You can't smell air.
75	Jamie:	If you can smell air, then I'm Humpty Dumpty.
76	Jason:	Because you can't smell air.
77	Jamie:	(Sarcastically) Smell that air! Smell that shit!
78	Jason:	There's Humpty Dumpty. Because you can't smell air.
79	Mary:	Come on! We're only on the first one.
80	Jason:	You can't smell air.
81	Boy X:	I know you can't smell air.
82	Marvin:	(Writing) Because you can't smell air.

That phrase, "Because you can't smell air," became the group's reason for deciding that air is a mixture, even though it wasn't particularly clear how that reason supported their claim for mixture.

The group's discussion of the second unknown substance, salt and sand, provided additional examples of several of the limitations of students' arguments. The group spent a long time reaching consensus on the identity of the substance. Three students argued it was salt based on their prior knowledge of "ground salt, the kind you use to melt ice on sidewalks." Jason argued it wasn't salt, based on empirical evidence obtained as a result of tasting the unknown substance. (122-127) He claimed that he had tasted "ground salt" before and this substance didn't taste like it. Jason was finally convinced that the substance was indeed salt after tasting the unknown a second time. (241-244)

During this argument, the group decided that the substance (whatever it was) was matter based on the canonical definition provided in their lessons. (157-164) However, while discussing whether the substance was pure or a mixture, several students, and in particular Jamie, insisted that the other students had to present convincing reasons for supporting their claims, and that canonical definitions alone were not sufficient. For this group, the convincing element seemed to be personal knowledge or experience.

165	Jamie:	Mixture!
166	Mary:	(To Jason) It's mixture? Because we tasted it?
167	Jamie:	No, that's not a good reason.
168	Jason:	It's pure!
169	Jamie:	How do you know?
170	Jason:	'Cause it's only made out of one substance.
171	Mary:	Yeah.
172	Marvin:	No!
173	Jamie:	(To Jason) How do you know?
174	Jason:	It's pure.
175	Jamie:	Answer the question, Jason!
176	Mary:	Because ...
177	Jason:	Because it's only made out of one matter.
178	Marvin:	No ...
179	Jamie:	How do you ... Have you made salt before?
180	Jason:	I put it in my mouth and it tasted like the same thing.
181	Marvin:	(To Jason) That's the reason ... Have you made it before?

The group finally agreed that the substance was pure, and their reason was based on shared empirical evidence: "Because we tasted it." (259-264) As was the case in their discussion of air, the logical link between the group answer and the corresponding warrant was not clear. The criteria for a good reason in both cases seemed to be the group's common empirical evidence and the ability of the group to reach agreement on any answer. However, the empirical evidence used by the group was very limited in scope. The group failed to see that the substance was really a mixture of salt and sand. They based their identification solely on taste without considering additional sources of empirical evidence, such as whether all of the particles looked the same or were equally soluble in water.

Student version - Group 2

Table 5.2 below presents a summary of the students' initial individual answers and reasons and the group's final answers and reasons for each of the substances they identified during the group discussion. (See Appendix 5-A for a copy of the discussion flow graph for this activity.)

Three members of Group 2 (Jennifer, Anna, and Sheronda) discussed three unknown substances during this activity. The fourth group member, Brett, was absent the day this activity was completed. The group began discussing air, and quickly disagreed on whether air was matter or non-matter. As pointed out above, a group of scientifically literate members would quickly resolve this question by referring to the canonical definition of matter as a solid, a liquid, or a gas. For Group 2, it became clear that, even though they could cite the definition, this was insufficient without a common understanding of the states of matter, and in this case an understanding of what constitutes a gas. (23-31) Despite the lack of consensus, Jennifer yielded on this point, although she did suggest that the group verify their answer by checking with the teacher. (33) A few moves later, the group found that their lack of a common understanding of the composition of air also led to disagreement. Although she did not appear to be convinced of the truth of the scientific information presented by Sheronda and Anna, Jennifer eventually yielded once again to the majority thinking, and the group discussion of this substance ended. (47-63)

Table 5.2: Summary of Group 2 Worksheet Entries - Activity #1

Student	Answers	Reasons
Sheronda	Air - matter, pure Sand/pepper - matter, mixture Salt water- matter, mixture	Gas- because there's nothing else in it Different things in it Salt in it
Anna	Air - (non)matter, pure Sand/dirt - (non)matter, mixture Water - matter, pure	It's gas and nothing mixed It's not a matter It's liquid
Jennifer	Air - non-matter, mixture Sand/pepper - matter, mixture Salt water- matter, mixture	Air has different mixtures There are little black stuff in it that is pepper Salt in it
Brett	*Absent*	*Absent*
Group	Air - matter, mixture Sand/pepper - matter, mixture Salt water- matter, mixture	Pollution Different things in it Salt in it

For the second unknown substance, the group decided fairly quickly and with little discussion that the substance was sand and pepper (actually sand and iron filings). (65-75) The group disagreed on whether sand was a solid or not, but this time a canonical definition seemed to help the group reach consensus.

102	Jennifer:	Mixture.
103	Sheronda:	Reason! Different things in it.
104	Jennifer:	(To Sheronda) No.
105	Sheronda:	Yes, girl.
106	Anna:	(Simultaneously) Different things in it. Because it's a solid.
107	Sheronda:	No, different things in it.
108	Jennifer:	(To Anna) That ain't a solid, is it?
109	Sheronda:	No, it isn't.
110	Anna:	It isn't? Then why is it matter? It's either solid ...
111	Jennifer:	The little, the little crystals in there are solid.
112	Anna:	That's what I said. It's solid.

For substance #3 (salt water), the group used canonical definitions as reasons for deciding that the substance was matter because it was a liquid (127), and that it was a mixture because it had salt mixed with the water (181-183). Empirical evidence (tasting) convinced the group that the substance was indeed salt water and not pure water (152-156).

Collective Validation Process

Student version - Group 1

Table 5.7 below of the students' participation rates shows that there were fairly equal participation rates for all group members during this activity. All of the group members had opportunities to put their ideas out on the table for consideration. No student seemed to dominate the discussions nor did one student's reasons seem to hold more value or be more persuasive than any other's.

The group proposed a wide variety of reasons when trying to decide whether air was pure or a mixture, but in most instances there was little direct discussion of each other's ideas. On several occasions, however, Mary's ideas were rejected by all three of the other students, and this consensus resulted in the group's final reason for one of the substances. (16-34, 72-82) Thus, arriving at the final group response was not always a matter of careful consideration of all possible answers and the elimination of all but the most suitable. Instead, it seemed to be a matter of accepting the answer or reason that the majority of students could agree on. Once agreement was reached, the group considered their task to be completed.

In general, the group members all showed an interest in having reasons for their answers, with each member requesting reasons at least once during the activity (Mary: 35, 44; Marvin: 19; Jamie: 63, 65, 169-175; and Jason:186-188, 201). Of course, the question of the students' motivation in requesting these reasons arises. In other words, it was unclear whether the students genuinely wanted to know how and why the other group members arrived at their answers, or whether their requests were prompted by the nature of the activity itself and specifically the worksheet that the students had to fill out. In terms proposed by Edwards and Mercer (1987), it was not clear whether students' participation in and understanding of the activity was ritualized or principled.

The general impression that emerged from the data for this group is that the students' engagement in this activity was predominantly ritualized in nature. As noted above, students seemed to reach consensus based on majority rule rather than based on a thorough consideration of all possible answers. Many different ideas were proposed, but very few elicited significant discussion. Additional evidence for this claim of ritualized participation was provided by the students' worksheets. A principled interpretation of this activity would be based on the understanding that the worksheet needed to be completed on a line-by-line basis rather than on a cell-by-cell basis. In other words, the answers to one cell for a substance clearly affect the possible answers for the subsequent cells. The students' individual answers on their worksheets showed little recognition of this, with every student except Jason labelling at least one substance as non-matter and then classifying that substance as either a pure substance or a mixture. From the students' perspective, their task seemed to be to fill in as many individual cells as possible and to get the worksheet filled out as completely and as quickly as possible.

This ritualized interpretation of the activity was clearly demonstrated by one of the students in this group. Mary's participation in this activity was characterized by her repeated statements about procedural matters and getting through the worksheet (moves # 25, 38, 52, 79, 114, 155, 251, 256, 266). On several occasions she reminded the rest of the group that their work would be graded, and she expressed frustration with the group's slow pace in completing the worksheet. Her contributions to the discussion revealed that she did not consider this to be a particularly meaningful activity.

Student version - Group 2

The discussion flow graph for this activity showed a predominance of procedural statements and very little extended discussion of the answers suggested by the three students. As was the case for the students in Group 1, the decision-making procedure for this group appeared to be based on the principle of majority rules. Once two of the three students agreed on a particular answer or reason, the discussion for that substance ended, regardless of whether all possible answers had been given equal consideration.

Similar to the students in Group 1, these students completed the activity in a ritualized manner, treating each cell of their worksheets as individual items to be completed. The students also disagreed on their interpretations of the kinds of reasons they were supposed to give for each substance. While discussing the second unknown substance, Anna claimed that the group needed to justify their classification of the substance as matter, while Jennifer and Sheronda argued that the group's reason had to explain why the substance was a mixture(108-123). Anna was eventually overruled by Jennifer and Sheronda, a pattern that was repeated many times during the unit.

Although the participation rates for this group were fairly equal, it was evident that Sheronda controlled much of the discussion. On several occasions she effectively ended the discussion of alternative answers by telling the other students what the group answer would be. For example, when the group was discussing the classification of air, Sheronda refused to discuss Jennifer's idea that air was not a gas, asserting that her answer and her reason were the right ones (23-38). In the example mentioned above on the discussion of the group's reasons for the sand and pepper, Sheronda repeatedly insisted that her answer was correct (103-112).

Summary

Student versions

In summary, the scientific arguments developed by both small groups during this activity were based on a combination of personal knowledge and anecdotes, empirical data, and scientific canon, primarily canonical definitions. Unlike the systematic data collection that would likely be performed by a hypothetical group of scientifically literate members completing this activity, the empirical evidence obtained by these students was very limited in scope and unorganized. They did not appear to place much value on accurate and organized empirical data collection, seemingly satisfied when the group was able to reach agreement based on only a few observations. The students rarely used the available equipment to further test the accuracy of their answers. The lack of commonly accepted understandings of key scientific concepts and criteria for evaluating reasons among group members resulted in arguments that were substantially different from and less developed than those that would be articulated by scientists.

Since this was the first collaborative problem solving activity of the unit, it is not terribly surprising that the students' scientific arguments during this activity were very limited in terms of their logical structure and their scientific accuracy. Prior to this activity, the students had not yet received any instruction on the components of good or complete arguments. Their teacher and the worksheet for this activity reminded them to provide reasons for their answers, but little if any discussion took place to talk about what constitutes a "good" reason. The students were encouraged to use simple equipment and observational data to help in developing their reasons for their answers. Although they had received some instruction on the definitions of the various terms such as matter, non-matter, and pure substance immediately prior to this activity, the students were also forced to rely to a large extent on their prior knowledge about the three states of matter and their own definitions of pure substances and mixtures. Finally, since this activity occurred at the beginning of the instructional unit, these students also had a very limited common knowledge base in terms of a shared understanding of scientific canon or shared in-class activities.

Generally speaking, the students' small group discussions reflected these limitations. Lacking a well developed set of theoretical criteria for judging the validity or the relevance of reasons, the groups resorted to the use of a few canonical definitions as their warrants. Lacking a well developed, shared, canonical knowledge base, they often resolved their disagreements on the basis of personal knowledge and anecdotes. Lacking an understanding of the importance of accurate empirical evidence in scientific decision making, they failed to take full advantage of the equipment and other resources at their disposal for collecting data that would be useful in the decision-making process.

The discussion flow graphs for the two groups revealed a number of similarities in the argumentation processes used by the students. In general, the discussions of both groups were characterized by little extended discussion of the reasons given to support individual answers, and by a ritualized procedure of filling in each of the cells on the worksheet with little consideration of how the answer to one cell would affect the answer for another cell. When reasons were given, they were often based on personal experience or anecdotal information that was not subject to group verification. Occasional reference was made to canonical definitions, and little use was made of systematic data collection for verifying group answers. Rather than considering a range of alternative answers and reasons, both groups showed a preference for ending their discussions as soon as a majority of students was able to reach agreement, resulting in incomplete or unclear arguments.

Activity #2: Weight and volume changes

Unlike the other three activities in this study which all included separate occasions for students to develop individual as well as group answers and reasons, this activity only consisted of a small group discussion during which students answered a series of questions on a supplemental worksheet designed by their classroom teacher. This group discussion was preceded by a series of lessons on: the three states of water and the molecular arrangement of each state; changes of state of water such as freezing, melting, and boiling; and teacher demonstrations of freezing and melting ice and the resulting changes in volume but constancy of mass. Seeing that the students were having trouble with these ideas, the teacher wrote up his own worksheet on mass and volume to help students think about and better understand the differences between these two units of measure. Having worked with the pilot version of the CPS unit the previous year, he knew that an understanding of the content issues of constant mass and variable volume for changes of states of water was crucial for the third activity, Water on the Spaceship, involving the choice of which state of water to take into space.

The four questions on the worksheet concerning weight and volume that students discussed in their small groups were:

1. Which weighs more, a quart of sand or a quart of cotton?
2. Which has the greatest volume, a liter of cotton or a liter of sand?
3. Which weighs more, 11 grams of sand or 11 grams of cotton?
4. Which has the greatest volume, 11 grams of sand or 11 grams of cotton?

Logical structure/scientific content

Students were given these questions to get them thinking about the differences between the weight and volume of different substances. These supplementary questions were designed to be used with the text section on weight and volume of a single substance undergoing changes of state. The text demonstrations, involving the freezing and melting of water, were intended to show that for water, the volume changes (volume increases when frozen, decreases when melted) but the weight (mass) remains the same. This demonstration was used to emphasize that the number of molecules of water (and therefore, the mass) did not change with a change of state. What did change was the arrangement of the molecules, with water molecules being farther apart in the solid state than in the liquid state. This change in molecular arrangement results in the volume of ice being slightly greater than the volume of the same mass of liquid water.

However, these questions were not simply about mass and weight. The teacher's questions also introduced the notion of density, or mass per unit volume, by comparing two very different substances, sand and cotton. His series of questions asked about differences in mass and volume, but correctly answering these questions required a correct understanding of the concept of density as well. It also required paying careful attention to the variable being requested by the question (volume or weight) and the unit of measure given in the question. For example, Question #1 asks, "Which weighs more, a quart of sand or a quart of cotton?" To correctly answer this question, a student would need to recognize that the requested variable is weight, while the given unit of measure is volume (quarts). In addition, the student would also need to see that because sand has a greater density than cotton (that is, a greater mass for a given volume), and since the question asked about equal volumes of the two substances, then the sand would weigh more.

In Question #2, "Which has the greatest volume, a liter of cotton or a liter of sand?", the students would need to realize that liters are measures of volume, and that the requested variable is also volume. In this question, the concepts of mass and density are irrelevant, because only volume is being considered, not weight or weight per unit volume.

Question #3, "Which weighs more, 11 grams of sand or 11 grams of cotton?" is similar to Question #2, only this time the requested variable and the given variable are both weight. To answer this question correctly, students would need to recognize that grams represent a unit measure of weight.

Question #4, "Which has the greatest volume, 11 grams of sand or 11 grams of cotton?" is similar to Question #1 because density is an important part of the answer to both of these questions. This time students would need to realize that because sand has a greater mass per unit volume than cotton (greater density), equal weights of the two substances would occupy different volumes, with 11 grams of cotton taking up much more space than 11 grams of sand.

Scientifically literate version

These questions represent a good example of the importance of the collective validation of the question being considered. A group of scientifically literate members would likely follow a series of steps similar to those described above to identify the relevant variables for each question and to identify the information provided in the problem statement that would be needed for correctly answering each question. Once this had been done and the group had reached consensus on the exact nature of the questions being considered, they could begin applying the concepts of mass, volume, and density to the four questions.

The argument components needed for answering these questions would be provided by the problem statement, the variables identified during the validation of the question, and the canonical definition of density. For example, for Question #1 the model argument could be written as follows: Given equal volumes of sand and cotton (D), a quart of sand would weigh more than a quart of cotton (C) since sand is more dense than cotton (W) because sand has a greater mass per unit volume than cotton (B). The same argument structure would apply to Question #4, with the given unit of measure being mass instead of volume, and the definition of density explaining that cotton has a smaller mass per unit volume than sand. For Questions #2 and #3, the argument simply involves recognizing that grams and liters are units of measure for mass (weight) and volume, respectively. So, the argument for Question #3 could be written as follows: Given equal weights of sand and cotton (D), 11 grams of sand would weigh the same as 11 grams of cotton (C) since grams are units of measure of weight (W).

Student version - Group 1

This group began answering these questions in reverse order, considering Question #4 first (although the videotape transcript begins with the group having already discussed Question #4 and moved on to Question #3). Jason and Nate dominated the discussion, with the two of them together accounting for more than 70 percent of the total moves for this discussion. (See Table 5.7 below.) Nate argued correctly that 11 grams of sand and 11 grams of cotton would weigh the same and he understood that this question was only asking about weight. Jason, on the other hand, failed to recognize that grams is a unit of weight, and his misunderstanding of this question was made clear with the example he gave the group to try to clarify his reasoning:

17	Jason	(Picks up notebook) Let's say this is eleven grams and (picks up another folder) this is eleven grams. (Hands both to Nate and Nate uses his hands as balances.) Which weighs more to you?
18	Nate	They're both the same.
19	Jason	(Points to yellow folder) That is definitely more!

A few moves later he argued that, although sand and cotton both weigh 11 grams, "maybe one doesn't weigh as much as the other" (24). When the group went back to reconsider Question #4, a critical source of confusion arose when different students used the terms "lighter" and "heavier" to mean both weight and density, without making the distinction between the two variables clear. For example, in response to Question #4, Nate said that cotton would have the greatest volume "because sand is heavier than cotton and it takes more cotton to make 11 grams, so therefore the cotton has a greater volume."(43) Here Nate used the common term "heavier" in the sense of density, meaning that sand has a greater mass per unit volume than cotton. Jason argued that Nate was being inconsistent in his answers to Questions #3 & 4 because, while Nate claimed that sand is "heavier" than cotton in Q#4 (40-43), he also stated that 11 grams of cotton and 11 grams of sand weigh the same. How could they weigh the same in one case and yet be different in another case? Jason's consistent failure to distinguish between the variables of weight and volume and his use of "heavier" and "lighter" to refer to weight, and Nate's use of the terms "weight," "lighter," and "heavier" as synonyms for density caused a great deal of confusion for the entire group (Cf. Moves 54-63, 65-75).

Throughout the discussion, Mary and Jason argued that Nate was being inconsistent in his claims that one substance was lighter than the other and yet both weighed the same. After several attempts at resolving this conflict, the group finally asked the teacher to intervene, and he tried to get them to clarify their use of the terms lighter and heavier and to identify the relevant variables for each question. After his attempts proved unsuccessful with Jason, the teacher left the group and asked Nate to explain things to Jason (Moves 127-167). Mary finally admitted that she understood the difference between Questions 3 & 4, and Jason reluctantly conceded defeat when he realized that he was outnumbered three to one.

177 Jason The sand would be heavier. That's the same as eleven grams in one hand and eleven grams in the other. They would be the same.
178 Nate Yeah, they would. There's more of cotton. We're not talking about volume on this question, we're just talking about the weight. Do you get what I'm saying?
179 Mary I get it.
180 Nate See! (To Jamie) Do you get it?
181 Mary Yeah.
182 Nate See, Jason? (Slaps hands together and smiles)
183 Jason Fine. What are we going to put then?

184 Nate Thank you. The same, the same weight.

.

.

.

190 Jason I'm putting "same." If I get it wrong, it's your fault.

191 Nate We're not going to get it wrong, Jason.

When the group moved on to the next two questions, the same problems arose, with Jason having difficulties distinguishing between weight, volume, and density, and in clearly defining the relevant variables for each question. The problem solving session ended with the group still undecided on their answers, and Nate tried one last time to convince Jason that he was right, saying, "Trust me on this one, Jason. I think I know what I'm talking about." (217)

Student version - Group 2

This group spent very little time on this set of four questions. While answering the first part of the worksheet which asked them to write a sentence for the term "volume," it became clear that they really didn't understand what the term meant, and had to ask the teacher to define it for them. Even after he did so, it wasn't at all clear that the students understood this concept because their sentence using the word volume was, "Molecules are made of lots of volume." (128)

This group's discussion of all of the weight and volume questions lasted only a few minutes, compared to Group #1 which was only able to answer three of the four questions in the twenty minutes of small group time. For the first question, Sheronda and Jennifer claimed (correctly) that a quart of sand weighs more than a quart of cotton, and the other group members accepted this answer with no discussion at all (129-130). For Question #2, Jennifer claimed that a liter of cotton has a greater volume than a liter of sand because "cotton fills the whole thing." (132) Sheronda accepted this answer and told Brett to move on to the next question, but Anna argued that "you can also fill it (the container) with sand."(134) In response, Jennifer argued that sand has air going through it and more space (implying that it doesn't fill the container all the way up) and that cotton is all together (135-39). When Anna argued that cotton has air in it too, Sheronda and Jennifer insisted that the correct answer was cotton(140) and that ended the discussion. Although Anna realized that the group's answer was incorrect, she was unable to convince Sheronda and Jennifer of this. The group's lack of understanding of the term "volume" prevented them from understanding what the question was asking for. The group also failed to correctly identify the relevant variable for this question and to identify the information provided in the problem statement.

For Question #3, Brett, Sheronda, and Jennifer all agreed that 11 grams of cotton weigh more than 11 grams of sand (140-43) with no discussion whatsoever of their reasons and no argument presented (no warrants or backing). The group claimed to have finished the worksheet without discussing Question #4.

Collective Validation Process

Student version - Group 1

Unlike the previous activity in which students contributed fairly equally to the group discussion, this activity was characterized by Nate and Jason's domination of the discussion. (See Table 5.7 below) The two of them together contributed nearly 72% of the total number of moves during the discussion. Mary and Jamie played relatively minor roles in this discussion in terms of the number of statements they made and the overall impact of their ideas on the group's final answers and reasons.

Much of the students' discussion revolved around their inability to agree on how to interpret these questions and what was needed to answer them. The failure of this group to collectively validate these questions led to much of the confusion and frustration that they experienced. Jason failed to realize that each of the questions provided different kinds of information and required considering a different set of variables. He believed that several of the questions were identical (e.g., Questions #3 & #4) with just a few word changes involved, when in fact answering the two questions involved much more than simply substituting weight and grams in one question for volume and liters in the other. As discussed above, correctly answering two of the questions (#1 & #4) required an understanding of the concept of density, and answering the other two required considering either weight or volume alone. Nate attempted to point out the appropriate variables for several of the questions (68, 178), but he was unable to make this clear for Jason and Mary. As mentioned above, the group members' failure to clarify their individual interpretations of the terms "weight," "lighter," "heavier," and "amount" also resulted in Nate and Jason consistently arguing at cross purposes.

Throughout this discussion, Jason and Nate were the only group members who explicitly explained their personal reasoning for their answers. Mary and Jamie participated very little in this discussion, with Mary primarily supporting Jason in his criticisms of Nate's apparent logical inconsistency (55, 65, 86-88, 103) and Jamie supporting Nate in his attempts to distinguish the relevant variables for Questions #3 &#4 (25, 105, 172).

Another pattern that characterized this group's discussion was the frequent appeals to outside authority to resolve disagreements. When one or more of the group members became frustrated with their inability to reach consensus, help was sought from the teacher, others within the classroom or, in one instance, from a television show. The classroom teacher became involved in the group discussion several times, providing suggestions on procedural aspects in one instance (29-39) and trying to help the group clarify its use of the terms "lighter" and "heavier" in another instance (127-167). Another time, Mary and Nate sought answers to the discussion questions from an adjacent group of students (108-111). At another point, Jamie even suggested, "Let's take this to People's Court," referring to the television show that features the presidings of a small claims court. (122) However, at least one student realized that ultimately the group had to find a way to resolve its own differences of opinion. Near the end of the discussion, Jason tried to solicit the teacher's assistance again, but was told by Nate, "We can't call on Mr. Donaldson every time we have a problem. You know that and I know that." (208).

Student version - Group 2

The group discussion for this activity showed limited group engagement in the task of answering these questions. Overall, the group spent very little time discussing any of their answers. The discussion flow graph for this activity was very linear, with very few connections made between any of the columns. The vast majority of the moves were classified as either procedural statements concerned with logistical problems such as whose turn it was to read or what to write down, or as specific answers to the questions. For the four discussion questions on weight and volume, there were no segments of the discussion that represented collective validation of the questions. The only chunk of the discussion that addressed reasons involved Anna's attempts to disagree with Jennifer on her answer to Question #2 (132-139). As mentioned above, Jennifer and Sheronda refused to consider her counterarguments, and the group discussion was squelched by Jennifer and Sheronda's insistence that their answer was correct.

During this discussion, Group 2 needed the teacher's help on two separate occasions. First, they needed his assistance in establishing a procedural system for addressing each question and ensuring equal participation by each group member (1). The group also needed the teacher's help in clarifying the definition of the term volume (119-128). Even though the teacher gave the canonical definition twice, "Volume is how much space something takes up," it was apparent that the group did not fully understand the meaning of the term, as shown by their sentence, "Molecules are made of lots of volume." (126-128)

It is clear from the discussion flow graph and from the table of student participation rates (See Table 5.7 below) that Sheronda and Jennifer exercised the most control in this group, with Sheronda being the most dominant member. She took on the role of maestro for the group, repeatedly telling other members what to do (10, 39-46, 55, 58, 64-80, 128, 131, 140) and, on one occasion, dictating an answer to the group (2-9). It is clear, however, that the other group members were not completely comfortable with this arrangement. When Sheronda tried a second time to unilaterally decide on a group answer, Jennifer objected and reminded Sheronda that the group answer should incorporate pieces of each member's individual response (24). However, when Anna later tried to question Jennifer's answer to Question #2, her arguments were ignored by Jennifer and Sheronda. It became clear that the working principle for this group was that once Jennifer and Sheronda agreed on an answer, there was no need for further discussion.

Summary

The discussion flow graphs for these groups revealed a number of patterns. First, two members of Group 1 (Jason and Nate) clearly dominated the discussion, while the other two members (Mary and Jamie) effectively sat on the sidelines and observed the action. The group as a whole demonstrated that cognitive consistency was important to them. They were constantly comparing their answers to one problem with their answers to another problem, identifying and arguing about apparent similarities and differences. When they were unable to reach consensus on an answer or reason, they frequently made appeals to outside authorities for help in resolving their disagreements.

In general, the group failed to adequately identify the relevant variables for each of the problems, resulting in a great deal of confusion and disagreement. The students also failed to adequately define several ambiguous terms concerning weight and density, leading to frequent misunderstandings of answers and reasons.

Group 2 demonstrated a general lack of engagement in this activity, spending only a few minutes on their discussion of the four questions concerning weight and volume. There was very little discussion of any kind, as shown by the overall linearity and disjointed nature of the discussion flow graph. The students demonstrated a general lack of content understanding for volume and density, and they failed to recognize the conceptual inconsistency in their answers to the discussion questions. Jennifer and Sheronda dominated the group discussion, effectively eliminating opportunities for the development of complete and consistent arguments.

Activity #3: Water on the Spaceship

In this activity, students were given the following problem to solve:

> Imagine that you are a scientist who has been assigned to a team whose job it is to help plan NASA's project to build a space colony on the moon. Your group is given this task: the astronauts will need to take water with them for the space flight. You must decide whether the water should be taken in the form of a solid (ice), a liquid (water), or a gas (water vapor). Use what you have just learned about water in the last few lessons to help you solve the problem.

The previous lessons in this Lesson Cluster dealt with the three states of water, explaining states of water in terms of molecules, and volume and mass changes with changes of state (including Activity #2, Weight and Volume Changes, discussed above). The major concepts covered in these lessons included the arrangement and motion of molecules in each of the three states of water, demonstrations of water changing states (melting, boiling, and condensing), and the idea that the volume of water increases slightly when it is frozen, decreases when ice melts, and increases tremendously when water evaporates. Students were also introduced to the following explanation framework, a modified version of the Toulmin framework, used throughout the rest of the unit:

A good **explanation** has three parts:

1. **Observations:** Telling what you can see, or hear, or smell, or feel.
2. Statements about **substances:** Telling what substances are in the system that you are working with, and what their properties are or how they are changing.

3. Statements about **molecules**: Explaining properties of substances or changes in substances by telling about the molecules that the substances are made of.

The teacher provided several models of good explanations and their components for students, and students were given practice in constructing their own explanations while discussing the three states of water and completing a worksheet on changes of state of water.

As noted above, immediately prior to the water on the spaceship activity, students studied about the properties of weight and volume, and how these properties do or do not change with changes of state (Activity #2). Thus, they had all of the components necessary for solving the water on the spaceship problem once they had discussed some of their assumptions about space travel and conditions inside a spaceship. The class assumed, for example, that the interior of the spaceship would be at room temperature and that the astronauts would have to take about 1000 pounds of water, regardless of the form (solid, liquid, or gas) it was taken in.

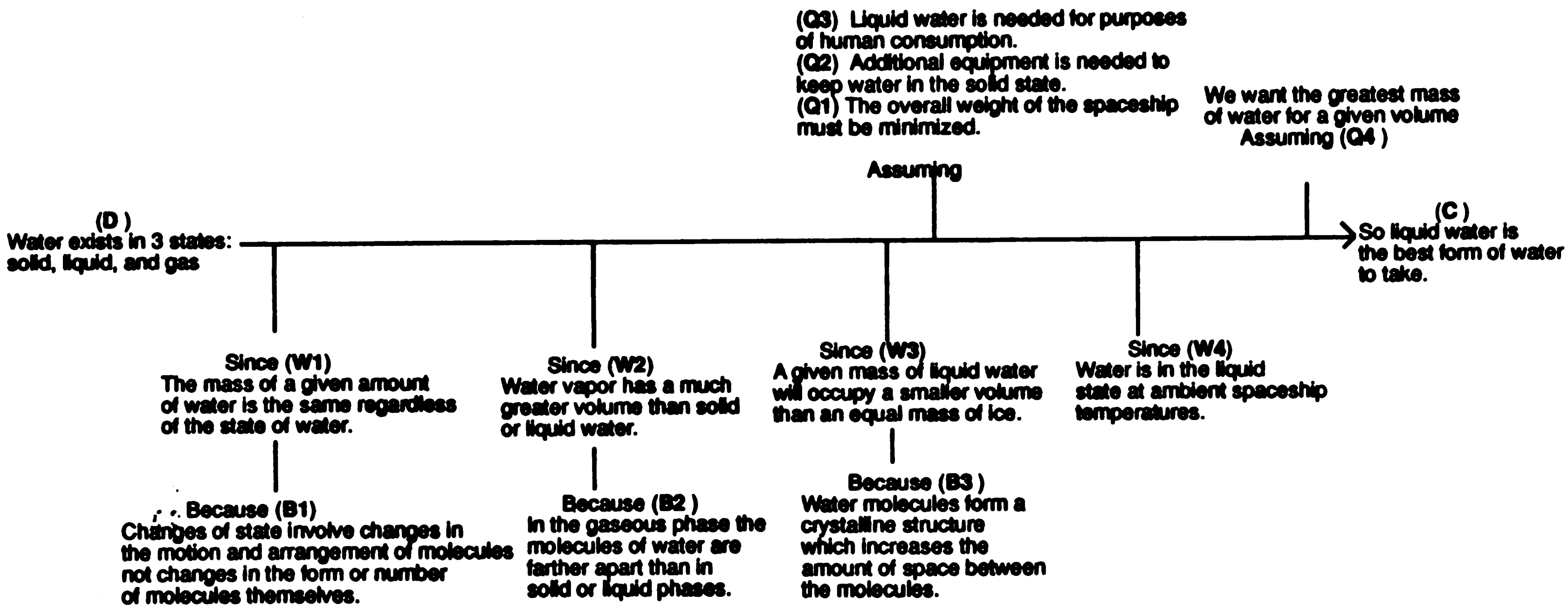
After the class had discussed these assumptions, the students began working on the spaceship problem. The students were first asked to think independently about the problem and write their own solutions, then to present their ideas to each other. The group as a whole was to reach consensus on their recommendation and reasons. These group conclusions were used as a basis for class discussion after all the groups had completed the activity. Students met in small groups on the first day (12-04-90) to present their ideas to each other without discussion, and then met again on the second day (12-05-90) to discuss their answers and reasons and to reach consensus.

Logical structure/Scientific content

Scientifically literate version

The argument that a group of scientists might use in constructing a solution to this problem has been discussed in detail elsewhere (Eichinger et al, 1991). In summary, the three principal variables that a group of scientifically literate members would most likely consider would be issues of mass, volume, and practical considerations involving the ease of storage and use. The most obvious variable, mass or weight, does not provide a basis for choice among the three states of water because a given amount of water has the same mass in all three states. Also, as noted above, the class decided to assume that the weight of water to be taken was 1000 pounds. With regard to the second variable, volume, liquid water takes up the least space, though only by a small margin over ice. The third variable, practical considerations involving the ease of use and storage, would be the most difficult to decide, with additional qualifying assumptions necessary in order to reach a definite conclusion. Most reasonable design assumptions, however, would probably lead to the conclusion that liquid was the preferable state. Figure 5.1 below uses Toulmin's argument framework to depict the elements of a scientific argument supporting the conclusion that liquid water is the preferable state.

In this case, it is clear that the scientists' argument would include a series of warrants and backing addressing each of the main variables mentioned above. Also, the complete scientific argument would take into account various practical considerations by stating a number of assumptions or qualifiers related to this problem. For the most part, the warrants would be represented by macroscopic statements (statements about substances) and the backing would consist of statements addressing aspects of the kinetic molecular theory (statements about molecules). Since this is a hypothetical question, there is no direct empirical evidence that students could obtain to support their arguments. However, the classroom teacher had performed several demonstrations on volume changes in water as it underwent changes of state during the lessons immediately preceding this activity.



D = data = evidence and/or observations
C = claim = proposed course of action or plan
W = warrant = reasons
B = backing = reasons
Q = qualifications = problem definition and assumptions
R = rebuttal = counterargument

Figure 5.1: Model Argument - Water on Spaceship Problem

<u>Student version - Group 1</u>

Table 5.3 below presents a summary of the answers and reasons that the Group 1 students developed on an individual basis prior to beginning their group discussion, as well as a summary of their final group answer and reasons. (See Appendix 5-C for copies of students' worksheets and the discussion flow graphs for this activity.) The initial individual answers and reasons served as the starting points for the development of the group's final solution to this problem. The answers included all three states of water, and the reasons ranged from very general statements about practical considerations to statements about molecular arrangements in particular states of water.

Table 5.3: Summary of Group 1 Worksheet Entries - Activity #3

Student	Answer	Reasons
Nate	Water vapor	Easy to carry, doesn't have a lot of weight, molecules won't get mixed up.
Jamie	Ice	Water will be cold when you melt it.
Jason	Ice	You can fit more ice molecules in the spaceship.
Mary	Water	So they could survive.
Group	Water	Lighter than ice and takes up less space than water vapor

On the first day (12-04-90) when the groups met to share their proposed solutions and reasons, Nate originally said vapor was the best form of water to take because it is easier to carry and doesn't have a lot of weight. Jason countered this argument by reminding Nate of the class assumption of needing 1000 lbs. of water, pointing out that "It's all going to weigh the same amount." (4) Nate agreed, but insisted that with vapor "you take more of it," (5) with "more" in this case meaning a greater volume of vapor.

Jason, on the other hand, claimed that ice was the best form "because you can carry more ice" (50) and pointed to a poster in the classroom that showed molecular arrangements for the three states of matter of a hypothetical substance. On the poster, the molecules of a solid are close together and arranged in a pattern, while the molecules of a gas are farther apart and moving freely. Using the poster as evidence, Jason argued that you could take more water with ice than with vapor because the molecules of the solid are closer together. In making this argument, it is clear that he failed to distinguish between the mass or weight of the water and the volume that each state would occupy. Eventually Jason convinced Nate that ice would be best because there would be more molecules of ice than vapor in 1000 pounds (75) and Nate agreed (76, 78, 80).

Jamie claimed that ice would be best because it would be cold when it melted, and would therefore be more suitable for human consumption (29-31). Jamie repeated this reason based on practical considerations several times during the two days of discussion. Mary's reason for choosing liquid water, "so they'll survive," was criticized by Jason and Nate and even ridiculed as a "stupid answer" (101-110).

On the following day (12-05-90) when the students got back together to discuss their ideas and reasons, Nate and Jason had switched their answers, with Nate now arguing for ice because it takes up the least amount of space and also insisting that 1000 lbs. of any state would still be 1000 lbs. Jason argued for vapor because ice is heavier than vapor and because the different states of water would have different weights. This reasoning was reminiscent of his confusion during Activity #2 when he claimed that two objects weighing 11 grams might not have the same weight.

Although Nate & Jason both considered molecular arrangements when discussing the volume of each state, molecular backing was not at all part of their final group answer or reasons. Warrants discussed by the group were a mix of volume and weight/density and practical issues. The group's inability to distinguish between weight and density and their use of the term "weight" for both mass and density continued to create confusion, especially for Jason. This ambiguous use of terms was also a problem for the group in the second activity, Weight and Volume Changes. The group needed Al's reminder about the class demonstrations on volume change with changes of state (water expands when it freezes and contracts when it melts) in order to reach consensus; otherwise they could have continued arguing weight/density vs. volume indefinitely. Despite the fact that these two activities (mass & volume changes and water on spaceship) took place within a week of each other, the students failed to remember the weight and volume changes activity while working on their solutions to the water on the spaceship activity or to see the relevance of the ideas discussed in Activity #2 for Activity #3.

Student version -Group 2

Table 5.4 below presents a summary of the initial individual and the final group answers and reasons for the students in Group 2. These students only considered two states of water, ice and water vapor, and all four students' reasons focused on practical considerations to some extent. Three of the students' reasons were exclusively practical with no mention of molecules, and the fourth student included a practical reason and a general molecular statement describing the motion of molecules in the gaseous state.

On the first day of this activity, two students (Jennifer and Brett) suggested ice and two (Anna and Sheronda) suggested water vapor. There was no discussion of the students' answers or reasons that day. As instructed by the teacher, each student simply recited his or her individual solution and the other group members wrote these down on their worksheets. On the second day of the activity, the students read their individual

Table 5.4: Summary of Group 2 Worksheet Entries - Activity #3

Student	Answer	Reasons
Jennifer	Ice	You could just warm it up and it would turn into liquid.
Sheronda	Water vapor	The water vapor molecules move around freely and because the water would float around in the spaceship if you had on the gravity system.
Brett	Ice	It would be cold when you drink it.
Anna	Water vapor	Easier to carry.
Group	Water vapor	Lighter and easier to carry around in space, also it is easier to turn into a liquid.

solutions again. Without any discussion of the reasons for the two possible answers, Sheronda told the group to choose between her reasons for vapor or Anna's reasons for vapor (101). Brett and Jennifer, who had originally chosen ice as their answer, did not question Sheronda's selection of water vapor, and the group reason was jointly constructed by Jennifer, Anna, and Sheronda.

As mentioned above, the overwhelming emphasis of students' reasons was on practical issues, with little consideration of the assumed weight of 1000 pounds (despite my reminder, 78-80), the molecular nature of matter, the class demonstrations on changes in volume when water changes states, or the relative volume occupied by each state of water. In other words, these students showed very little evidence of seeing any connection between this activity and what they had been studying in the book and in class for the past several weeks. The only mention of molecules was by Sheronda, and it is not at all clear what she meant by her statements/reason. She correctly described the motion of molecules in the gaseous state, but it is not clear how this statement supported her choice of water vapor over the other two states of water. The group eventually claimed that vapor is easier to turn into liquid, but there was no discussion or presentation of backing for this at all. The group simply accepted it - Jennifer suggested the idea (127) and Sheronda dictated the group reason (128) that all members wrote on their worksheets.

Collective Validation Process

Group 1

Although the teacher told the class on the first day (12-04-90) of this activity that the students were to simply write each others' ideas down and not discuss their answers (38-40), Nate and Jason could not resist arguing over their answers and reasons. When challenged, Nate and Jason both relied on scientific canon, such as the poster in the classroom of the arrangement and motion of molecules for each of the three states of matter, as their warrants and backing. Jason used these canonical resources to eventually convince Nate of the validity of his reasons for taking ice (76-78). It was clear from this discussion that, for the two boys in the group, the canonical ideas were persuasive pieces of evidence.

However, it was also clear during the first day's discussion that Nate considered the two girls' reasons, which were based mostly on practical considerations, as trivial and irrelevant. Nate resorted to using mockery and scorn when rejecting both girls' reasons, calling Mary's reason "stupid" (110) and making sarcastic remarks about Jamie's answer (124).

During the second day of the discussion (12-05-90), Nate and Jason resumed their arguments using warrants and backing based on scientific canon and often incorrect notions of density. However, as it became clear that the canonical reasons alone were not sufficiently convincing, the two boys began incorporating practical concerns as warrants in their own arguments. For example, Nate argued that water vapor was a poor choice because of the impracticality of trying to weigh a gas (32,157), and that ice was the best form to take because it would take up the least amount of space and leave more room on the spaceship for other necessary equipment (74). Jason also used practical concerns to counter Nate's ideas, arguing that it would be too hard to keep ice cold (123) and that the astronauts would have to take a huge freezer for storing the ice (144).

Not all practical concerns were treated equally, however. Throughout the discussion on the second day, Jamie repeated her arguments for ice and against liquid water based on practical considerations (231, 233, 236, 280). She assumed that, since the water would be used for human consumption, it would be best if it were cold. She wanted to take ice because it would provide cold water as it melted, and she argued that liquid water would get warm in the spaceship and would be unsuitable for drinking. Even after Jason and Nate decided that water would be the group answer because "it is lighter than ice and takes up less space than water vapor," Jamie remained unconvinced that liquid was best because it would still get warm. For her, the canonical variables of volume, weight, and density were secondary in importance to the practical considerations.

Throughout the discussion the group demonstrated that they placed a high value on providing reasons for one's arguments. As discussed above, there was disagreement among the group members as to what counted as a "good" reason, but it was clear that any idea that was suggested for group consideration had to be based on reasons. On one occasion Mary stated her choice of ice as the preferred state of water, and Jason and the teacher made it clear that her answer would not be considered by the group unless she had reasons for her choice (182-189).

Although Nate and Jason seemed to ignore the girls' ideas and reasons, they still showed some concern for making sure that Mary and Jamie understood the reasons behind their (the boys') answers. When Jason left the group to try to clarify a point with the teacher, Nate asked the two girls if they understood his reasons for wanting to take ice and repeated his ideas for them (45-51). On another occasion, after Nate and Jason had decided that ice was the preferred form of water, Jason told Nate that it was important for Mary and Jamie to understand their reasons. Nate's reply made it clear that he didn't share this concern (257-263).

Another pattern that was apparent with this group was their appeal to outside authority to try to resolve conflicts within the group. Early in the discussion on the second day, Nate tried to get the teacher to validate one of his reasons and Jason rejected this as a valid problem solving strategy for resolving the group's conflicts (7-9). Yet on two other occasions Nate and Jason both requested the teacher's help in clarifying some points that were causing confusion in the group. (52-54, 195-197) In fact, the teacher's suggestion to think about the weight and volume demonstrations from previous classes proved to be a turning point in helping the group (at least Nate and Jason) reach consensus.

Group 2

The student participation rates for this activity show that Sheronda and Jennifer continued to dominate the discussion in their group, accounting for nearly 65% of the total number of moves on the second day of the activity (see Table 5.7 below). On the first day of the activity the students presented their individual answers and reasons without discussion, as instructed by the teacher. Even on the second day there was very little consideration of alternative answers or reasons, despite the apparent disagreement over water vapor and ice. Rather than discussing each other's ideas, each student simply repeated his or her personal answer and reason, and then Sheronda told the group to agree on a reason for taking water vapor (101). Sheronda's unilateral decision did not elicit any questioning or disagreement whatsoever from the two students who had previously supported ice.

The students in this group attempted to resolve a disagreement over the properties of water vapor by requesting help from an outside authority (in this case, the researcher). When they were told that they would have to resolve the conflict themselves, the group abandoned their discussion of the issue altogether, focusing instead on procedural matters (75-85).

<u>Summary</u>

As was the case in the previous activity, the two boys in Group 1 dominated this discussion. They were also the ones who profited the most from having engaged in this discussion, since their individual understandings of the scientific content improved as a result of their collaboration. However, the two girls in the group were once again effectively left out of the discussion completely. It is not at all clear whether they understood the arguments for choosing liquid water as the preferred state. This was especially true for Jamie, who continued to argue against liquid until the very end of the discussion because of what she considered to be real problems with liquid due to practical considerations. Jamie's questions were never really answered and her objections were never regarded as important.

The arguments developed by Nate and Jason were much more complete than in earlier activities, and they consistently provided reasons for their answers. Their reasons included both canonical and practical warrants and backing and included both macroscopic and molecular components. However, their final group reasons for choosing liquid included scientifically incorrect notions about the relative "weights" of ice and liquid water, and were stated in macroscopic terms only. Once again, the ambiguous use of terms such as "weight," "lighter,"and "heavier" created a great deal of confusion for the group as a whole. Finally, the group failed to recognize the relevance of the previous activity on weight and volume changes for this discussion.

The discussion flow graph for Group 2 was once again very linear and column-bound, with very few connections made between the various categories of statements. The vast majority of the students' statements were procedural, with very little consideration of the reasons supporting individual's ideas. Nearly all of the reasons that were suggested focused on practical considerations, with no discussion of the molecular nature of matter. Like the students in Group 1, the students in Group 2 failed to see any connection between this activity and the previous one, and they showed little genuine commitment to their own ideas. This was especially true for Jennifer and Brett, who presented no arguments whatsoever when Sheronda ignored their suggestions for taking ice instead of water vapor.

Activity #4: Dissolving Races

This activity was part of Lesson Cluster 4 dealing with the process of dissolving. Prior to the dissolving races activity, students completed an activity entitled Sugar and Tea Bags, in which they were to devise a plan and explanations for getting sugar out of a closed tea bag without tearing or opening it. This was followed by a discussion of dissolving which included both macroscopic and molecular explanations for this process. Briefly, the text explained that when sugar is put in water, the sugar crystals become smaller until they are no longer visible in the water. The molecular explanation stated that the water molecules, which are constantly moving, hit the grains of sugar and break off sugar molecules from the crystal, causing it to get smaller. The sugar molecules then mix with the water molecules, forming a sugar and water mixture that tastes sweet.

The next lesson was the Dissolving Races Activity, in which students developed plans for dissolving a sugar cube in a cup of water under three different sets of conditions: as slowly as possible, as fast as possible, and as fast as possible without touching or disturbing the cup, the water, or the sugar cube after it was dropped in the water. As was the case with Activities #1 and #3 described above, students were first given time to develop individual plans for each of the races, and then they met in groups to reach consensus on their plans and their reasons. The races were then carried out on the following day, and students recorded the amount of time required to complete each race. The entire class got back together to discuss their results and their interpretations of these results.

Logical structure/scientific content

Scientifically literate version

The process of dissolving sugar can be explained as the result of the interaction between water molecules and sugar molecules, and the rate of dissolving depends on the rate of interaction of these molecules. In an activity such as the Dissolving Races which requires consideration of situations that would alter the rate of dissolving, a group of scientifically literate members would likely consider factors that would increase or decrease the rate of interaction between the water and sugar molecules. There are basically two ways to control the rate of dissolving: by controlling the speed at which the water molecules are moving, thereby controlling how quickly and how forcefully they strike the sugar molecules; or by controlling the number of sugar molecules that are exposed to the water. The first variable could be controlled by changing the temperature of the water, since water molecules move faster in hot water and slower in cold water. (The students had previously discussed this change in the rate of molecular motion during changes of state in Lesson Cluster 3). The second variable could be controlled by either altering the surface area of sugar that is exposed to water molecules or by moving the dissolved sugar molecules away from the surface of the sugar crystal as fast as possible. To increase the surface area, the sugar cube could be crushed, exposing more sugar molecules to the water molecules. To move dissolved sugar molecules away from the sugar cube quickly, the water could be stirred, removing the dissolved molecules and exposing undissolved molecules to the water.

With these variables and explanations in mind, a group of scientifically literate members would likely choose very cold water for the slow race and very hot water for both of the fast races. In addition, for the fast race which allows touching the sugar, the group would likely crush the sugar cube and stir the water to increase the rate of dissolving. Stirring the water before the sugar cube is dropped in would also increase the rate of dissolving for the no-touch fast race.

Thus, the complete scientific argument would consider all of the above variables in light of the constraints imposed by the conditions for each race. Of particular importance for all of the races would be the water temperature and the movement of the dissolved sugar molecules. The complete argument would include statements about the substances involved (Toulmin's warrants) and statements about the molecules (Toulmin's backing) and their role in the process of dissolving.

Student version - Group 1

Table 5.5 below presents a summary of the answers and the reasons that the Group 1 students developed for each of the races as well as their final group answers and reasons. (See Appendix 5-D for copies of students' worksheets and the discussion flow graphs for this activity.) For the slow race, there was unanimous agreement on the use of cold water, but students gave a variety of reasons for why this was preferable. Nate (9) and Mary (26) both gave macroscopic warrants that were essentially tautologies stating that the sugar would not dissolve as fast or as much in cold water. Jason recognized the inadequacy of these reasons and insisted that "we need to put a molecule answer." (27) He stated that the sugar would dissolve slower because it would take longer for the molecules to hit the sugar cube because the molecules go slower in cold water. (57-58, 119) The reasons discussed by this group were based strictly on canonical information - the group members did not use personal experiences to justify their answers. They also did not talk at all about melting as a way of explaining dissolving, in contrast with the students in Group 2 (see discussion below).

For the fast race, the group quickly agreed that boiling hot water was necessary, and their reasons included more molecular warrants and backing: "It won't take as long for the water molecules to hit the sugar" (149) because "the molecules move faster in hot water" (141). Again, their reasons were based only on canonical information, with

Table 5.5: Summary of Group 1 Worksheet Entries - Activity #4

Student	Answer	Reasons
Nate	Slow: put sugar cube in water ahead of time and freeze water	Ice won't let sugar cube dissolve
	Fast: put hot water instead of cold water	Sugar will dissolve faster
	No-touch: same as fast race	Same as fast race
Jamie	Slow: freeze cube and put it in cold water	Cold things take a long time to dissolve or melt
	Fast: hit the sugar cube and then put it in hot water	Sugar would be spinning around and then will get more water
	No-touch: put a piece of foil over it and let the moisture	*No reason given*
Jason	Slow: ice cold water	Molecules go slower and it will take longer for water molecules to hit the sugar cube slower
	Fast: boiling water in the cup	Water molecules go faster when hotter so they will hit the sugar cube faster
	No-touch: boiling water in the cup before the cube	Same as fast race
Mary	Slow: put cold air in the cup	Water would be too cold for it to dissolve
	Fast: put the cup above some fire	Water would get real hot and start to boil and the cube would dissolve faster
	No-touch: it could be by the window and the sun comes out	The sun is hot and it would melt the sugar cube and it will dissolve
Group	Slow: put sugar cube in ice cold water	It will take longer for molecules to hit the cube because water molecules move slower in cold water
	Fast: put sugar cube in boiling water	It won't take long for the water molecules to hit the sugar cube
	No-touch: put it in hot water	Same as fast race

no personal experience or observational data to support or confirm them. This canonical information appeared to be sufficiently convincing for all of the group members.

The students ran out of time before they got a chance to discuss their plans for the no-touch race, much to Jason's dismay. (160) However, all of the students wrote "put it in hot water" and "same as fast race" on their worksheets for their group answer and reason.

Student version - Group 2

Table 5.6 below presents a summary of the initial individual and the final group answers and reason for the students in Group 2. (Anna was absent the day the students wrote their individual answers and reasons on their worksheets, but she participated in the group discussion the following day.) The reasons column shows that there was no discussion of molecules whatsoever by this group. All of their reasons were macroscopic and described dissolving in terms of melting (Sheronda) or as a result of the physical action of moving water on the sugar cube (Jennifer).

For the slow race, the group agreed that cold water was best and the reason was because "we all tried it before at home." (115) Their reasons were based strictly on previous personal experiences with dissolving sugar. There was no use of canonical information from the preceding lessons, and no mention whatsoever of molecular motion. However, the students did discuss the relevance of the temperature of the water in determining the efficiency or completeness of dissolving sugar in Kool-Aid (71-77) and as a relevant variable for this activity, and they suggested that stirring was necessary to make the sugar dissolve in cold water. (77-80)

Table 5.6: Summary of Group 2 Worksheet Entries - Activity #4

Student	Answer	Reasons
Jennifer	Slow: keep pulling it up to the top of the water very fast so it won't set in and dissolve Fast: shake the cup up and down so the sugar cube will be stirred up No-touch: boil the water so the bubbles will pop and separate the sugar cube	If you keep it slow or still it will soak in better Water will be pushed and pulled together to make the cube dissolve Popping bubbles will separate the cube
Sheronda	Slow: put the cube in cold water and watch it Fast: put the cube in hot water so the cube will melt fast No-touch: put the cube in hot water	In hot water the cube would melt after two minutes It would dissolve faster and you wouldn't have to wait as long We wouldn't have to wait as much as you would for the fast and slow race together
Brett	Slow: stick it in ice cold water Fast: stick salt on the sugar cube No-touch: let it sit there	I don't know why I tried it I don't know why
Anna	*Absent for individual work*	*Absent for individual work*
Group	Slow: keep it in cool water Fast: put cube in warm water No-touch: put cube in boiling water	We all tried it before at home The sugar melts right away Bubbles will dissolve sugar

For the fast race, the group's discussion focused on the similarities between dissolving and melting. Jennifer used the analogy of melting wax with heat and compared this with the conditions of the fast race. This interpretation of dissolving as analogous to melting was a common idea in the discussions for this entire activity, with students talking about sugar melting in both the slow (77) and the fast races (124-128). Once again the group reason was based on prior personal experience, with no mention of water temperature, molecular motion, or any of the other canonical knowledge presented in class that the scientifically literate group would consider important.

Time ran out before the group was able to discuss their answers and reasons for the no-touch fast race. However, the students' worksheets showed that the group decided that the bubbles of boiling water would dissolve the sugar faster, similar to Jennifer's initial individual answer. It is clear from their answer and reasons that they thought it was the physical action of the bubbles that would make the sugar dissolve, and that they were not thinking of dissolving in terms of the interaction of water and sugar molecules.

<u>Collective validation process</u>

<u>Student version - Group 1</u>

As was the case with the previous activities, Jason and Nate dominated this discussion, accounting for nearly 62% of the total moves (See Table 5.7). Of particular interest was the very limited participation by Jamie in this discussion, who only spoke four times during the entire session. She did not contribute any ideas to the group's discussion of their reasons for each of the plans. For whatever reasons, she was clearly not engaged in this discussion. Even Mary's contributions were mostly procedural, repeating portions of the group's answers and reasons as they were written down, or urging the group to move on to the next part of the worksheet (120, 128). As was the case in the previous activities, most of the content-oriented discussion took place between Nate and Jason.

On their worksheets, students were told to write their plans and to give their explanations of why they would work. No explicit reminders were given to provide reasons in terms of molecules. Knowing this, it is interesting to note that Jason was the only one who included any molecular reasons for his individual answers - all three other students had only macroscopic reasons. During the discussion, Jason insisted that the group needed to have molecule answers, and rejected macroscopic reasons alone as being insufficient. (27) Jason was also careful about reviewing the group's first reasons for the slow race. He realized that what they had written down really didn't make sense (91) and drew Nate's attention to this fact. The students then went on to revise and clarify their reasons (103-119). Jason's written work and his contributions to the group discussion indicate that he had internalized the explanation framework suggested in the text, and that, for him, a complete argument had to include molecular components in addition to macroscopic statements about the substances involved in the activity. It is also clear that he took this activity seriously, and that he would not be satisfied with just any answer that the group was able to agree on.

Student version - Group 2

In terms of overall participation rates, this activity had the most equitable distribution of moves for each student, with no student dominating in terms of the number of statements made (See Table 5.7). However, analysis of the discussion flow graph showed that the same pattern of decision-making was still in effect. Once Jennifer and Sheronda reached consensus on an answer or a reason, that became the group's answer. This pattern was evident in this activity when Jennifer and Sheronda disregarded Anna's objections about describing dissolving as melting. (125-133)

The discussion flow graph also revealed a continual struggle for power in this group, with constant bickering over who was supposed to go first and who went next. This procedural haggling required a great deal of time and discussion and occasional intervention from the classroom teacher, as was evident in the analyses of the previous activities. This in-fighting was a sign that this wasn't a particularly healthy group. Each time these students got together they struggled for leadership and had to redetermine the procedural aspects of group functioning (4, 8, 34-39). Another unproductive procedure that surfaced during this activity was the group's decision to present all of the individual answers for all three races before discussing the group answers and reasons for each race (30-68). This eventually required each student to restate his or her individual answer before the group could begin reaching consensus. All of this procedural activity left less time for discussion of the scientific content and resulted in less developed arguments.

Despite these procedural problems and the off-task talk during the discussion, Jennifer tried repeatedly to keep the group focused and on-task (28, 83, 85, 102, 137). She tried to get the group to finish their worksheets at the very end of class even though one of the group members was missing (141). All of this added to the impression that the students approached these activities in a ritualized way, more concerned about getting the activity done than with the content or the quality of their answers.

Summary

As discussed above, a complete scientific argument for any of the dissolving races would likely include consideration of the two main variables that affect the rate of dissolving, the temperature of the water and the number of sugar molecules exposed to the water. During their discussion, the students in Group 1 only considered the temperature variable, and at Jason's insistence, they developed arguments that included molecular explanations for their plans. There was no discussion of surface area or stirring by the group, even though Jamie's individual plan on her worksheet included a suggestion to move the sugar cube during the fast race so that more water would get to it. Since the group only considered temperature, they failed to differentiate between the plans required for the fast race and the no-touch fast race. Group 1 based its arguments solely on scientific canon, with no reference to personal experiences nor any explicit references to the previous sugar and teabag activity.

The discussion by Group 2 was characterized by a complete lack of canonical reasons and molecular explanations, and the students' reasons were based on their previous personal experiences with dissolving Kool-Aid and a scientifically incorrect belief that dissolving is similar to melting.

Once again, the usual patterns of student domination were repeated in both groups. Jason and Nate dominated the discussion in Group 1, and Mary and Jamie continued to play minor roles in terms of their overall participation in the discussion and in terms of the extent to which their ideas were incorporated into the final group answers and reasons. In Group 2, Jennifer and Sheronda continued to decide what the group's answers and reasons would be, ignoring Anna's objections and counterarguments.

In general, this domination was also evident in the content understanding demonstrated on students' post-instruction clinical interviews and tests. During the clinical interviews students were asked to explain how sugar could get out of a closed teabag when it was dipped in water. Of the three students in Group 1 who were interviewed, only Jason spontaneously provided molecular arguments to correctly and completely explain the process of dissolving. Nate was able to talk about molecules after prompting by the interviewer, and Jamie was not able to explain how the sugar got out of the teabag. On the post-test, only Jason explained dissolving in terms of molecules. The others described the process in macroscopic terms only, and Mary said that the sugar dissolved in the air.

Among the Group 2 students who were interviewed, Jennifer said that the holes in the teabag got bigger when dipped in water, allowing the sugar to escape. Brett said that the sugar leaked through the teabag, and that the sugar disappeared once it got in the water. On the post-test, only Anna explained dissolving in molecular terms. Brett and Jennifer talked in general terms about sugar mixing with water, and Brett said that the sugar disappeared and went into the air. No interview or test data were available for Sheronda.

Thus, in Group 1, the students who dominated the group discussion demonstrated a consistently better scientific understanding of the process of dissolving than the less active students. Interestingly, in Group 2 the one dominant student (Jennifer) for whom complete post-instruction data were available appeared to have a less complete scientific understanding of dissolving than one of the lower status students (Anna).

Research Question #2

The results of the analyses for each of the four collaborative activities have been presented above. The following section discusses these results in light of the second research question concerning changes in students' scientific arguments over time.

Common patterns in student problem solving

As it was originally formulated, the second research question was designed to investigate whether individual students and their collaborative groups demonstrated changes in the nature and content of their scientific arguments as they progressed through the curriculum unit on matter and molecules. This research question was based on the following hypothesis: given direct instruction in the necessary components of complete scientific arguments and multiple opportunities to practice developing arguments while completing a series of collaborative problem solving activities, students would provide evidence that their individual and group solutions to these problems would become progressively more sophisticated and complete versions of scientific arguments. In other words, their problem solving discussions and their problem solutions would more closely approximate the kinds of discussions and arguments that would be developed by a group of scientifically literate members.

However, having examined the nature of the discussions and arguments that were actually developed by the two groups of students for each of the activities, it seems that, in many respects, most of the target students did not significantly change the way they approached these problems or the kinds of answers they developed. Rather, they seemed to develop fairly regular and consistent methods for working with each other and for arriving at group solutions to the problems they were given. Thus, rather than asking about the kinds of changes that took place over time in the nature of students' argumentation processes and problem solutions, a more appropriate question to ask would be concerning the patterns that emerged as these students worked individually and in groups to develop and defend their solutions to relatively complex and messy science problems.

One pattern that became apparent involved the nature of the interaction between the students as they discussed their answers and their supporting reasons for each of the activities. Analyses of the discussion flow graphs showed that the discussions in both groups were consistently dominated by a few individuals, and in both groups these were students who were originally designated by their teacher as either high or medium high ability students. Their domination became apparent in two different respects. First, these students were the ones doing the most talking during their group discussions and they accounted for the largest percentages of moves for each of the activities (Cf. Table 5.7 above). More importantly, these students dominated their group discussions by deciding whose ideas were discussed and whose answers and reasons were ultimately accepted as part of the group's problem solution. In most cases, the final group answers and reasons represented the dominant students' ideas and excluded the contributions made by the lower status students. In general, these latter students had fewer opportunities for substantive involvement in the group discussions, and their contributions were often limited to procedural concerns and off-task behavior.

While the pattern of domination was apparent in both groups, the discussion flow graphs revealed that the means by which the dominant students exerted their authority and maintained their dominance over the other students in each of the groups were different. In Group 1, the two dominant students, Jason and Nate, maintained their superiority and strongly influenced the outcomes of their group discussions based on their recognized academic ability. On several occasions, the students in this group discussed the grades they had received in the course and their scores on quizzes and tests as a way of establishing or maintaining the hierarchy of students within the group (Cf.

Activity #1, moves 38-43; Activity #2, moves 82-85; Activity #3, Day 2, moves 162-168, move 310). Based on these discussions, it was clear to all of the group members that Nate and Jason were higher achieving students, and this academic achievement accorded them and their ideas higher status. In addition, both Nate and Jason were much more fluent in "talking science," that is, in using the terminology of science in presenting and defending their answers and reasons.

In contrast, dominance in Group 2 appeared to be based more on individual personality traits, such as persistence in defending one's own ideas, overbearingness, and talkativeness. Sheronda often used sarcasm and personal put-downs to intimidate other group members or to belittle or dismiss other students' answers and reasons (Cf. Activity #1, move 59; Activity #2, moves 39-46; Activity #4, moves 37-39, 52). She also showed little receptivity to other students' ideas during their discussions of alternative answers or reasons, and she would repeatedly insist that her answer was the correct answer (Cf. Activity #1, moves 103-123; Activity #2, moves 12-24; Activity #3, Day 2, moves 135-146).

The second major pattern that developed concerned the general nature of the argumentation processes used by the students. Two basic types of processes were apparent. First, if the dominant students agreed from the start on what the group answers should be, the argumentation that occurred was primarily ritualized in nature. There was very little discussion of ideas, and little if any consideration of possible alternative answers. Reasons were provided because the worksheet or the teacher required them, not because the students necessarily felt the need to defend or justify their own ideas. Once consensus was reached between the dominant students, the argument was considered to be complete. As mentioned above, lower status students played only minor roles in these kinds of discussions. This pattern was especially common for Group 2, with Sheronda and Jennifer often agreeing fairly quickly on an answer or reason, and with Brett and Anna having few opportunities to contribute or to contradict the dominant students' responses.

If, on the other hand, the dominant students disagreed on their answers, then genuine arguments developed. That is, the students spontaneously provided warrants and backing in order to defend their own ideas, not just because the worksheet said they had to. During these arguments, the lower status students actually had opportunities to play fairly significant roles. Once they sided with one of the dominant students, the opposing dominant student was outnumbered three to one and was often forced to admit defeat (Cf. Activity #2, Group 1, moves 177-191).

When disagreements between dominant students did arise, there were a number of different kinds of reasons used to resolve them. The first two were based on the idea of using the authority of knowledge to persuade the other group members of their validity. These reasons were based on a) warrants and backing derived from the scientific canon or b) previous observations or data collected during the classroom activities. In both cases, the interpretations of the canon and the observations and data were contestable. That is, different students interpreted the canon and the data in different ways, depending on the nature of their conceptual understanding. So, for example, during the discussion of the water on the spaceship problem, Nate argued that all three states of water had to weigh the same amount. Jason agreed, but also insisted that one state of water could weigh more than the others, based on his interpretation of the arrangement of molecules in the three states of matter.

The other ways of resolving disagreements used by the students were more arbitrary in nature and were generally considered to be non-contestable. These reasons were based on a) personal ideas or experiences, b) invoking procedural constraints such as the need to finish the worksheet, and c) the assertion of personal status or power. For the students, these kinds of reasons often proved to be equally or more convincing and effective for moving the group to consensus than the scientific canon and empirical evidence.

In most cases, the principle of "majority rule" determined when the argument was considered complete. For most of the activities, once consensus was reached, especially between the dominant students, the argumentation ended. This was in contrast with the likely scientific process of reaching consensus, which would involve the careful consideration of many possible answers and the elimination of all but the most suitable.

The analyses of students' argumentation processes also revealed a few other patterns. First, the students spent very little time doing what I have referred to as collectively validating the question to be answered. In general, there was very little discussion of what the problem was asking for, what the relevant variables were, and what information was provided in the problem statement itself. This resulted in additional confusion and frustration for the students as they tried to reach agreement on their answers and their reasons. In addition, the students spent little time discussing the problem constraints or qualifiers that were applicable to the problems, leaving them uncertain about the precision and completeness of their answers.

Another pattern that was evident during the students' discussions was the frequent appeal to outside authority when the students found themselves unable to reach consensus, especially when the dominant students disagreed among themselves. When this occurred, the students would often look to the teacher or to classmates for help in resolving the disagreement. These appeals rarely led to resolution, and one group of students recognized that ultimately they had to try to clarify issues among themselves. However, even after admitting this, they continued to seek outside help.

Finally, it was clear that the students in both groups needed a consistent format for handling procedural matters in order to provide opportunities for equal participation by all group members. Unless the students could decide whose turn it was to read, who was supposed to give their plan, and so forth, they were not able to spend much time on substantive discussion of the content. For the students in Group 1, this did not prove to be much of a problem, but the students in Group 2 needed the teacher's help on several occasions in initiating and maintaining the procedural aspects of their group argumentation processes.

While many of these patterns were apparent in varying degrees in the discussion flow graphs for both of the groups, there were some fairly significant differences between the two groups in terms of their overall development of scientific arguments and argumentation processes and between individuals within the groups. In general, Group 1 showed more progress than Group 2 in developing arguments and argumentation processes that were more like those that would be developed by a group of scientifically literate members. With the exception of the first activity, the analyses of the discussion flow graphs for Group 1 showed a fairly consistent pattern of well-developed discussions of answers and reasons. Most of the group's reasons were based on warrants and backing derived from the scientific canon or previous observations or data collected during earlier classroom activities, rather than on personal experiences, procedural constraints, or personal status or power. As the unit progressed, the group's arguments became more and more complete, including most or all of the three parts of a good scientific explanation (observations, statements about the substances, and statements about molecules) that were presented and emphasized in the student text.

Much of this progress, however, was due to the presence of the two boys in this group, especially Jason. Both Nate and Jason were intellectually aggressive students who had strong opinions about things and who were not afraid to express or defend their opinions. Jason, however, was clearly the one who internalized the explanation heuristic the most and who used the heuristic as a tool for helping him construct his answers and his reasons. On several occasions during the water on the spaceship and the dissolving races activities, he insisted that the group answer had to include statements about molecules in order to be complete. Although he tenaciously defended his own ideas, he also demonstrated a willingness to consider possible alternatives when the group discussion became deadlocked . A very good example of this occurred during the water on the spaceship activity. Jason and Nate had argued strongly for their respective answers of ice and water vapor and appeared to be getting nowhere in terms of reaching consensus. Finally, Jason suggested they consider liquid water as a possible alternative, and this ultimately allowed the group to decide on liquid water as their answer.

Unfortunately, Jason and Nate's progress in developing their scientific understanding may have occurred at the expense of the other two group members. The two boys completely dominated their group's discussions and, as a result, Mary and Jamie had very few opportunities to present or defend their personal ideas. While the group as a whole demonstrated real progress, the individual gains were not equally distributed.

In general, Group 2 showed little progress in their understanding of the science content or in their development of more sophisticated and complete scientific arguments. Few of their answers or reasons were based on scientific canon, relying instead on personal experiences or scientifically incorrect or incomplete prior knowledge. The discussion flow graphs for this group showed little development of more complete or sophisticated arguments. The students relied heavily on macroscopic answers, with little if any discussion of molecular explanations for the phenomena being studied. Much of the group's attention was focused on procedural difficulties and conflicts, leaving little time or energy for serious consideration of the conceptual issues. The students in the group showed little interest or engagement in the scientific content that formed the basis of the activities, preferring to complete them in a ritualized manner.

Table 5.7: Percentage student participation rates for small group activities*

	Dates of collaborative activities				
STUDENT	10-24-90 Pure substance vs. mixture	11-28-90 Weight vs. volume changes	12-05-90 Water on spaceship	01-08-91 Planning dissolving races	MEAN
Group 1					
Nate	-	38.7	38.0	35.6	37.4
Jason	26.3	33.2	33.5	36.3	32.3
Mary	23.7	13.4	14.7	25.0	19.2
Jamie	22.9	6.5	9.4	2.5	10.3
Marvin**	18.8	-	-	-	-
Group 2					
Sheronda	38.9	36.6	35.6	25.9	34.3
Jennifer	29.6	24.2	28.9	28.7	27.9
Anna	29.1	16.3	14.1	23.8	20.8
Brett	-	7.2	10.7	19.6	12.5

* = Percentage as number of moves for each student out of total number of moves for the activity. Percentage rates for the teacher and other participants are not included; thus, column totals may not add up to 100%.

** = This student participated in Group 1 for only one activity - he was replaced by Nate for all other activities.

CHAPTER SIX

CONCLUSIONS AND IMPLICATIONS

This chapter begins with a set of conclusions based on the findings presented in Chapter 5. Then, implications of the study for future research are addressed.

Conclusions

As described above in the discussion of the results of the study, there was a great deal of variability in the degree of scientific and logical sophistication that students developed in their individual and group arguments during their study of the curriculum unit. With the exception of two students in Group 1, most of the target students consistently discussed and solved the collaborative problems in fairly simple and scientifically unsophisticated ways. A few students dominated the discussions and the decision-making processes in each of the target groups, resulting in group answers and reasons that consistently included the personal ideas of the higher status students and excluded the ideas of the less aggressive members of the groups. For the students in Group 2, much of the discussion that took place showed that the students were not very meaningfully engaged in the problem solving process. Their argumentation processes were primarily ritualized or procedural in nature, with students providing reasons that were based on personal ideas and experiences rather than scientific canon or empirical evidence.

Although many of the students showed limited progress in the nature of the argumentation processes they used and the kinds of arguments they developed, there are some very important ways in which the group problem solving activities provided classroom experiences that were significantly different from the kinds of problem solving that typically occur in classrooms using more traditional curriculum materials and teaching methods. First, on many occasions, the collaborative groupwork helped students clarify their understanding of the canon in ways which would not likely occur in more traditional science classrooms. By first working individually and then together on the activities, students were confronted with conflicts between their personal ideas and the scientific canon. Group discussions provided opportunities for the students themselves to resolve some of these differences and to develop answers and reasons more consistent with scientific interpretations of the phenomena they were studying.

Second, both the teacher and the problem solving activities in this unit consistently emphasized the importance of giving reasons for one's answers. The curriculum materials provided a framework for developing complete scientific arguments, and the collaborative context allowed and encouraged students to reinforce the need for giving reasons for their peers. In addition to the text and the teacher asking "Why?," students were asking each other to develop arguments supporting their answers.

Third, the collaborative problem solving activities provided opportunities for all students to participate in the discussions and to share their ideas with their peers. Even though the discussions were usually dominated by a few individuals and student participation was fairly ritualized, the lower status students were at least given regular opportunities to present their ideas to the group and to get involved in the decision making processes.

Finally, the collaborative groupwork allowed the classroom teacher to get a better idea of what most of the students were thinking, how well they understood the content, and the nature of the arguments they were developing. Student worksheets provided the teacher with information concerning both individual and group answers and reasons, and the teacher gained additional insight into students' understanding by monitoring the small group discussions and by conducting the class discussions that followed each of the problem solving activities.

Implications

This study has demonstrated that, although the collaborative problem solving instructional technique has great potential for helping students develop a more meaningful understanding of science, there are also many difficulties that must be addressed before this potential can be fully realized. First, this study and previous research have shown that collaborative groupwork often results in unequal participation by and unequal benefits for different group members, especially for those students who are judged by themselves or by others to be low status students (Cohen, 1986; David & Palincsar, 1991; Eichinger et al., 1991; Palincsar, David, & Anderson, 1992). Typically, the less aggressive and lower status students have fewer opportunities to develop either their content understanding or their argumentation processes, resulting in a lack of meaningful participation by these students and little if any improvement in their understanding of the scientific content.

This ritualized participation represents a second area of concern. In part, it may be a result of the social and intellectual domination of the problem solving activities by a few high status students. It may also be due to the use of problem situations that are too highly structured and too constrained. One benefit of using highly structured problems and specific procedures for solving them is that students are given specific guidelines that help support them in their attempts to solve the problems and develop complete arguments. However, an obvious disadvantage of these kinds of problems is that they are so highly structured that they do not allow for input of students' own interests and interpretations of the phenomena being studied (Anderson & Palincsar, 1991). Thus, students fail to see the relevance of these "real world" problems for themselves, and they approach them as just another set of school tasks to be completed. This lack of meaningful engagement in the problem solving process was also evident in the standards used by students for determining when an argument was complete. Rather than relying on a set of internalized criteria for checking whether their arguments were complete or cognitively consistent, most students showed that they considered an argument to be complete once they were able to reach consensus on any answer. Completing the task seemed more important to them than making sense of the content.

Another related area of concern involved students' failure to see the relevance of the scientific canon they were studying for solving the problems included in the collaborative activities. As noted above, many of the students' arguments were based on personal ideas and experiences rather than on the scientific concepts that were presented in their lessons. In addition, most students failed to recognize the usefulness of the information gained from earlier activities for solving the problems included in the later activities. In spite of the careful design and sequencing of the weight and volume demonstrations and the water on the spaceship problem, or the sugar and teabag activity and the dissolving races activity, students treated these as completely separate and unrelated tasks that had few, if any, interconnections.

Many of these areas of concern are currently being addressed by the larger CPS research project. In the third year of the project, several changes were made to resolve some of the problems that became apparent during Year 2, represented by this study. These changes and their results are discussed in detail elsewhere (Anderson & Palincsar, 1991; David & Palincsar, 1991). Briefly, they included such changes as: creating less constrained problem spaces and allowing the students to have more choice in determining which problems they wanted to investigate; embedding the group problem solving process in the larger process of reaching consensus among all of the students in the class, a process much more like the consensus-building process used in scientific communities; paying more careful attention to particular social norms by anticipating and responding to likely social difficulties; and more directly addressing the issue of scientists' activities and the roles of evidence and theory in these activities (Anderson & Palincsar, 1991).

While the CPS project continues to address these issues and areas of research, there are still many additional questions that merit further investigation. Based on the findings of this study, it is clear that further investigation is needed on the nature of the social interactions between students in their collaborative groups, especially as it relates to the domination of some students by others and the effects of this domination on the eventual outcomes of collaborative problem solving activities and the students' learning experiences. Among the questions that deserve further attention are the following:

Is this domination an artifact of this particular study, or does it represent a typical pattern of student interaction in collaborative problem solving contexts? What factors determine which students are dominant and which are low-status? Are there particular aspects of the classroom context that contribute to this domination? What can be done to minimize this domination and to ensure more equitable participation by all students? Would assigning specific roles for group participation to each student affect the extent of domination experienced by group members?

The results of this study also point to significant differences in the nature of the arguments presented by the two target groups, with Group 1 generally providing more principled arguments and Group 2 providing primarily ritualized arguments. In particular, the two groups differed in the types of reasons they used to support their individual and group answers. The students in Group 1 relied more on macroscopic and molecular canonical explanations, while the students in Group 2 consistently used personal ideas and experiences and completely ignored the molecular aspects of the phenomena they were studying, despite regular reminders by the teacher and the text to provide molecular explanations. These results suggest that further research is needed to investigate the following questions:

What is the relative importance of these different kinds of explanations for students? Are the argumentation patterns reported in this study general, or are they unique to these two groups of students? If the argumentation heuristic used in this study was not very effective in helping the majority of students develop complete scientific arguments, how else could the nature of scientific arguments be presented so that students could be aided in bridging the gap between their everyday explanations and more complete and sophisticated scientific explanations? Given the extent of the procedural difficulties experienced by many students in their collaborative groups, would a more structured procedural format allow students to devote more of their time and energy to substantive discussions of the content? How would this affect the nature of their individual and collaborative answers and reasons?

In addition to the questions presented above, there are also many research questions that grow out of the specific limitations of this study. For example, this study represents a first attempt at developing an analysis tool for examining the scientific problem solving of both individual students and collaborative groups and the scientific arguments and argumentation processes that they developed. This study has also focused primarily on the nature of the arguments that were developed by students as they worked in collaborative groups to seek solutions to a series of relatively complex science problems. As yet unanswered is the question of how different task environments (such as individual versus collaborative work, in-class versus clinical interview settings, and explanation versus design problems), and differences in students' knowledge influence the kinds of arguments they develop.

This study is clearly limited in scope, focusing on only eight students in one classroom at one grade level while they studied one particular curriculum topic. Additional research is needed to investigate the applicability and usefulness of this analysis approach in a variety of classroom contexts and for a variety of science topics. It would also be useful to investigate the arguments and argumentation processes of high school and university students, both science majors and non-majors, to compare and contrast the collaborative problem solving activities of students of varying ages and different content backgrounds.

The focus of this study and of the larger CPS research project has been on students and their use of curriculum materials that are designed to help them develop conceptual understanding of scientific ideas, establish norms for scientific argumentation, and establish social norms for peer collaboration (Eichinger et al., 1991). An important and interesting element of the whole education process that has not yet been investigated is the role of the teacher in the planning, implementation, and evaluation of these curriculum materials. The CPS project has involved a variety of teachers, including both classroom teachers and university researchers, in the teaching of a common set of curriculum materials. It would be interesting to investigate the roles of the different teachers, the nature of their training prior to their participation in the research project, and the nature of their instruction on the students' development of conceptual understanding and competence in learning scientific forms of argument.

Another important variable that deserves additional research attention is the amount of time allowed for the investigation of students' collaborative problem solving activities. While this study examined the instruction of the curriculum materials for ten weeks, it could be argued that this was insufficient time for allowing the students to become accustomed to working in collaborative groups. Additional research involving studies spanning an entire semester or academic year could investigate the impact of varying amounts of training and practice on students' collaborative problem solving abilities.

Finally, additional research is needed to investigate the questions of whether and how meaningful participation by all students can be achieved, especially in the increasingly heterogeneous classrooms that characterize our schools. If scientific literacy for all students is truly a goal of American science education (AAAS, 1989; U.S. Dept. of Education, 1991), then we must continue to investigate ways in which we can minimize or, ideally, eliminate the disenfranchisement of ethnically, culturally, and socially diverse students.

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APPENDICES

APPENDIX 4-A: OBSERVATION SUMMARY FORM

Observation Summary Form

Date: __________ Teacher: __________ Lesson cluster: ____ Lesson: ____________________ Observer: __________

Time	Activity	Back Camera	Front Camera
This column should have the starting and ending time for each activity e. g., 1:43-1:49	This column should have a brief description of the nature and content of the activity. e. g., Whole class discussion of states of matter	This column should have notes on what we see through the back camera. When the teacher is talking to the whole class, this might have a brief summary of the nature of the discussion, including anything that the observer considers important or noteworthy. Comments on special problems, quality of the tape or anything else that it seems we might want to know later could go here.	This column should have notes about target students during whole-class activities, particularly if one of them did something noteworthy (good or bad), whether the camera caught it or not. During group activities, notes about the target groups (or other events in the classroom) should be recorded under the camera that caught them, or in either column if they happened off-camera.
	If you are working on the MS Word template, start a new row for each new activity.	Good notes are nice when we go back later, but prompt sketchy notes are better than good late ones.	

APPENDIX 4-B: CLINICAL INTERVIEW RECORD

Clinical Interview Record

Task 1: Card sort of terms

1A. Let's begin by reading the terms on each of these cards. (Provide any terms with which the student has difficulty)

1B. Now let's make two piles - one pile of the terms you know something about and a second pile for those about which you know nothing.

Known	Unknown
____ matter	____ matter
____ solid	____ solid
____ liquid	____ liquid
____ gas	____ gas
____ pure substance	____ pure substance
____ mixture	____ mixture
____ atom	____ atom
____ molecule	____ molecule
____ particle	____ particle
____ pollution	____ pollution

1C. Let's take a look at the terms that you know something about.
Use the following prompts to elicit definitions of each of the terms in the "known" pile:
"Tell me about...," "What is...," "What do you know about...," "How would you define...?"

matter ____

____

solid ____

____

liquid ____

____

gas ____

____

pure substance ____

____

mixture ____

____

atom ____

____

molecule ____

____

particle____

____

pollution____

____

1D. I would like you to sort these cards into piles that go together. As you do this, tell me about the reasons you are putting certain terms together. (If the student does not verbalize while sorting, prompt occasionally, "Tell me what you're thinking about as you put those particular cards together.")

_____	matter	Reasons:
_____	solid	
_____	liquid	
_____	gas	
_____	pure substance	
_____	mixture	
_____	atom	
_____	molecule	
_____	particle	
_____	pollution	

_____	matter	Reasons:
_____	solid	
_____	liquid	
_____	gas	
_____	pure substance	
_____	mixture	
_____	atom	
_____	molecule	
_____	particle	
_____	pollution	

_____	matter	Reasons:
_____	solid	
_____	liquid	
_____	gas	
_____	pure substance	
_____	mixture	
_____	atom	
_____	molecule	
_____	particle	
_____	pollution	

_____	matter	Reasons:
_____	solid	
_____	liquid	
_____	gas	
_____	pure substance	
_____	mixture	
_____	atom	
_____	molecule	
_____	particle	
_____	pollution	

1E. **Probing understandings of relationships among clusters.**

E1. **Show the student the cluster: matter, solid, liquid, and gas.**

How would these four terms go together?

What do solids, liquids, and gases have to do with matter?

E2. **Show the student the terms: pure substance, mixture, and pollution.**

How would these three terms go together?

How can you have a pure poison?

How can something be very clean without being pure?

E3. **Let's look now at particle, atom, and molecule.**
How would these three terms go together?

How do a speck of dust, a molecule, and an atom compare in size?

Task 2: Sorting and analyzing substances

Display the labelled materials and identify each for the student:

rock
penny
pure water
salt water
muddy water
bag of pure air
a card that says, "Light in the room."

2A. Ask the student to arrange these in a way that makes sense and to, once again, talk about the reasons for the way in which he or she has organized them. (We should not use the word "substances" as light is not a substance).

rock ____ **Reasons:**
penny____
pure water ____
salt water ____
muddy water ____
bag of pure air ____
a card that says, "Light in the room."

rock ____ **Reasons:**
penny____
pure water ____
salt water ____
muddy water ____
bag of pure air ____
a card that says, "Light in the room."

rock ____ **Reasons:**
penny____
pure water ____
salt water ____
muddy water ____
bag of pure air ____
a card that says, "Light in the room."

rock ____ **Reasons:**
penny____
pure water ____
salt water ____
muddy water ____
bag of pure air ____
a card that says, "Light in the room."

2B. Place the cards that were used in the first task in front of the student and ask him or her how these terms could be used to describe the items that they have just grouped. "You have grouped each of these two sets. Let's take a look now at how we might put the two sets together. How would you combine these two groups in a way that makes sense?"

Record the students responses by graphically depicting the arrangements the student makes (on the following page).

If the student does not seem to understand this activity, model the following: "For example, I could put the penny and rock with the term solid since these are two substances that are in the solid state."

The remainder is derived from the original clinical interview. At this point, we will rely upon the transcripts of the interview. Questions from 2-C up to Task 3 should be used discriminantly depending upon responses to 2-A and 2-B.

Task 2C-1: States of matter

Set up rock, water and plastic bag of air in front of the student.

<u>Questions</u>:

O: Can you tell me how these three things (rock, water, bag of air) are different?

P1: Do you know what the three states of matter are? (If the student doesn't know) Have you ever heard of solids, liquids, and gases?

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 2C-2: Molecular constitution of matter

<u>Questions</u>:

O: Can you think of any way that these three things are similar?

P1: Have you ever heard of molecules?

P2: What are they?

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 2C-3: Nature of gas(air)

Questions:

O: What is 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?

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? Are they moving? If so, are they always moving?

P5: (If student mentions molecules) Is air a mixture? What does that mean? Is air made of different molecules?

Task 2C-4: Nature of liquid(water)

Questions:

O: Suppose you can see water with magic eyeglasses. What is water made of?

P1: Draw a picture of what you would see.

P2: (If the student draws dots, waves, etc.) What are these dots (wave, etc.)? Are they all the same? What is between them? Are they moving? If so, are they always moving?

Task 2C-5: Nature of solid

Questions:

O: Another student told me that a rock is made of very , very, very small particles or pieces that are always jiggling back and forth. What do you think of that?

P1: (If student agrees and/or mentions molecules) Are the molecules of 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?

Task 2C-6: Comparison of three states of matter

Questions:

O: Now you have drawings of air, water, and rock. What is the difference among these substances from your drawings?

P1: (If the student mentioned that there is space between... in the 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 are moving) Is the movement the same in all states? (If the student says no) Which has the most movement? Which has the least movement?

Task 3: Explaining changes of states of matter

Task 3-1: Melting ice

Leave ice cubes melting in the plastic cup.

Questions:

O: What's happening to the ice cubes?

P1: What state of matter is ice? What state of matter is water?

P2: How does ice change into water?

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: Boiling

Boil water in the beaker on the plate.

Questions:

O: What's happening to the water? Describe what you see.

P1: If we leave water boiling, what happens to the amount of water in the beaker?

P2: Why is the amount of water lower?

P3: Where is the water going?

P4: (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?

P5: How does the water change from liquid to gas? Can you explain in terms of molecules?

P6: Which has more space between molecules, liquid or gas?

P7: In which state do molecules move farther apart?

Task 3-3: Condensing on glass plate

Pop can and glass plate above boiling water.

<u>Questions</u>:

O: What is happening on the plate?

P1: Where does the water come from?

P2: (If the student mentions "air") How does air change to water? or (If the 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 molecules move farther apart?

Task 3-4: Evaporation

Place drops of alcohol on the slide.

<u>Questions</u>:

O: What do you see happening here?

P1: Where did the alcohol go?

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: Smell

Take top off of perfume container.

Questions:

O: Can you smell the perfume?

P1: What is the smell made of?

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

Materials: sugar, tea bags, cups, cold water

Situation: Dissolve sugar (in tea bag) in water.

Task 4-1: Dissolving sugar

Questions:

O; What is happening to sugar?

P1: (If the student mentions "dissolves") What do you mean by "dissolves"?

P2: How does it get out of the tea bag? Can you explain in terms of molecules?

P3: If we leave 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 tea bag 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

Materials: Balloon, bottle, ball, ring, hot plate

Situations: Put the balloon on the rim of the cold bottle, and then 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.

Task 5-1: Thermal expansion of gas

Questions:

O: What will happen to the balloon after we put our hands on the bottle?

P1: What happens to the balloon? Why?

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?

P8: Do molecules move faster, when the bottle is cold or heated?

P9: Do molecules move farther apart, when the bottle is cold or heated?

Task 5-2: Thermal expansion of solid

Questions:

O: The ball goes through the ring now (unheated). What will happen if we heat the ball?

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 4-C

Clinical Interviews - Argument Questions

1) Reporters from a television science show were interviewing people at a science museum to ask them to explain how the space shuttle blasts off. They talked to two different people and here are their answers:

> Person 1: They start the engines of the shuttle, and there's lots of fire and smoke, and a really loud noise from the fuel burning. Then, when the push of the motors is strong enough, the rocket starts to move up slowly and then it goes faster and faster and higher and higher until you can't see it anymore.
>
> Person 2: The fuel, which is composed of liquid oxygen and liquid hydrogen, is ignited and combustion of the fuel takes place. This combustion produces large quantities of flames, particulate matter, and reverberation. When the engines produce enough thrust to overcome the force of gravity, the rocket begins ascending and accelerates into the atmosphere until it is beyond visual contact.
>
> Is one of these explanations better than the other?
>
> If so, why? In what ways is it better?
>
> Would one of these explanations be better than the other for a scientist?
>
> If so, why? In what ways would it be better?

2) Imagine you are trying to explain [how a bicycle works] to one of your friends from Pattengill and to a scientist from Michigan State University. Would your explanation to your friend be different from your explanation to the scientist?

> If so, how would the two explanations be different?
> Why would they be different?
>
> What kinds of things would you need to include in your explanation to your friend or to the scientist to make it a good or a complete explanation?
>
> Is there anything else you would need to add to make your explanation complete or good?

3) Imagine you and Martha are having a discussion in science class about how rust forms on a nail. Here's what Martha says:

> **Martha: It just rusts. It has to. I mean, that's what happens to nails. They just sit around long enough and then they get rusty.**
>
> **What do you think about Martha's explanation? Is it a good or a complete explanation?**
>
> **Is anything missing from her answer?**
>
> **What kinds of things would you need to include in order to have a good or a complete explanation?**

APPENDIX 4-D

Post Instruction Interview Questions

Given pieces of explanations on 3 x 5 cards, ask students to:

1) choose the necessary pieces for a complete explanation
2) construct a complete explanation with these pieces
3) identify observation, substance, and molecular components
4) explain why they chose these particular pieces.

1. Anna bought a helium balloon at the mall on a very cold day. Outside the mall on her way to the car, she met Alan and started talking about all the news at school. When she finally got back to the car, she noticed that the balloon looked different. Assuming that none of the gas in the balloon leaked out, what do you think happemed to the balloon? How could you explain what happened?

a. The helium molecules got cold, slowed down, and sank to the bottom of the balloon.
b. The rubber of the balloon contracted.
c. The balloon got smaller.
d. The molecules of the helium gas slowed down and moved closer together.
e. The helium gas contracted.
f. The balloon expanded.

Probes for all three questions

1. What parts of an explanation are needed to make a complete explanation?
2. Which part of your explanation (observation, substances, molecules) is each of the cards you have chosen?
3. Why did you choose these cards instead of the others?

2. Ed noticed that, when he wanted to make Kool-Aid, it was easier to make it using warm water than cold water. Can you explain this?

a. Kool-Aid dissolves faster in warm water than in cold water.
b. Kool-Aid powder (solid) dissolves in the water and forms a solution.
c. The molecules of warm water hit the Kool-Aid crystals faster and harder and pull the Kool-Aid molecules away faster than molecules of cold water.
d. The Kool-Aid melts faster in warm water than in cold water.
e. Warm water molecules melt the Kool-Aid molecules and cause them to start bumping and sliding past each other

3. Explain what happens to a pan of water that is put on the stove and the heat is turned on high.

a. The water boils.
b. The water condenses.
c. The air in the water heats up and forms bubbles that rise to the top.
d. Liquid water forms water vapor at the bottom of the pan and rises to the top in bubbles.
e. The liquid water molecules get hot and change into water vapor molecules.
f. The water molecules move faster and far enough apart to form water vapor.
g. The water molecules split into hydrogen molecules and oxygen molecules.
h. Bubbles form at the bottom of the pan and rise to the top.

APPENDIX 4-E: PRE- AND POST-INSTRUCTION TEST

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?

____

____

____

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

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 <u>molecules</u>? ______ 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

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 <u>windy air</u>?**

    a. **Yes, they are moving**
    b. **No, they are not moving**
    c. **I don't know**

Do you think the molecules are moving in <u>still air</u>?

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 <u>rock</u>?

a. **Yes, they are moving**
b. **No, they are not moving**
c. **I don't know**

Explain your answer.

____

____

____

10. **When a piece of metal is heated:**

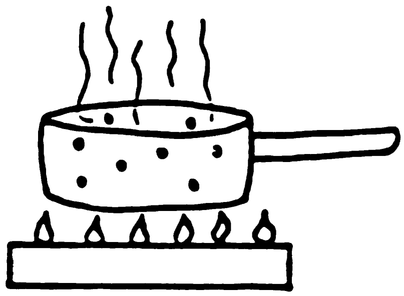
    a. **The number of molecules increases**
    b. **Molecules expand or get larger**
    c. **Molecules stay the same size but move farther apart**
    d. **Molecules contract or get smaller**
    e. **I don't know**

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.**

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?

____

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 <u>less</u> than the ice
b. The water would weigh <u>the same</u> as the ice
c. The water would weigh <u>more</u> 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

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 4-F

Preconception by Goal Conception Chart for Kinetic Molecular Theory

Issue	Goal Conception	Typical Naive Conception
	Macroscopic level: Conceptions about observable substances and phenomena	
1. Definition of matter	a. Solids, liquids, and gases are matter, other things (e.g., heat, light) are not.	a. Gases and non-matter often incorrectly classified.
	b. Matter takes up space, non-matter does not.	b. Classification based on other properties (e.g., matter is something you can see or feel).
2. Conservation of matter	Matter is conserved in all physical changes.	Matter not always conserved especially in changes involving gases. Words like "dissolve" and "evaporate" sometimes used as synonyms for "disappear."
3. Thermal expansion	Substances expand when heated.	Substances may "shrivel up" when heated; expansion of gases explained in terms of movement of air.
4. Nature of smells	Smells are gases, therefore matter, made of molecules, etc.	Smells considered ephemeral, not really matter.

5.	Distribution of gases in space	Gases spread evenly through the spaces they occupy.	Distribution of gases is uneven after expansion or compression.
6.	Compression of gases	Gases can be compressed.	Gases move from one region to another when compressed or expanded.
7.	Water vapor in air	Air contains invisible water vapor (humidity).	Water in air is visible (e.g., fog, "steam").
8.	Condensation	Water vapor in air condenses on cold objects.	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	All matter is made of molecules, non-matter is not.	Material substances not described as molecular; non-matter described as molecules (e.g., "heat molecules") molecules are in substances.
10.	Size of molecules	Molecules are too small to see, even with a microscope.	Molecules may be comparable in size to cells, dust specks, etc.
11.	Constant motion	All molecules are constantly moving.	Molecules may sometimes be still, especially in solids.
12.	Visibility of molecular motion	Molecular motion continues independently of observable movement.	Molecules simply share in observable movements of substances (e.g., convection currents).

13.	Molecular explanation of dissolving	Molecules of solute break away and mix with molecules of solvent.	Focus on observable substances or molecules themselves "dissolve".
14.	Effects of heat on molecular motion	Molecules of hot substances move faster.	Molecules themselves can be hot or cold.
15.	Molecular explanation of thermal expansion	Increased motion moves molecules farther apart.	Molecules themselves expand.
16.	Spaces between molecules	Molecules of gases have empty spaces between them.	Molecules have "air" or other things between them.
17.	Molecular explanaation of states of matter	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	States of matter described only in terms of observable properties <u>or</u> 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	Heating and cooling cause changes of state by making molecules move faster or slower.	Heating and cooling make molecules "melt", "evaporate", etc.
19.	Molecular explanation of evaporation	Fast-moving molecules escape from liquid.	Molecules "evaporate" or dissappear.

APPENDIX 5

Copies of the Appendices for Chapter Five are available from the author at the following address:

David Clair Eichinger
401 Catherwood Drive
West Lafayette, IN 47906