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IN MIDDLE SCHOOL CLASSROOMS

By

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ABSTRACT

MOTIVATION TO LEARN SCIENCE IN MIDDLE SCHOOL CLASSROOMS

by

Okhee Lee

Science educators have been concerned that many students do not expend the necessary effort in classroom situations to achieve scientific understanding. This study examined issues of student moivation in science classrooms according to two research traditions: (a) conceptual change in science and (b) student motivation.

Three research questions were examined: (a) What are the patterns of task engagement (i.e., choice of goals and strategies); (b) what are the key factors related to those patterns ; and (c) what happens to student motivation when students succeed or fail in academic achievement after a period of instruction

One particular interest of this study was student motivation to learn science Motivated students engage in classroom tasks with the goal of achieving scientific understanding as they try to: (a) integrate their personal knowledge with scientific knowledge and (b) apply scientific knowledge to describe, explain, predict, and control the world around them.

Twelve sixth grade students from two classrooms in a midwestern urban school district participated in this study. According to the conceptual change approach, the curriculum materials and instruction provided extensive support for students to achieve scientific understanding of kinetic molecular theory. Various types of data were collected during several phases of instruction (i.e., before, during, and after) through classroom observations, clinical interviews, and other formal and informal interviews. Data analyses combined both informal and formal analysis techniques.

The results show six different patterns of task engagement in science classrooms. Some students were motivated to learn science and exhibited high quality of task engagement to achieve the goal of scientific understanding, while others chose low quality of task engagement to achieve alternative goals. The patterns of task engagement were related to four factors: (a) students' interpretations of the nature of classroom tasks, (b) students' success or failure to make progress in scientific understanding, (c) students' general goal orientations in science class, and (d) to a limited extent, students' affective orientations toward science. Finally, success or failure in academic achievement after unit instruction was related to changes in students' goal orientations and affective orientations, but not in systematic ways.

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When everything is said and done in this project, many names of people who have helped me complete this project come to my mind. First of all, I was fortunate to conduct this study in association with the Science Achievement Project directed by Glenn D. Berkheimer and Andy (Charles) Anderson at Michigan State University. Glenn has always been supportive of this work, providing both encouragement and funding for the research. Without this opportunity, the ideas in this study would have never been tried out.

Because this study attempted to integrate several areas of research, I was particularly fortunate to have committee members with expertise in these very areas. This study was based on the definition of classroom motivation proposed by Jere Brophy. Andy (Charles) Anderson introduced me to research in conceptual change in science. Linda Anderson helped me with issues of classroom learning and guided my design approach using semi-qualitative, descriptive methods. Thomas Carr always tried to make sure that the research methods were logically sound and helped me see things from different perspectives. Finally, Andy Porter provided critical, but productive discussion and comments. I wish his schedule could have allowed him to see the completion of this project.

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CHAPTER ONE

INTRODUCTION

Statement of the Problem

Science educators agree that understanding is the goal of science education. For those who claim higher-level, long-term goals, such as self-regulated learning or scientific literacy, understanding is still a basic requirement. To achieve this goal, students must engage in classroom tasks with the goal of achieving scientific understanding and activate strategies that allow them to accomplish this goal.

The benefits of scientific understanding are obvious from both individual and social perspectives. At the individual level, students who achieve scientific understanding gain personal satisfaction through *meaningful learning* of science according to both personal and disciplinary criteria (C. Anderson & Roth, in press; Driver, 1987; Floden & Buchmann, 1984; Nickerson, 1985; Pines & West, 1986). These students also gain extrinsic benefits from scientific understanding, such as good grades, recognition from peers, teachers, and parents, and improved job opportunities in the future. Society benefits from improved scientific literacy, because the nation needs more scientifically and technologically literate citizens for its work force and for their input into policy.

Despite such obvious benefits, many students (as much as 80% of the student population) fail to achieve understanding in science classes (C. Anderson, 1987; Fensham, 1985; Yager & Hofstein, 1986). Some have given up trying altogether. Evidence from various sources indicates that students are not learning enough science and do not understand important scientific concepts. National reports on science education generally show small but consistent declines in student achievement in science subjects since the mid-1960s (Education Commission of States, 1983; Heuftle, Rakow, & Welch, 1983; National Assessment for Educational Progress, 1978; National Science Foundation & the Department of Education, 1980). The proportion of high school students enrolled in science courses has also declined steadily since the mid-1960s (Harnischfeger & Wiley, 1977; Harms & Yager, 1981; National Science Foundation & the Department of Education, 1980; Welch, 1979). In addition, comparisons of science achievement between American students and those in other countries show that Americans perform significantly worse than their counterparts (Hurd, 1982; International Association for Evaluation of Educational Achievement, 1987; National Science Foundation & the Department of Education, 1980). Finally, a growing body of research on student learning difficulties in science classrooms supports the achievement test data, demonstrating that students are not developing any meaningful understanding of important scientific concepts.

Student Motivation in Science Classrooms: Two Research Traditions

Science educators are concerned about students' unwillingness to work hard in science classrooms. Even those who expend effort settle for less valued outcomes, such as memorizing vocabulary words or facts, rather than trying to achieve scientific understanding (C. Anderson & Roth, in press; Blumenfeld & Meece, 1988; Mergendoller, Marchman, Mitman, & Packer, 1988; Meece & Blumenfeld, 1987; Olson, 1983; Roth, 1985; Sanford, 1987; Stake & Easley, 1978; Tobin & Gallagher, 1987). Other students rely on strategies such as rote memorizing, distorting scientific knowledge to fit their prior knowledge, mindlessly answering questions, copying others' answers, or not completing the work (C. Anderson & Roth, in press; Blumenfeld & Meece, 1988; Meece & Blumenfeld, 1987; Roth, 1985).

Why are so many students unwilling to work toward achieving scientific understanding? Two research traditions have proposed explanations for these problems of student motivation. One tradition focuses on curriculum and instructional development in content areas; research on conceptual change in science is an example of work in this tradition. The other tradition involves motivation research and is concerned with cognitive and affective aspects of student characteristics.

Conceptual change research in science education claims that problems of student motivation are largely attributable to the nature of traditional curriculum materials and instruction. These researchers argue that traditional curriculum materials and classroom teaching do not provide an opportunity for students to learn something meaningful and valuable. These materials and instruction do not identify scientific understanding as a major learning goal. Consequently, some students do not perceive scientific understanding as attainable, while others do not value it as a goal because the curriculum materials and instruction do not emphasize it. In this regard, a student's decision not to work hard is a rational choice, since the curriculum materials and instruction do not promote scientific understanding as a better alternative (C. Anderson, 1987; Driver, 1987; Hesse & C. Anderson, 1988; Posner, 1982; Roth, C. Anderson & E. Smith, 1987).

Conceptual change researchers believe that most students work hard when curriculum materials and instruction provide both opportunity and extensive support for them to achieve scientific understanding. When students engage in activities that require high quality effort, they not only increase their chances (expectancy) of achieving this goal but also experience its value. Research on conceptual change, and more broadly the curriculum and instructional development tradition, focuses on content knowledge but remains silent on other factors related to student motivation.

*Research on classroom motivation,*on the other hand, suggests that student motivation is a complex interplay of curriculum, instruction, and student characteristics. Motivation researchers claim that motivation problems result from students' decision-making processes that are not entirely rational For instance, students' self-perceptions lead them to place low value on the goal of scientific understanding or to express low expectancy of success in achieving that goal. Without even making an effort to achieve scientific understanding, these students choose alternative goals. Thus, motivation researchers believe that students' beliefs and characteristics play an important role in their decisions about whether to,work hard to achieve scientific understanding. Although motivation researchers recognize the importance of curriculum materials and instruction, they are primarily concerned with cognitive and affective aspects of student characteristics.

Research on classroom motivation claims that to understand the problems of student motivation, educators need to examine why (i.e., goals) and how (i.e., strategies) students do academic work while engaging in classroom tasks. In science classrooms, for instance, students who are motivated to learn engage in classroom tasks with the goal of achieving scientific understanding, and they activate strategies associated with such learning.

To explain why students work (or do not work) hard to achieve scientific understanding in science classrooms, two research traditions suggest four hypotheses in terms of students' content knowledge in a content area or their motivational variables.

The first hypothesis concerns students' recognition of academic goals in classroom tasks. Research has examined how students' interpretations of the nature of classroom tasks are related to their goals and learning strategies while engaging in those tasks (Blumenfeld, Mergendoller, & Swarthout, 1987; Doyle, 1979, 1983, 1986; Mergendoller, Marchman, Mitman, & Packer; 1988; Posner, 1982; Sanford, 1987; Stake & Easley, 1978; Tobin & Gallagher, 1987). Some students either fail to recognize the content objectives of classroom tasks or do not realize when they are having trouble understanding them. Even when students realize that they do not understand, they perceive their difficulty in terms of procedural complexity or amount and duration of effort, rather than the nature of the concepts being taught or the quality of effort required. In the face of difficult tasks, students tend to use strategies that merely complete the tasks, instead of trying to understand the content of those tasks. Especially in sceince classrooms, students' prior knowledge, often incorrect, could pose a problem to adequately interpret the nature of classroom tasks.

A second hypothesis concerns student progress in achieving scientific understanding for classroom tasks. Research suggests that the quality of students' task engagement is related to the degree to which they are making consistent progress (Brophy, 1985; Corno & Mandinach, 1983). When students fail to make progress over task situations, they do not possess the necessary scientific knowledge in subsequent task situations. This lack makes it difficult for them to expend a high quality effort and, as a result, they develop low expectancy of success in achieving understanding. The issue of student progress seems to be particularly important in science classrooms, as research consistently shows that the achievement of scientific understanding is difficult and demanding for many students (C. Anderson & Roth, in press; Nussbaum & Novick, 1982; Pines & West, 1986; Posner et al., 1982; Roth, 1985).

A third hypothesis concerns the existence of multiple, often competing, goals of students in science classrooms. Research suggests that students' behavior in achievement situations is motivated by a complex interplay of goals, and they behave in ways to achieve their own goals (Blumenfeld & Meece, 1988; Dweck & Elliot, 1983; Maehr, 1984; Pervin, 1982). In addition to their personal goals, students are also influenced by the expectations of significant others, including parents, teachers, and peers (Eccles, Midgley & Adler, 1984; Maehr, 1984). These various goals often conflict, forcing students to select certain goals at the expense of other competing goals. Problems in classroom learning occur when students are overly concerned with external influences, which may not be compatible with the goal of scientific understanding. As a result, students place low value on the goal of scientific understanding. Unfortunately, the pressure to conform to external demands seems to increase as students experience school environments which emphasize external evaluation or social comparison, rather than task engagement for the mastery of academic content or skills (Eccles, 1983; Eccles, Midgley & Adler, 1984; Stipek, 1984, 1988).

A final hypothesis concerns students' affective orientations toward science. Research suggests that affective aspects of student motivation, such as attitudes, interest, and curiosity, are related to cognitive aspects in science learning (Steinkamp & Maehr, 1983; Welch, Walberg, & Fraser, 1986; Wilson, 1983). Students who have negative attitudes and low interest are less likely to try hard to achieve scientific understanding than those who have positive attitudes and high interest. Research consistently shows that students' affective orientations deteriorate as they advance in school (Cannon & Simpson, 1985; Huefle, Rakow, & Welch, 1983; James & Smith, 1985; Schibeci, 1984).

Examination of the research in both student motivation and conceptual change raises a number of questions. Provided with the opportunity to learn science in a meaningful way, will students actually try to achieve the goal of scientific understanding? Will they realize the value of scientific understanding and/or expect to succeed in achieving scientific understanding? How do features of curriculum materials and instruction interact with studentscharacteristics? Under what conditions do students try to achieve scientific understanding? Which research tradition provides better explanations for issues of student motivation? Under what circumstances is one tradition more accurate than the other? What are the limitations of each tradition?

To answer these questions, it is necessary to conduct research in classroom settings where both the curriculum materials and instruction provide extensive support for students to achieve scientific understanding. If students accept the goal of scientific understanding as a better alternative, assumptions of conceptual change research are supported. If students do not take advantage of the opportunity, problems of student motivation can be attributed to student characteristics, as motivation research claims.

The present study was associated with the Science Achievement Project, a major research study funded by the National Science Foundation (Berkheimer, C. Anderson, &

Blakeslee, 1988a). The primary purpose of this larger project was to develop curriculum materials and instructional strategies that promote scientific understanding of kinetic molecular theory at the sixth-grade level. The curriculum and instructional development were based on the conceptual change approach in science. For the present study, this research context offered a unique opportunity to examine issues of student motivation from both research traditions.

Objective and Research Questions

The overall objective of the present study was to develop an integrated theory of student motivation in science classrooms. Of primary interest were major aspects of student characteristics (i.e., motivation research tradition). Yet, owing to the research context in which the present study was conducted, aspects of curriculum materials and instruction (i.e., conceptual change research tradition) were also examined.

This study focused on *student motivation to learn science,* which is defined as engagement in classroom tasks with the goal of achieving scientific understanding. Student motivation to learn science exists when students engage in classroom tasks to: (a) integrate their personal knowledge with scientific knowledge and (b) use scientific knowledge to describe, explain, predict, and control the world around them. This definition integrates two distinct approaches of classroom research: student motivation to learn (Brophy, 1983, 1987) and conceptual change in science (e.g., C. Anderson, 1987; C. Anderson & Roth, in press; Pines & West, 1986).

The specific research questions addressed in this study were as follows:

1. To identify patterns of students' task engagement (i.e., choice of goals and strategies) in science classrooms.

2. To understand how patterns of students' task engagement is related to:
   (a) students' interpretations of the nature of classroom tasks (i.e., the content objectives and difficulty of classroom tasks as perceived by students);
   (b) students' success or failure to make progress in achieving scientific understanding;
   (c) students' general goal orientations in science class; and
   (d) students' general affective orientations toward science (i.e., attitudes and interest).

3. To examine the relationship between achievement of scientific understanding after instruction of a science unit and changes in students' general goal orientations and affective orientations.

Overview of Research Design

This study was an in-depth investigation of the issues of student motivation and conditions under which students expend (or fail to expend) effort in science classrooms. The study involved twelve sixth grade students from two science classrooms in which both curriculum and instruction provided extensive support for students to achieve scientific understanding of kinetic molecular theory.

First, patterns of students' task engagement were defined in terms of their choice of goals and strategies while they engaged in science classroom tasks. The quality of task engagement, especially cognitive engagement, was used as a measure.

Further the study examined four key factors related to patterns of task engagement, and collected various kinds of data during different phases of the investigation. Classroom observers interacting with target students during task engagement collected data on student interpretations of classroom tasks . Clinical interviews with target students before and after instruction of a particular science unit as well as assessment of their scientific understanding in specific task situations over the instruction period yielded data on student progress in scientific understanding. Formal interviews with target students prior to and after instruction of the science unit produced data on students' goal orientations in science class and affective orientations toward science.

Finally, at the end of the science instruction unit, the project examined the relationship between achievement of scientific understanding and changes in students' goal and affective orientations

Research Assumptions

Three basic assumptions underlie the present study. First, it is important to understand student motivation in terms of both cognitive and affective aspects. One major goal of science education is to motivate students to learn science, in addition to helping them develop positive attitudes and high interest. The present study focused on cognitive aspects of motivation, since they seem to be more closely related to classroom learning than its affective aspects.

Second, research on conceptual change shows that the process involved in scientific understanding is strenuous and demanding, requiring students to expend high quality (i.e., kind) as well as quantity (i.e., degree) of effort during task engagement. Students who are motivated to learn science demonstrate high quality of cognitive engagement and persist in task engagement in order to achieve their goal of scientific understanding. Although difficult and often frustrating, the achievement of scientific understanding is a rewarding process as students develop a deeper and richer understanding of scientific knowledge. Through numerous successes in scientific understanding, students internalize a conception of meaningful understanding of science and eventually learn how to learn science independently (i.e., self-regulated learning).

Finally, student motivation to learn science can be construed as both a general disposition and a situation-specific state. Although both are equally important, the present study focused on the state of student motivation to learn science—students engaging in classroom tasks with the goal of achieving scientific understanding in specific task situations. The ultimate goal of this study was to develop methods to stimulate student motivation to learn science as a general disposition, so that students find learning intrinsically rewarding and take satisfaction in expanding their scientific knowledge. It was assumed that when such motivation exists consistently over task situations, it stimulates the development of student motivation to learn science as a generalized disposition.

Methodological Limitations

As described earlier, the present study was conducted in classroom settings where both the curriculum materials and instructional strategies stressed scientific understanding for students. This research context presented advantages and disadvantages. One advantage was that the larger research project (the Science Achievement Project) provided a rich store of data about the students' content learning as well as other information related to their motivation in science classrooms. Additionally, this research context provided a unique opportunity to examine the effects of a conceptual change approach in curriculum development and instruction on student motivation in science classrooms.

On the other hand, the research context limited the generalizability of the findings to other classrooms with little or no emphasis on promoting scientific understanding. This limitation seems warranted; research shows that traditional curriculum materials and teaching strategies generally fail to help students achieve scientific understanding. Further, many science teachers are neither trained in, nor even aware of, the conceptual change approach (C. Anderson & E. Smith, 1987; Blakeslee, C. Anderson, & E. Smith, 1987; Driver, 1987; Hesse & C. Anderson, 1988; Hollen & C. Anderson, 1987; Roth, 1987; Roth, C. Anderson & E. Smith, 1987; D. Smith, 1987; D. Smith & Neale, 1987).

Second, this study involved only twelve students from two classrooms taught by two different teachers. The limited number of subjects allowed the researcher to achieve the stated objective of developing an in-depth understanding about issues of student motivation. However, the small sample size precluded the use of statistical analyses of research questions.

Third, constraints in classroom situations and modes of instruction sometimes interfered with data collection procedures. Some research questions required data collection primarily through informal interviews with target students while they were actually engaged in specific task situations. Although the classroom observers tried to interact with individual target students during class activities, it was not always possible. This restricted both regularity and extensiveness of data collection. (L. Anderson et al. [1985] encountered the same problem.) This was particularly true of one classroom where the teacher devoted so much class time to whole-class activities (e.g., class discussion or reading aloud in class) that it was difficult to conduct needed interviews. As a result, data for some research questions were not substantial, especially Research Question 2(a).

Fourth, students' participation in the study may have affected their classroom learning and motivation. Personal contact with the observers prior to, during, and after instruction of a science unit could have made the participating students more aware of their learning processes than they would have been otherwise Such awareness could, in turn, have influenced the quality of their task engagement i and other aspects of motivation in science classrooms This could have diminished as the study continued over time (from early October, 1987 through mid-January, 1988), and as observers interacted with students in normal classroom settings.

Finally, this was a correlational rather than an experimental study. A major goal of the present study was to understand the nature of student motivation in naturalistic classroom situations. The relationship between student motivation and several factors examined in this study also involved correlational rather than causal interpretations. Further, although the curriculum materials and instructional strategies used here can be considered a type of experimental treatment—in the sense that they were specially developed according to a conceptual change approach and, thus, different from traditional practicess—there was no control group to compare its relative effectiveness. It is hoped this study can serve as a starting point for future experimental studies.

CHAPTER TWO

REVIEW OF LITERATURE

This chapter reviews a body of literature relevant to the research questions examined in this study. The discussion includes not only what has been investigated in previous research but, more importantly, what needs to be done to better understand student motivation in science classrooms. Thus, this literature review provides a rationale and theoretical basis for this study.

This chapter consists of three sections, each of which covers one of the three research questions addressed in the study. The first section concerns the students' motivation during task engagement.. The discuss will focus on the definition and measurement of student mortivation to learn science. The second section discusses several key factors in the literature related to student motivation during specific task engagement. These factors involve cognitive as well as affective aspects of student characteristics, ranging from task-specific to more general situations in science classrooms. The discussion focuses on whether these factors are related to student motivation during task engagement and, if so, how they are related from the two research traditions: conceptual change research and student motivation. The third section examines the relationship between achievement of scientific understanding and changes in general motivational orientations of students after completion of a science unit. The chapter concludes with a discussion on why the research questions in the present study are important. to increased understanding of student motivation in science classrooms. Finally, this chapter also discusses how the insights from previous research are incorporated in designing the present study.

Part I: Student Motivation To Learn Science: Conceptualization and Operationalization

When a student is motivated to learn science, how will he or she engage in academic tasks in science classrooms? How can we tell whether a student is motivated to learn science? What other patterns of students' task engagement do students exhibit in science classrooms?

The definition of student motivation to learn science in this study has two major components: (a) motivation to learn (i.e., students' engagement in academic tasks with the goal of achieving understanding) and (b) learning science (i.e., scientific understanding). This definition integrates two distinct approaches in classroom research: Brophy's theory of student motivation to learn (1983, 1987) and conceptual change learning in science (e.g., C. Anderson, 1987; C. Anderson & Roth, in press; Pines & West, 1986; Roth, 1985). The discussion focuses on three issues: (a) the conceptualization of student motivation to learn, (b) the definition of *scientific understanding,* and (c) measures of student motivation to learn science.

Student Motivation to Learn

Research on classroom learning and motivation have reported concerns about students' failure to understand the purposes of classroom tasks. This seems to be closely related to low quality of task engagement (L. Anderson, 1981; Corno & Mandinach, 1983; Meece & Blumenfeld, 1987). For example, L. Anderson (1984) and L. Anderson et al. (1985) found that during seatwork assignments, first-grade students, even high achievers, seldom gave evidence of realizing the content-related purposes of assignments. Instead, students perceived the purposes in terms of doing the work, as one student said to himself, "There! I didn't understand it, but I got it done"(L. Anderson, 1984, p. 98). Rohrkemper and Bershon (1984) found that only two out of 49 elementary students working on mathematic problems mentioned trying to understand, whereas most students were concerned about getting correct answers, and a few simply wanted to finish the work.

Blumenfeld and Meece (1988) reported that elementary students in science classrooms were more concerned with procedures or products of assignments than with content per se. When asked the goal of their task engagement, students mentioned a test or some vague future benefits, such as "So, I'll know, if I want to be a scientist" (p. 246). In short, research findings suggest two common characteristics of students' task engagement: (a) Students do not understand the content-related purposes of classroom tasks being taught; and (b) students do not engage in those tasks with the goal of understanding.

Other studies show that students often do not understand how to do their classroom work. L. Anderson et al. (1985) found that while working on seatwork assignments many first graders, especially low achievers, lacked strategies or skills necessary to complete assignments in the intended way. As a result, these students developed work completion strategies that had nothing to do with learning the content intended in the assignments. Rorhkemper and Bershon (1984) found that when elementary students experienced difficulty with mathematics problems, they tried to get help to complete the work rather than searching for cognitive strategies. Blumenfeld and Meece (1988) also found that elementary science students used help-seeking or avoidance strategies, especially with difficult tasks, rather than engaging in cognitive strategies. Some students, lacking either the desire or the skills to identify their learning deficiencies, did not even seek help from the teacher or other resources (L. Anderson et al., 1985; Rohrkemper & Bershon, 1984).

Thus, research suggests that a new definition of classroom motivation is needed, one that integrates learning and motivation while students engage in academic tasks in classrooms. L. Anderson (1981) claims that students' understanding of why (i.e., goals) and how (i.e., strategies) they do classroom work is the key factor related to their behavioral and cognitive responses in classrooms. Corno and Mandinach (1983) also call for an integrated theory of learning and motivation in classrooms to understand *motivated learning* of students in classrooms (p. 88, original emphasis).

Brophy (1983, 1987) proposed a conceptualization of student motivation to learn which "applies to student attention to lessons and engagement in academic learning tasks in classrooms" (1987, p. 181). This conceptualization is construed as both a general trait and a situation-specific state: .

> As a general *trait*, motivation to learn refers an enduring disposition to value learning and mastery in learning situations. This trait is most characteristic of individuals who find learning intrinsically rewarding—who enjoy or take satisfaction in expanding their knowledge of information, increasing their understanding of concepts or processes, or mastering skills.
>
> In specific situations, a *state* of motivation to learn exists when task engagement is guided by the goal or intention of acquiring the knowledge or mastering the skill that the task is designed to teach Whether or not they find a particular task interesting or enjoyable, students who are motivated to learn that task will try to get the intended benefits from it by striving to make sure that they understand and will remember what they are supposed to learn (1987, p. 182, original emphasis).*

Several aspects of this conceptualization make it especially applicable to the present study. In particular, it addresses both classroom learning and motivation by integrating aspects of academic tasks, learning processes, and student characteristics in specific situations as well as more general situations. The following are the major implications of this conceptualization for the present study.

1. Focus on state, not just trait. Motivation is conceptualized as a situation-specific state, in addition to a general trait or disposition. Brophy (1987) states the importance of situation-specific motivation and its difference from a more general trait this way:

> All students who take a particular academic task seriously and attempt to get the intended knowledge or skill benefits from it could be described as "motivated to learn" the task, even though only some of these students might possess a generalized trait that could be called motivation to learn (p. 184)

This emphasis on situation-specific motivation shares a common concern with research on classroom learning, suggesting that we need to examine more closely why and how students engage in specific classroom tasks (L. Anderson, 1981; L. Anderson et al.,

*Note: Instead of the term trait, Brophy now prefers to use the term *disposition*. Motivation to learn at a more general level indicates a disposition which has the potential to be activated depending on contexts, rather than a fixed, static notion as implied by the term *trait* (personal communication)

1985; Blumenfeld & Meece, 1988; Corno & Mandinach, 1983; Doyle, 1983; Posner, 1982).

2. Focus on value, not just expectancy. This conceptualization fits within the *expectancy x value theory* of motivation (Feather, 1982). The theory posits that the degree of effort an individual will expend in attempting to reach a particular goal (or accomplish a specific task) is a product of: (a) the value they place on reaching the goal and (b) the expectancy of being able to reach it if they make the effort. This is the same orientation shared by other theories of motivation, such as achievement motivation (Dweck & Elliot, 1983), causal attribution (Weiner, 1979), perceptions of efficacy (Bandura, 1982), and perceptions of causation (DeCharms, 1976). In contrast to these theories, stressing the expectancy side, however, the conceptualization of student motivation to learn focuses on the value side (see Parsons & Goff, 1980 on this point). This conceptualization concerns itself with the reasons for participating in academic activities in the first place, the desire to learn content and master skills, and valuing the process of learning.

3. Focus on goals and strategies during task engagement. Student motivation to learn is defined in terms of student goals during task engagement. Due to the cognitive nature of classroom tasks, learning strategies are also implied in the conceptualization. For instance, students who are motivated to learn have the goal of understanding content, and they activate strategies associated with such learning in specific task situations. In contrast, students who are not motivated to learn have alternative goals (e.g., completing classroom tasks or even avoiding them) and activate strategies to achieve those goals (e.g., memorizing facts, mindlessly answering questions, or copying others' answers). Brophy (1987) states that: .

> In discussions of typical school learning situations, then, reference to a state of student motivation to learn implies the presence not only of motivational elements (goals), but also of learning and cognition elements (cognitive and metacognitive strategies)...so the term "student motivation to learn" will routinely imply student adoption of the goal of mastering the content or skills being taught (mastery orientation) and activation of the cognitive and metacognitive strategies needed to reach this goal (pp. 184–185).

Thus, the conceptualization of student motivation to learn considers both students' goals of task engagement and the strategies activated to meet these goals, as specified in research on classroom learning (e.g., L. Anderson, 1981; Corno & Mandinach, 1983).

4. Focus on cognitive, not just affective aspects. The conceptualization of student motivation to learn focuses on cognitive aspects of motivation, not just its affective aspects. It emphasizes students' efforts to achieve the goal of content understanding or skill mastery, rather than mere liking, interest, curiosity, or enjoyment (see Carr & Evans, 1981 in the case of children's early reading). Whether or not they find a particular task interesting or enjoyable, students who are motivated to learn will strive to understand content or master skills. Thus, student motivation to learn is independent of affective aspects.

5. Focus on the quality of student's task engagement. This is an issue of measurement (which will be discussed later in detail). Common measures of student learning and motivation in classroom settings have been behavioral indicators, such as attention, involvement or time-on-task. Yet, researchers claim that such measures are inadequate in classroom settings where academic tasks require primarily cognitive, unobservable processes during learning. Instead of behavioral engagement, measures of students' cognitive engagement have been proposed (Corno & Mandinach, 1983; Peterson & Swing, 1982; Peterson, Swing, Braverman & Buss, 1982; Peterson, Swing, Stark & Waas, 1984; Tobin, 1986).

The conceptualization of student motivation to learn emphasizes the *quality of student engagement in academic activities* as a measure of classroom motivation (Brophy, 1987, p, 183, original emphasis). In particular, it is "the quality of students' cognitive engagement in the activity--the degree to which they approach the activity purposefully and respond to it thoughtfully" (Brophy & Merrick, 1987, p. 11, original emphasis).

In sum, the conceptualization of student motivation to learn shares common concerns reported in research on classroom learning. Further, this conceptualization presents a significant advance over previous theories of motivation. Differing from previous theories of motivation, this conceptualization focuses on: .

1. motivation as a state, not just a trait;
2. value side of expectancy x value theory;
3. student goals and strategies during task engagement;
4. cognitive aspects, not just affective aspects;
5. the quality of students' engagement, especiallycognitive engagement, in academic tasks.

As discussed so far, the conceptualization of student motivation to learn provides a framework for defining a generic notion of student motivation in classrooms. Yet, it has two major shortcomings for explaining student motivation in science classrooms. The first concerns the nature of science and science learning. What does it mean when students are motivated to learn science? Because of the unique nature of science content and its influence on students' task engagement, the conceptualization of student motivation to learn needs to be contextualized and refined within the subject area of science. The conceptualization of learning science or *scientific understanding* will be discussed in the following section.

The other shortcoming concerns the issue of measurement. Once student motivation to learn science is conceptualized, how can we operationalize it? If the quality of students' task engagement is the measure of classroom motivation, how can we distinguish high quality from low quality engagement? How can we identify different kinds of students' goals and strategies based on the quality of their task engagement? The issue of measurement will be discussed subsequently.

<u>Scientific Understanding</u>

The meaning of *understanding* has been a critical issue in education. What does it mean to understand? In fact, part of the difficulty defining understanding is that this concept is "one that we understand intuitively" (Nickerson, 1985, p. 215) and also "an elusive concept: it can mean different things to different people" (C. Anderson & Roth, in press). Nevertheless, a number of researchers have attempted to define understanding in science (C. Anderson, 1987; Brook, Driver & Johnston, 1988; Carey, 1986; Driver, 1987, in press; Finley, 1985; Nickerson, 1986; Nussbaum & Novick, 1982; Petrie, 1981; Pines &

West, 1986; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985; Shuell, 1987; Toulmin, 1972; Vosniadou & Brewer, 1987; Wittrock, 1985).

Two major common elements in the definition of understanding in science emerge in the literature. First, understanding involves the integration of new experience or information with learners' prior knowledge or what is already in their minds. Second, understanding has some functional usefulness to learners, primarily to explain the world around them. The two elements are based on the fundamental assumption that understanding occurs when learners actively construct their own meanings, rather than passively acquiring knowledge that is transmitted to them. Thus, learners have the ultimate responsibility for their learning, although curriculum materials and teachers share this responsibility in classroom settings (Porter & Brophy, 1987).

The two-component definition of scientific understanding advanced by C. Anderson and Roth (in press) seems to be the most useful for the present study:

> The first of these (components] is functional: Students should develop knowledge that is useful for the essential functions of describing, explaining, predicting, and controlling the world around us. The second criterion is structural. Students should develop knowledge that is conceptually coherent and integrated with their personal knowledge of the world,as well as being scientifically accurate (original emphasis)

Further, the structural and functional components of scientific understanding are inextricably intertwined and dependent on each other. That is, any of the four basic functions of science requires the integration of multiple concepts; conversely, any given concept can be used for multiple functions. Thus, scientific understanding requires "extensive conceptual integration and an ability to work out the complex relationships between structure and function" (original emphasis).

In the following, three issues of scientific understanding will be discussed: (a) the structural component of scientific understanding, (b) the functional component of scientific understanding, and (c) students' learning difficultiesin achieving scientific understanding in science classrooms.

The Structural Component of Scientific Understanding

Perhaps the single most important issue in human cognition concerns the role of prior knowledge in learning. As Resnick (1983a, p. 477) states: "All learning depends on prior knowledge." Without prior knowledge, new experience will be unintelligible or pure symbolic abstraction detached from personal meaning. Pines and West (1986) state: "Without such consideration (of students' personal knowledge), the formal knowledge presented in school will at best fall on 'deaf' ears ...." (p. 599).

The importance of students' prior knowledge has been recognized in science classrooms. Science educators emphasize that to teach the disciplinary knowledge of science in a way that students can understand better, students' prior knowledge needs to be incorporated as an essential part of classroom teaching. Thus, research is making extensive efforts to identify students' prior knowledge across content areas and across grade levels in science classrooms.

Of critical importance when using students' personal knowledge as a basis for teaching formal, scientific knowledge is the nature of interactions between these two sources of knowledge. For example, is students' prior knowledge congruent with scientific knowledge or does it conflict? When congruence exists, prior knowledge is a bridge to new learning; when conflict exists, prior knowledge could be a barrier. The role of students' prior knowledge in either fostering or interfering with the learning of scientific knowledge has generated much discussion among science educators (C. Anderson, 1987; C. Anderson & Roth, in press; Brook, Driver, & Johnston, 1988; Carey, 1986; Driver, 1987, in press; Finley, 1985; Nickerson, 1985; Nussbaum & Novick, 1982; Pines & West, 1986; Posner, Strike, Hewson, & Gertzog, 1982; Shuell, 1987; Strike & Posner, 1985; Vosniadou & Brewer, 1987).

Pines and West (1986) identify these two major types of situations as congruence and conflict. In a *congruent* situation, a student's prior knowledge may be consistent with the scientific knowledge being taught in classrooms. The knowledge structure the student brings with him (or her) to the science classroom, although less well organized or structured than formal knowledge in the discipline, can be linked with scientific knowledge. Within the framework of his prior knowledge, the student elaborates his initial knowledge structure by incorporating scientific knowledge. This type of learning is variously termed weak restructuring (Carey, 1986; Vosniadou & Brewer, 1987), assimilation (Nussbaum & Novick, 1982; Posner et al., 1982), and a type of evolutionary learning (Wittrock, 1985).

In a *conflict* situation, on the other hand, a student's prior knowledge is inconsistent with disciplinary knowledge of science. Simply linking prior knowledge with scientific knowledge is not adequate for successful learning. Instead, the student has to modify his prior knowledge into scientific knowledge, or even completely abandon his prior knowledge and become committed with new ideas that appear counter-intuitive or that he used to think incorrect. Researchers use various terms to describe students' prior knowledge (or conceptions) which is substantially different from scientific knowledge (or conceptions): preconceptions, misconceptions, alternative conceptions, alternative frameworks, naive theories, incorrect prior knowledge, and intuitions.

Students solve the problem of conflicts between prior knowledge and scientific knowledge in different ways (e.g., C. Anderson & Roth, in press; Pines & West, 1986; Roth, 1985). Many students do not accept scientific knowledge. They cling to their prior knowledge and may not even recognize the existence of conceptual conflicts. Others ignore scientific knowledge as irrelevant or inappropriate. Still others come to hate scientific knowledge as meaningless or useless information that has nothing to do with their personal lives.

Some students accept scientific knowledge, but fail to integrate it with prior knowledge. For example, some memorize vocabulary words or factual information through rote learning. Others adequately comprehend scientific knowledge, while maintaining their prior knowledge. These students use scientific knowledge in formal school settings, but rely on their prior knowledge for real-world problems. Still others distort scientific knowledge to fit to their prior knowledge.

Finally, some students make sense of scientific knowledge and successfully integrate it with their personal knowledge. This involves a complex process of *conceptual change,* in which students must modify or restructure their previous knowledge or even accept scientific knowledge that they previously deemed incorrect. Although the process of conceptual change is difficult and confusing, achieving conceptual change is rewarding as students develop a more coherent scientific knowledge. Various terms describe the process of conceptual change, including accommodation (Nussbaum & Novick, 1982; Posner et al., 1982; Strike & Posner, 1985), radical restructuring (Carey, 1986; Vosniadou & Brewer, 1987), and a type of revolutionary learning (Wittrock, 1985).

The Functional Component of Scientific Understanding

Another major component of scientific understanding involves basic functions of scientific knowledge in terms of four general categories: *description, explanation, prediction,* and *control* of natural phenomena (C. Anderson, 1987; C. Anderson & Roth, in press; Hesse & C. Anderson, 1988). These functions have been major science activities for individuals who desire to understand how the world around them works, as well as for a community of scientists who develop scientific principles or theories (Toulmin, 1972).

First,the descriptive function of scientific knowledge involves activities such as labeling, observation, measurement, classification, and description of objects or natural events. Compared to common-sense descriptions, scientific descriptions are more precise and accurate as they are dictated by some underlying scientific concepts or theories.

The explanatory function of scientific understanding derives from people's drive to explain how the world around them works. Everyone, scientifically trained or not, notices natural events or phenomena in the world and develops explanations for them. Everyday explanations are accepted because they appear to make sense. Scientific explanations, in contrast, are usually built on careful descriptions of the phenomena to be explained and developed by relevant scientific concepts or theories. Although making scientific explanation has been emphasized as a primary goal of science (Toulmin, 1972), "it is generally the most neglected of the four functions in science curricular" (C. Anderson & Roth, in press).

The predictive function of science also has a basis in everyday actions, as people constantly engage in making predictions about the natural and human worlds. Everyday predictions are usually based on personal intuitions or experiences; scientific predictions derive from scientific concepts or theories. Thus, scientific predictions are often more precise and accurate, and the limits of precision are specified. Further, the ability to generate precise, accurate predictions is a key test of a scientific theory.

Finally, the control function involves ordinary citizens as well as scientists; both need to control natural events or phenomena when they are engaged in experimental work (not necessarily in laboratory settings). When people make use of relevant scientific knowledge, they control events more effectively and with greater understanding. In this regard, control of natural phenomena is more a function of technology than science per se, although scientific knowledge contributes to the development and use of technology.

These four basic functions of science are not confined to scientifically literate people. Those who know little or nothing about science are capable of describing, explaining, predicting, and controlling the world around them. Scientific knowledge, however, provides people with conceptual and technological tools. People who use these tools can engage in such activities with power and precision than would be possible otherwise. **

**Note: The functional and structural components of scientific understanding are also expressed in terms of *tasks* and *conceptions*, respectively (C. Anderson, 1987). The meaning of *tasks* in research on conceptual change in science differs from that used in research on classroom learning and motivation. Tasks in conceptual change research in science indicate the functional criteria of scientific understanding: description, explanation, prediction and control of the world around us. Tasks in classroom research are class assignments or activities for which students are held accountable (Blumenfeld, Mergendoller & Swarthout, 1987; Doyle, 1983). To reduce the confusion in the present study, the term *science tasks* refers to the context of conceptual change research in science. The terms *classroom tasks* and *academic tasks* refer to the context of research on classroom learning and motivation.

Students' Learning Difficulties in Science Classrooms

How successful are students in achieving scientific understanding in science classrooms? The answer is "not very successful." A significant portion of students' learning failure is attributed to commercial curriculum materials and traditional instruction which generally do not promote scientific understanding for students (to be discussed in Chapter 3, Background for This Study). Research on conceptual change in science reports extensive data about students' learning difficulties across content areas and across grade levels.

Even before entering school, children generate their own common-sense theories to describe, explain, predict, or control natural phenomena. Such understanding has been established through interactions with their environment and has served them successfully for everyday reasoning. When children enter school, they bring extensive, personal knowledge about the world around them. In science classrooms, however, these naive theories are often incompatible or in conflict with scientific knowledge and, thus, interfere with students' understanding. As a result, scientific understanding cannot be accomplished through assimilative learning. Instead, there need to be radical changes in existing knowledge structure through conceptual change.

Research findings show that many students in science classrooms are not successful in achieving scientific understanding. Even after considerable traditional instruction using commercial textbooks, many students continue to cling to their original naive theories for understanding and explaining natural phenomena. For example, after eight to ten weeks of traditional instruction, including a series of experiments, fifth grade students learning about photosynthesis did not give up their misconceptions about food sources for plants in favor of the scientific theory of photosynthesis (Roth, E. Smith & C. Anderson, 1983). Not understanding the scientific concept that photosynthesis is the only food source for plants, many students still explained that plants get food from multiple sources, such as soil, water, air, fertilizer, etc. Recent research has examined students' learning difficulties for a number of important science concepts across subject areas and across grade levels: C. Anderson and E. Smith (1983) on light and vision, Hesse and C. Anderson (1988) on chemical change, Lee et al. (1989) on matter and molecules, Minstrell (1985) on Newtonian laws of motion, and Nussbaum and Novak (1976) on concepts of the earth.

Students are extremely resistant to changing their misconceptions. Even in classrooms where there is a strong emphasis on conceptual change, a substantial portion of students still maintained their misconceptions after instruction. For instance, Lee et al. (1989) found that only about 50% of sixth-grade students demonstrated adequate understanding of kinetic molecular theory after instruction, despite extensive support from curriculum materials and instructional strategies which incorporated extensive knowledge about students' misconceptions. However, this result showed a significant improvement over the 26% of students who developed scientific understanding after instruction using a commercial textbook.

Students' misconceptions do not disappear over the years. Studies show that a significant portion of adults (e.g., college students or elementary teachers) hold the same misconceptions as younger students. It seems that they have successfully completed science course requirements without really understanding basic scientific concepts. Researchers have investigated a variety of science topics involving college students, such as the particulate nature of matter (Gabel, Samuel & Hunn, 1987); sinking and floating of objects in water (Stepans, Beiswenger, & Dyche, 1986); principles of Newtonian mechanics (Champagne, Klopfer & Anderson, 1980); ecological matter cycling (E. Smith & C. Anderson, 1986); and evolution by natural selection (Bishop & C. Anderson, forthcoming). Others have conducted studies involving non-science major elementary teachers with such topics as light and shadows (D. Smith, 1987; D. Smith & Neale, 1987) and color (Appleman, 1984).

Research also suggests that students have difficulties describing, explaining and predicting natural phenomena. Even students who appear to understand scientific concepts rely on their misconceptions when they attempt to explain real-world phenomena. These students seem to separate "the 'life world' from the 'science world,' each relevant to its own range of contexts" (Driver, 1987, p. 2). For example, Roth (1985) reports how students used different sources of knowledge in explaining real-world problems as opposed to answering questions in textbooks. In the study, students read a passage about photosynthesis, answered textbook questions and provided their reasoning, and then explained how a real plant in front of them gets food. The results show that many students had great difficulties explaining this real-world event. Some students used their misconceptions to answer both real-world and text-based questions. Others included "big" words or facts to answer text-based questions, but relied on their misconceptions to answer real-world questions. Even students who appeared to comprehend the reading passage and gave adequate answers to text-based questions still fell back on their misconceptions to answer real-world questions. Only those who successfully integrated scientific knowledge with personal knowledge gave correct answers for both text-based and real-world questions.

In sum, the literature defines scientific understanding in terms of structural and functional criteria: (a) integration of personal knowledge with scientific knowledge through conceptual change and (b) use of scientific knowledge to understand and explain the world around us. In science classrooms, however, students often fail to achieve scientific understanding. Their learning difficulties seem to be caused primarily by their prior knowledge which often conflicts with scientific knowledge. Students' misconceptions are extremely resistant to change, remaining in place even after instruction or over the years into adulthood.

Student Motivation to Learn Science: Operationalization

Once conceptualization of the term *student motivation to learn science* is completed, we turn to operationalization. The first part of this discussion advances the quality of students' task engagement, especially cognitive engagement, as a measure of classroom motiv

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motivation. In the second part, difficulties in the measurement of cognitive engagement in classroom settings are considered. The final portion of this section examines, high quality of task engagement as evidence of student motivation to learn science.

The Quality of (Cognitive) Task Engagement.

Different ways of measuring motivation are used in various settings. For instance, much of motivation research has taken place in free choice or play settings, and measures tend to be based on the choice of certain activities among a range of alternatives or the allocation of time to different activities. Self-report measures of affective variables, such as attitudes or intrinsic motivation, are also used. These measures, however, are not appropriate in classroom settings where students are required to attend to lessons and work on assignments without much free choice.

The quality of students' task engagement has been suggested as a more valid measure of student motivation in classroom settings (Brophy, 1983; Brophy, Rohrkemper, Rashid & Goldberger, 1983). Operationalizing the quality of task engagement has taken two distinctive approaches: observable, behavioral responses versus covert, cognitive processes. Each approach presents relative strengths and weaknesses.

Some research used observations of students' behavioral responses during task engagement as measures of classroom motivation (e.g., Brophy, Rohrkemper, Rashid & Goldberg, 1983; Carr & Evans, 1981; Tobin, 1986). The most commonly used measure involved observations of apparent attention or time-on-task during class. Behavioral indicators included gaze, involvement in class activities, and apparent interactions with task materials, the teacher, peers, playthings or other non-task stimuli. Common procedures for collecting data involved time-sampling techniques, whereby, for example, trained observers attended to one student for a designated time period, recording characteristics of behaviors of interest on coding systems, and then moved to another student in a systematic manner. After data collection, statistical techniques were used to analyze the data.

This approach can be defended on several grounds. Methodologically, such measures are more reliable. It is easier to collect data from a large number of students within time constraints with behavioral techniques than it is with sustained individualized observations (usually in detailed narratives) or interviews (in verbal protocols). Also, data analysis is generally more straightforward than individualized observations or interviews. Theoretically, general observational measures of students' task engagement seem to be significantly related to measures of achievement and also to more precise measures of student engagement (reviewed by Borg, 1980).

However, many researchers question the validity of behavioral measures. The major criticism is that although behavioral observations may be a useful proxy, they are only a gross, crude measure of students' task engagement. Instead, students' cognitive processes are proposed as more valid and more precise measures of classroom learning or motivation. Researchers argue that although behaviorally some students may appear to be engaged in a task, cognitively they may not be engaged. Further, only the quality of cognitive processes can distinguish students who are engaged in classroom tasks from those who are not (L. Anderson, 1981; L. Anderson, Brubaker, Alleman-Brooks, & Duffy, 1985; Blumenfeld & Meece, 1988; Corno & Mandinach, 1983; Doyle, 1979, 1983; Peterson & Swing, 1982; Peterson, Swing, Braverman, & Buss, 1982; Peterson, Swing, Stark & Waas, 1984; Rohrkemper & Bershon, 1984; Tobin, 1986; Winne & Marx, 1982; Wittrock, 1987).

Research shows that students' observed behaviors often are not valid indicators of their task engagement. In a series of studies conducted in fifth and sixth grade mathematics classrooms, Peterson and her colleagues (Peterson & Swing, 1982; Peterson, Swing, Braverman, & Buss, 1982; Peterson, Swing, Stark, & Waas, 1984) found that students' reports of their attention and cognitive processes were better predictors of classroom learning and motivation than observations of student behavior. Further, observed student engagement was sometimes not significantly related to learning and motivation. Thus, Peterson and Swing (1982) state: "Interviewing students about their thought processes can provide rich information beyond what can be obtained by merely observing their behavior in the classroom" (p. 489).

Specifically addressing the topic of classroom motivation, Brophy (1987) states: "Measures of student motivation to learn must reflect the *quality of student engagement in academic activities*" (p. 183, original emphasis). "Especially, it is the *quality of students' cognitive engagement in the activity*—the degree to which they approach the activity purposefully and respond to it thoughtfully" (Brophy & Merrick, 1987, p. 11, original emphasis). Further, as goals and strategies are inseparable in academic tasks, the quality of students' cognitive engagement also indicate learning strategies during task engagement (Brophy & Merrick, 1987).

Difficulties in the Measurement of Cognitive Engagement

Although many advocate using the quality of students' cognitive engagement as a more valid measure of classroom motivation than indicators of behavioral engagement, there seem to be several potential difficulties involved in collecting and interpreting data about cognitive engagement in classroom settings.

One major problem is the effect of the constraints inherent in classroom settings on collecting data in a systematic way,(L. Anderson et al., 1985). For instance, to probe students' cognitive processes, it is desirable for the observer to interact with individual students while they engage in academic tasks. However, finding time to talk to students during class is not always convenient, and is especially problematic in classrooms where the primary mode of instruction involves whole class activities (Tobin, 1986). On the other hand, students' cognitive processes during class discourse or content-related conversations with the teacher or peers can count as evidence. Yet, such events occur with low frequency, and the nature of the data is generally not extensive. Also, if student responses on activity books or seatwork assignments are to be used as data sources, close inspections are required to ascertain that the written materials reflect the cognitive processes of the target students, not somebody else's.

Another major difficulty concerns the validity of data. To collect more substantial, in-depth evidence of students' cognitive engagement, methods of stimulated-recall or self-reports on questionnaires have been used. Since these methods are usually administered after class sessions, they do not measure what students do cognitively while actually engaged in classroom tasks (Winne & Marx, 1982). As a result, students' self-reports may not validly reflect the events that are being probed (Ericsson & Simon, 1984; Nisbett & Wilson, 1977). For instance, some students, due to memory constraints, might not remember accurately what they thought or felt during class. Others, due to social desirability response tendencies, might construct what they might have been doing or would do if given another chance, rather than report what they actually did. The former problem is more serious with cognition, and the latter, with affect.

Finally, in contrast to the unobtrusive nature of observational data collection during which the target students are not likely to be aware of when and how their apparent behaviors are being observed, data collection for cognitive engagement sometimes makes students be aware that they are the targets of observation. This occurs either in an implicit manner (e.g., when the observer interacts with target students individually or in small-groups during class) or in an explicit manner (e.g., when the observer interviews students after class). The students' awareness may also have instructional or intervention effects which lead them to be more conscious of their cognitive and affective processes during task engagement than they would otherwise be (L. Anderson, 1981).

Thus, although the quality of students' cognitive engagement seems to be a more valid measure of classroom motivation than other available measures, there seem to be difficulties in the measurement of cognitive engagement in classroom settings. The discussion suggests that with emphasis on measures of cognitive engagement, measures of behavioral engagement could also be included. For instance, the combination of cognitive and behavioral engagement could represent four different types of task engagement: (a) both cognitively and behaviorally engaged; (b) cognitively engaged, but behaviorally not engaged (although unlikely); (c) cognitively not engaged, although behaviorally engaged; and (4) neither cognitively nor behaviorally engaged. As data from different measures produce more converging evidence, our understanding of student motivation in science classrooms becomes richer and more accurate.

Measures of Student Motivation to Learn Science

The measures of classroom motivation in this study concern the quality of students' task engagement, especially cognitive engagement, as indicators of their choice of goals and strategies during specific task engagement. What counts as evidence that students are motivated to learn science? The structural and functional criteria of scientific understanding provide one way to operationalize student motivation to learn science. Students who are motivated to learn science expend high quality of task engagement as they activate strategies that allow them to achieve the goal of scientific understanding. First, they try to integrate personal knowledge with scientific knowledge through conceptual change. They become aware of their personal knowledge and often its incorrectness, recognize conceptual conflicts between personal and scientific knowledge, and try to modify or restructure incorrect personal knowledge into more scientific knowledge. Second, they apply scientific knowledge to describe, explain, predict, and control the world around them. Of course, the students are behaviorally engaged as they pay attention in class and actively involve in class activities.

In contrast, students who are not motivated to learn science expend low quality of task engagement in science classrooms. They engage in classroom tasks with alternative goals, such as memorizing vocabulary words or facts, merely completing classroom work, or even trying to avoid the work. To accomplish these goals, they choose strategies that minimize the risk of failure and expenditure of effort, such as mindlessly answering questions, copying others' answers, not realizing their misconceptions, rote memorizing of facts, maintaining their misconceptions separately from scientific knowledge, or distorting scientific knowledge to fit to their misconceptions. Further, some of these students may not even be attentive in class or involved in class activities.

One study examining different types of learning strategies and goals during science reading (C. Anderson & Roth, in press; Roth, 1985) suggests distinctions between high quality and low quality of cognitive engagement. While reading science textbooks, some students used strategies that represented high quality engagement, i.e., integration of personal knowledge with disciplinary knowledge and use of disciplinary knowledge to explain real-world problems, while others demonstrated low quality of cognitive engagement. Only those students who demonstrated high quality engagement seemed to have the goal of scientific understanding, while others revealed alternative reading goals.

There is an important distinction here between learning and performance. The measures of students' task engagement involve the process of learning during task engagement, not later performance (Brophy, 1987, Stipek, 1988, p. 13). Students who are motivated to learn science are likely to succeed in actually achieving scientific understanding. However, despite the activation of necessary strategies and sustained effort to achieve scientific understanding, they do not necessarily succeed in the achievement. For instance, some students may not be able to resolve their conceptual conflicts, and others who understand component scientific ideas may not be able to put them together to make adequate, scientific explanations, especially for complicated classroom tasks.

In sum, classroom motivation can be measured by the quality of students' task engagement, especially cognitive engagement, indicating their choice of goals and strategies during task engagement. Students who are motivated to learn science expend high quality of task engagement, as they engage in classroom tasks with the goal of achieving scientific understanding and activate associated strategies to: (a) integrate their personal knowledge with scientific knowledge and (b) apply scientific knowledge to describe, explain, predict and control the world around them.

Summary: Student Motivation to Learn Science

The first part of this chapter focused on the conceptualization and operationalization of student motivation to learn science. The first section discussed the conceptualization of student mootivation to learn in classroom settings, in terms of students' goals and strategies during academic task engagement (Brophy, 1983, 1987). The second section discussed the conceptualization of "learning science", in terms of the structural and functional criteria of scientific understanding (C. Anderson, 1987; C. Anderson & Roth, in press). The last section discussed the operationalization of student motivation to learn science in classrooms, in terms of the quality of task engagement, especially cognitive engagement.

Part II: Factors Related to Patterns of Task Engagement

What key factors are related to students' choice of certain goals and strategies during task engagement in science classrooms? What are the key differences between students who are motivated to learn science and those who are not? Under what conditions do students expend high quality of effort to achieve scientific understanding during task engagement? What key barriers need to be overcome for students to be motivated to learn science?

Research on classroom learning and motivation suggests that student motivation is a complex phenomenon related to various aspects of classroom settings, including curriculum materials, teaching strategies or teachers, and student characteristics (Blumenfeld & Meece, 1988; Blumenfeld, Mergendoller, & Swarthout, 1987; Corno & Mandinach, 1983; Doyle, 1983). When curriculum materials and instruction provide extensive support for students to achieve scientific understanding (as in the present study, which will be discussed in Chapter 3, Background for This Study), do students become motivated to learn science while engaging in classroom tasks? If not, problems reside significantly in motivational variables of student characteristics.

Research on student motivation in classroom settings suggest four factors (i.e., hypotheses) related to students' task engagement. These factors represent cognitive as well as affective aspects of student characteristics, ranging from task-specific to more general situations in science classrooms. Research on conceptual change in science, however, also provides implicit or explicit explanations for each of the four factors. In other words, motivation research explains these factors in terms of motivational variables of students, while conceptual change research explains the factors in terms of variables related to students' content knowledge.

In this second part of the literature review, the discussion focuses on how motivation research and conceptual change research, respectively, explain the relationship between each of the four factors and students' task engagement. Of particular interest is whether each of these factors differentiates students who are motivated to learn science from those who are not during task engagement.

Students' Interpretations of the Nature of Science Classroom Tasks

There has been a growing interest in how the way students interpret the nature of classroom tasks is related to their task engagement. To achieve understanding during task engagement, students must understand what the classroom tasks are intended to teach. Further, they need to monitor their learning processes, especially when they have learning difficulties. According to theory, those students who expend high quality engagement can accurately understand the nature of classroom tasks.

Research suggests that students' interpretations of classroom tasks depend as much on the nature of the tasks, the quality of instruction, and the social contexts of their classrooms as on the students' own characteristics. Thus, students' misinterpretations of the nature of classroom tasks could be attributed to many factors. With regard to the nature of classroom tasks, for instance, some tasks might not involve the goal of understanding in the first place. Other tasks might not clearly communicate to students the curricular goals. (These two possibilities often exist in traditional curriculum materials.) Or, students' prior knowledge, especially misconceptions, might pose difficulty for students.

The present study examines how students' interpretations of the nature of academic tasks are related to their choice of goals and strategies during task engagement, given the situation where curriculum materials and instruction emphasize the goal of understanding and clearly communicate the content objectives. The study examines two major aspects of academic tasks, from among the several identified in classroom research (e.g., Blumenfeld, Mergendoller & Swarthout, 1987; Doyle, 1983): the content objectives and difficulty of classroom tasks as perceived by students. The discussion focuses on issues of students' task interpretations from two research traditions: (a) research on classroom learning and motivation; and (b) research on conceptual change in science.

Research on Classroom Learning and Motivation

Research on classroom learning and motivation focuses on student characteristics and social contexts of classrooms related to students' task interpretations. However, this research approach has ignored issues of content knowledge, including the nature of classroom tasks, quality of instruction, and students' prior knowledge in a content area.

1. Content objectives. Most research focused on the differences between high and low achievers. Peterson, Swing, Stark, and Waas (1984) found significant differences in their study of elementary mathematics classrooms. Students who mentioned a key concept either spontaneously or after being prompted by the interviewer during stimulated-recall tended to do better on their seatwork problems and achievement tests. In addition, high achievers tended to report the names of key concepts or describe concepts that were central in the lesson.

Other studies found no differences between high and low achievers. L. Anderson et al. (1985) found that during seatwork assignments in first-grade classrooms, adequate responders as well as poor responders rarely demonstrated evidence of understanding the content-related purposes of assignments. No student consistently explained assignments in terms of the specific content. Instead, even adequate responders explained them in vague terms, such as "it's just our work" or "we learn to read" (p. 133). They also reported that in those few instances in which students identified the specific content of assignments, poor responders and adequate responders were equally represented. In contrast, Blumenfeld and Meece (1988) found that although students in elementary science classrooms were mainly concerned with products and procedures, rather than content per se, most students had some understanding of the content of the lesson when they were specifically asked.

2. Perceived task difficulty. Another aspect of students' interpretations of classroom tasks is task difficulty. The nature of task difficulty can be understood either as difficulty inherent in itself or as difficulty experienced by individual students. Task difficulty has been described through objective criteria (e.g., Bloom's taxonomy, Gagne's learning hierarchy, or Doyle's types of academic tasks). Some classroom research has also used such objective criteria (Blumenfeld & Meece, 1988; Meece & Blumenfeld, 1987). However, Nickerson states: "What appear to be simple to one student may appear to be quite difficult to another student" (p. 231). Research findings show that subjective task difficulty as experienced by students seems to be just as important as, or even more important than, objective task difficulty (L. Anderson et al., 1985; Peterson & Swing, 1982; Peterson, Swing, Stark, & Waas, 1984; Rohrkemper & Bershon, 1984).

Classroom research examined the nature of classroom tasks and its influence on students' task engagement. Some classroom tasks, especially those involving understanding and higher-level cognitive processes, were difficult for students to accomplish. When faced with difficult tasks, students tended to be easily discouraged or confused. Concerned with the ambiguity and high risk of failure involved in such tasks, students tried to minimize cognitive demands of the tasks or avoid them completely. Further, due to the accountability system and management concerns in classroom settings, both the students and the teacher often agree to reduce the demands of classroom tasks. As a result, tasks that initially required understanding or higher level cognitive processes were transformed into those that produce trivial learning (Blumenfeld, Mergendoller, & Swarthout, 1987; Doyle, 1979, 1983, 1986; Mergendoller, Marchman, Mitman, & Packer, 1988; Posner, 1982; Sanford, 1987; Stake & Easley, 1978; Tobin & Gallagher, 1987).

Some studies examined the differences between high and low achievers with regard to their perceived difficulty of academic tasks. Peterson and Swing (1982) found that in elementary mathematics classrooms, low achievers often could not articulate what and why they had trouble understanding the content being taught. In contrast, students who were able to analyze why they did not understand a problem or a part of the lesson tended to be high achievers (Peterson et al., 1984). In a study about elementary students' perceived difficulty of mathematics problems, Rohrkemper and Bershon (1984) also found that high-achieving students were better able to articulate when they did not understand something. However, research findings by L. Anderson et al. (1985) were inconsistent with these findings. Their research found that although lower achievers in first-grade seatwork activities more often experienced the assigned work difficult than higher achievers who could easily complete the work, the lower achievers often seemed to be aware that something was difficult or did not make sense to them.

Other studies examined the nature of task difficulty reported by students. Rohrkemper and Bershon (1984) found that most students in elementary mathematics classrooms, regardless of their achievement differences, described problem difficulty in primarily algorithmic as opposed to conceptual terms. Tobin and Gallagher (1987) found that high school science students faced with difficult tasks tried to reduce the cognitive demands of those tasks into algorithms and procedures. Blumenfeld and Meece (1988) also found that students in elementary science classrooms perceived difficulty of academic tasks in terms of length and amount of work or ease of procedures, rather than ideas or concepts taught in class.

Studies also examined learning strategies students use in the face of difficult tasks. L. Anderson et al. (1985) found that the tendency for lower achievers to put an answer down on seatwork assignments, but not necessarily to understand the content, occurred more often with assignments they found difficult. Blumenfeld and Meece (1988) also found that elementary science students used help-seeking and avoidance strategies more often with high-difficulty tasks. Further, some students lacked either the desire or the skills to identify their learning deficiencies and sought no help from external resources, reflecting an attitude of passivity or indifference to learning (L. Anderson et al., 1985; Rohrkemper & Bershon, 1984).

Dweck and her colleagues (Diener & Dweck, 1978; Dweck, 1986; Dweck & Elliott, 1983; Elliott & Dweck, 1988) distinguished the helpless motivational pattern from the mastery-oriented pattern in achievement situations. In the face of difficulty, helpless-oriented students avoided challenge and lacked persistence, whereas mastery-oriented students sought challenge and demonstrated high, effective persistence. They suggest that these two groups of students pursued different goals in achievement situations, with helpless students seeking to gain favorable judgments of their competence or avoid negative judgments, and mastery students seeking to expand or develop their competence.

Research on Conceptual Change in Science

Research on conceptual change in science has focused on how students' prior knowledge in a content area relates to their interpretations of classroom tasks. This research approach also stresses features of curriculum materials and quality of instruction. However, it has been silent on motivational variables of students and social contexts of classrooms.

1. Content objectives. Conceptual change research suggests that to achieve scientific understanding, students should recognize the content objectives of classroom tasks while engaging in those tasks. Then, students are likely to bring to bear their prior knowledge relevant to the content being taught in science classrooms. As discussed earlier, learning occurs when students connect the content being taught to their prior knowledge. Thus, correctly understanding the content objectives of the given instruction seems to be a precondition for conceptual change to occur (and effective curriculum materials and quality instruction greatly help students).

In contrast, students who are not engaged in conceptual change learning fail to understand the content objectives of the tasks. Roth (1985) found that some students who were reading commercial textbooks completely failed to understand the content objective of the reading passage. For example, a student read a passage that explained milk as an example of how all foods can ultimately be traced back to green plants, the food producers. The student stated that "most of this stuff I already know" and "it was about milk" (p. 15). When probed, this student still responded that "It's just about milk ... how we get our milk from cows" (p. 15). This student never recognized that the content objective in the reading passage was that plants make their own food.

2. Perceived task difficulty. Perceived difficulty of classroom tasks involves students' beliefs in their personal knowledge as opposed to formal, scientific knowledge. Conceptual change research shows that the process of conceptual change learning is difficult and confusing (C. Anderson & Roth, in press; Nussbaum & Novick, 1982; Posner et al., 1982). As students have long been committed to common-sense theories that have served them successfully, it is difficult to modify or restructure their personal knowledge into scientific knowledge, especially since the two sources of knowledge are often in conflict. As a result, conceptual change runs the risk of inherently being difficult for students. Roth (1985) found that students who read textbooks on photosynthesis with the goal of achieving conceptual change sense-making expressed confusion and frustration, although they eventually understood scientific conceptions.

On the other hand, these same tasks were perceived as simple and easy by students who did not undergo conceptual change learning (C. Anderson & Roth, in press; Roth, 1985). Some did not even recognize their misconceptions or conceptual conflict. Others felt that the scientific knowledge being taught was consistent with their prior knowledge, although incorrect, and that they already knew the content. When these students reported confusion or difficulty, it was attributed to unfamiliar vocabulary words or too much factual information to memorize. Further, these students erroneously felt they understood the content after reading textbooks. Some even wondered why textbooks repeated the same concepts several times, the ones they already knew! For these students, science tasks which are potentially difficult appear to be simple and easy. They are satisfied with half-truths because they do not recognize they are wrong.

In sum, students' interpretations of the nature of classroom tasks seem to be related to their goals and strategies during specific task engagement, differentiating students who are motivated to learn science from those who are not. Students who are motivated to learn science accurately interpret the nature of classroom tasks. They understand the content objectives and recognize when they have learning difficulties. In contrast, students who are not motivated to learn science misinterpret the nature of classroom tasks. Further, even when some students accurately interpret the nature of the classroom tasks, they settle for less desirable goals and easier strategies.

Students' Success or Failure to Make Progress in Scientific Understanding

Literature on student motivation suggests that students' success or failure to make progress in scientific understanding seems to be related to their choice of goals and strategies during task engagement. Brophy (1986) suggests that to stimulate student motivation to learn, teachers should "stress the quality of students' task engagement and the degree to which they are making continuous progress" (p. 22).

Students' failure to make progress can be attributed to many factors. Perhaps the curriculum materials and instruction do not provide enough support for students (as is often the case with traditional curriculum materials and instruction techniques). Some students expend sustained effort only to fail, because the curriculum materials and instruction are too difficult for them (i.e., conceptual change research). Others do not expend effort because they have low expectancy of success in achieving scientific understanding (i.e., motivation research).

This research question examines how students' success or failure to make progress in scientific understanding is related to their choice of goals and strategies during task engagement. Do students who are motivated to learn science show a different pattern of progress from those who are not motivated to learn science? The discussion examines students' progress in scientific understanding from the perspective of both the conceptual change research in science tradition and that of the motivation research. traditon

Development of Scientific Understanding

The current view of students' learning in science is that "students' scientific knowledge consists of many different conceptions that are integrated in a complex conceptual ecology", rather than a collection of isolated facts and skills (C. Anderson, 1987, p.18). To master a body of scientific knowledge, students must increase and expand scientific understanding over task situations, as they successfully integrate personal knowledge with scientific knowledge and use scientific knowledge to understand and explain the world around them in diverse task contexts.

Research on conceptual change in science shows that students often fail to achieve scientific understanding while engaging in science tasks. They have difficulty modifying their misconceptions into more scientific knowledge and applying scientific knowledge to understand and explain natural phenomena. Even students who understand scientific conceptions have difficulty putting them together in a logical and coherent manner to make adequate scientific explanations.

Further, students are not good at generalizing what they have learned in one task context to other contexts. Instead, they acquire scientific conceptions in specific task contexts (C. Anderson, 1987; Brophy, 1986, p. 22; Nickerson, 1985, p. 217; Posner et al., 1982). For instance, the scientific conception of thermal expansion is that substances expand when they are heated. As opposed to this scientific conception, a student might think that when an iron bar is heated (i.e., thermal expansion of solids), it would "shrink" or "shrivel up." Then, this student might think that a balloon on top of a cold bottle inflates when the bottle is warmed (i.e., thermal expansion of gases) because "hot air rises." Further, this same student might think that when the bottom of a thermometer is warmed (i.e., thermal expansion of liquids), the colored liquid inside "gets out of the bulb and moves up" because "the heat (pressure) pushes it up" (Eichinger & Lee, 1988; Lee et al., 1989). Thus, students need to experience the scientific conception of thermal expansion in different task contexts.

If knowledge is situated, can students ever develop general understanding, or are they limited to the mastery of specific tasks? After all, it is clear that students can develop understanding of broadly generalizable scientific conceptions or theories. How is this accomplished? In a specific task situation, learning occurs when students relate a scientific idea to one in their complex cognitive structure and use that idea in diverse task contexts. As students make consistent progress over task situations, they gradually construct an integrated body of scientific knowledge until they reach general understanding of a theory. For instance, students gradually understand the scientific conception for thermal expansion as they modify their misconceptions into scientific conceptions across different contexts including gases, liquids, and solids. They apply their scientific knowledge to other, even unfamiliar contexts, such as "Why do bridges and railroad tracks have expansion joints?" Eventually, they understand thermal expansion as an aspect of kinetic molecular theory.

The discussion sounds as if the growth of scientific understanding is a steady progression; one idea after another is connected into other ideas, or an incorrect idea is simply exchanged for a scientific idea. Research on conceptual change, however, indicates that developing a general understanding involves "much fumbling about, many false starts and mistakes, and frequent reversals of direction" (Posner et al., 1982, p. 223). Further, as students become confused between their personal knowledge and scientific knowledge, they develop new misconceptions over a course of instruction. For instance, Lee et al. (1989) found that as students learned molecular explanations of thermal expansion, some developed new misconceptions, such as when a substance is heated, its molecules got bigger. Some of them further reasoned that since molecules expand, there must be less space between molecules!

Thus, research suggests that students are often confused and frustrated as they try to achieve scientific understanding (C. Anderson & Roth, in press; Nussbaum & Novick, 1982; Posner et al., 1982; Roth, 1985). Although strenuous and demanding, success in achieving scientific understanding is a rewarding process which allows students to develop a deeper and richer understanding of scientific knowledge (C. Anderson & Roth, in press; Posner et al., 1982; Strike & Posner, 1985). As students make progress in scientific understanding over task situations, they come to realize how seemingly separate ideas fit together to form a scientific conception and, further, how scientific conceptions fit together to form a general theory. Also, as students become better at using their increasing scientific knowledge to explain a wider range of natural phenomena, they come to realize the power and precision of more broadly generalizable understanding.

In short, as knowledge is situated, students develop general understanding of a scientific concept or theory only gradually as they: (a) progressively integrate a new scientific idea or conception into their complex cognitive structure and (b) become more proficient at using scientific knowledge to describe, explain, predict and control the world around them.

Research on Conceptual Change in Science

Research on conceptual change suggests that success or failure to make progress in scientific understanding is related to the quality of students' task engagement. As discussed earlier, learning depends on prior knowledge. The role of prior knowledge is even more significant in a specific content domain in which knowledge within that domain is structured and integrated as conceptual networks. Thus, students' prior knowledge that has been constructed from preceding task situations can influence their engagement in subsequent task situations.

Students who have made continuous progress in scientific understanding over previous task situations have acquired the scientific knowledge necessary for subsequent task situations and, thus, are likely to expend high quality of effort in order to achieve scientific understanding. These students might be more willing to expend effort as they gain a deeper and richer scientific understanding. In contrast, students who have failed to make progress do not possess the scientific knowledge necessary for subsequent task situations, rendering it difficult for them to expend high quality of effort.

Research on Student Motivation

Research on student motivation suggests that students' progress is related to their expectancy of success in achieving understanding. According to achievement motivation theory (Dweck & Elliot, 1983; Feather, 1982; McClelland, 1985), when students experience success in scientific understanding, they expect to succeed in future task situations. The high expectancy of success in scientific understanding encourages students to maintain or even increase their high quality of cognitive engagement in subsequent task situations. In contrast, students' failure to make progress diminishes their expectancy of success in achieving scientific understanding. This is especially the case in classroom situations in which the curriculum materials and instruction emphasize scientific understanding and provide extensive support for students to achieve scientific understanding, rather than focusing on trivial learning such as vocabulary words, technical details, or factual knowledge (like in the present study).

In sum, students' success or failure to make progress in scientific understanding seems to be related to their motivation in science classrooms. Those who have made progress in scientific understanding are likely to maintain or even increase a high quality of cognitive engagement in subsequent task situations, because they have developed better content knowledge and/or higher expectations of success in achieving scientific understanding. In contrast, students who have failed to make progress exhibit low quality of cognitive engagement as instruction continues.

Students' General Goal Orientations in Science Class

Motivation research indicates that students' behavior in achievement situations is driven by a complex interplay of goals, and they behave in ways to achieve their goals. Research has also increasingly recognized the relation between students' goals and their task engagement in classroom settings (Ames & Archer, 1987; Blumenfeld & Meece, 1988; Dweck, 1986; Dweck & Elliot, 1983; Eccles, 1983; Elliot & Dweck, 1988; Maehr, 1984; Meece & Blumenfeld, 1987; Pervin, 1982; Wenzel, 1987).

Student goals can be identified in terms of general orientations as well as situation-specific states (Brophy, 1987; Dweck, 1985; Pervin, 1982). Such goals vary to a certain extent from situation to situation, depending on changes in circumstances, and a situation-specific state is important to understand behavior in that particular situation. In addition, general goal orientations are also an important factor for understanding consistency and stability of behavior across diverse situations and over a period of time (Pervin, 1982; Vallacher & Wegner, 1987; Wegner & Vallacher, 1986). While previous discussion on student motivation to learn science emphasized students' situation-specific goals during task engagement, the focus here is on students' general goal orientations in science class.

Why do students not perceive understanding as a major goal in science class? Perhaps some students do not have a sense of what understanding involves (i.e., conceptual change research). Others who recognize understanding might place low value in the goal of scientific understanding, being more concerned about other competing goals (i.e., motivation research).

The research question examines how students' goal orientations in science class are related to the quality of task engagement. Do students who are motivated to learn science display general goal orientations different from those who are not motivated? The central interest is students' perceptions of the goal of scientific understanding. Can students who recognize understanding as a major goal in science class actually be motivated to learn science during specific task engagement? The discussion investigates students' goal orientations in science class from both the conceptual change and the motivation research traditions.

Research on Student Motivation

Types of student goals. Research on motivation has identified several different types of student goals in achievement situations. Dweck and her colleagues (Dweck, 1985, 1986; Dweck & Elliot, 1983; Elliot & Dweck, 1988) identified two general classes of achievement goals: (a) learning goals, in which students strive to acquire a new skill or master a novel task; and (b) performance goals, in which students seek to obtain positive judgments of their ability or avoid negative ones from others. Maehr (1984) suggested four general categories of student goals: (a) task goals, in which students are totally engaged in tasks; (b) ego goals, in which students compete against peers or socially defined standards, (c) social solidarity goals, in which students try to please significant others; and (d) extrinsic rewards, in which students try to obtain tangible rewards. Nicholls, Patashnick, and Nolen (1985) and Blumenfeld and Meece (1988) proposed three categories of student goals: (a) task orientation, (b) ego and social orientation, and (c) avoidance of work.

The general types of student goals identified in motivation research seem to represent five major aspects of classroom or school settings: (a) mastery of content or skills in academic tasks, (b) expectations of significant others (e.g., parents or teachers), (c) performance in class (e.g., getting good grades or excelling peers), (d) extrinsic rewards, and (e) avoidance of academic work.

Goal structures. Although comprehensive and parsimonious, these broad categories of student goals seem to have some problems as tools for adequately understanding student goals in classrooms. First, research suggests that people possess multiple goals at different levels of generality (Pervin, 1982; Vallacher & Wegner, 1987; Wegner & Vallacher, 1986). For example, Wentzel (1987) found that students could identify a variety of goals, as many as 12, in school settings. Also, broad categories of goals can not identify more specific aspects of classroom learning. For example, *learning* as a goal means different kinds of learning to different people, such as increasing vocabulary, memorizing facts, understanding content, or applying knowledge to real-world problems.

Second, goals are not exclusive from each other; rather, they interact. In other words, goals are not simply a collection of isolated phenomena, nor does only one goal exist in a given situation. Instead, goals are hierarchically organized in a structure and function in relation to one another and their subgoals. Pervin (1982) used the term *goal structure* to describe how multiple goals are organized and interact with one another. Structured in a hierarchy, superordinate goals are generally more likely to be enacted into behavior across situations or over time than subordinate goals (of course, they will be influenced by situational factors in specific circumstances).

It is important to understand how student goals are organized into a hierarchical structure, rather than a collection of individual goals. Understanding of students' goal structures in science class can allow us to better understand their achievement behavior across specific situations or over time, in addition to expanding our understanding of their task-specific goals in particular situations.

Competing student goals. Research indicates that students' goals seem to be influenced by external factors. Expectations of significant others, including parents, teachers, and peers, seem to be among the most influential factors (Eccles, 1983; Maehr, 1984). According to the social learning theory of motivation, students are in the process of being socialized under the influence of these significant others. Thus, their achievement behavior is influenced by their perceptions of the beliefs and expectations of parents and teachers. Further, students' goal orientations in school learning also seem to be influenced by their experiences in school environments which tend to emphasize evaluation of ability, social comparison, and competition more than task engagement for content understanding or skill mastery (Eccles, 1983; Eccles, Midgley, & Adler, 1984; Eccles & Wigfield, 1985; Maehr, 1984; Stipek, 1984, 1988).

Thus, students encounter multiple goals from various sources, in addition to their personal goals, in science class. External influences can interact with students' personal goals in different ways (Pervin, 1982). External influences and personal goals can be compatible and, thus, achieved simultaneously. For example, students who stress understanding as a major goal in science class realize that it can also serve to achieve other goals. However, student goals from various sources can also be in conflict, forcing students to select certain goals at the exclusion of other competing goals.

Problems in classroom learning can occur when students are overly concerned with external influences, which may not be compatible with the goal of scientific understanding. Even students who personally perceive understanding as important in science class may be concerned about external influences, such as getting good grades or pleasing their parents or teachers, which often produce more concrete and immediate results than the goal of understanding. Research suggests that many students are concerned about extrinsic reasons rather than content understanding or skill mastery. Further, this tendency to seek extrinsic reasons increases as students advance in grade.

Research on Conceptual Change in Science

According to conceptual change research in science, a critical problem with the goal of understanding in science class is the fact that many students do not have a conception of the nature of science and science learning. In other words, students do not have a sense of what scientific understanding involves in terms of the structural and functional criteria. Roth (1985) found that most elementary science students reading commercial textbooks did not have a conception of scientific understanding. Despite failure to achieve scientific understanding, the students felt successful and said they understood the texts they were reading.

Conceptual change research suggests that it is important to understand not only the types of goals students espouse but also how they define those goals. Some students espouse goals without knowing how they can be achieved, rendering them "empty goals". For example, one student might espouse a goal of understanding in science class without knowing what scientific understanding involves. Another might espouse the goal of becoming a scientist, a goal too distant from the action or too general to conceive. Thus, a goal is *substantive* only when the student has realistic perceptions of what it involves and how it can be achieved through specific strategies.

Thus, conceptual change research claims that if students have a conception of the nature of science and science learning, and if they have a sense of what scientific understanding involves, they would emphasize understanding as a major goal in science class. While engaging in science tasks, they expend high quality of cognitive engagement to achieve scientific understanding.

In sum, research on student motivation suggests that students possess multiple goals in academic learning situations in a hierarchical structure. Student goals are influenced by external factors, including expectations of parents and teachers or student experiences in school environments. Problems in classroom learning occur when students are overly concerned with external influences, all of which may not be compatible with the goal of scientific understanding. Conceptual change research, on the other hand, suggests that students need to have a conception of scientific understanding in order to expend high quality of cognitive engagement in science classrooms.

Students' Affective Orientations Toward Science

Extensive research efforts have been invested on affective aspects of students in science, especially attitudes and interest, for two major reasons: (a) Students' attitudes toward and interest in science are related to science achievement; and (b) the development of positive attitudes and high interest is a major goal of science education (Haladyna & Shaughnessy, 1982; Laforgia, 1988).

This study examines how students' affective orientations toward science are related to their choice of goals and strategies during task engagement. Is there a systematic relationship between students' affective orientations and their task engagement? Do students who are motivated to learn science show affective orientations different from those who are not motivated? As with other sections of this paper, students' affective orientations toward science are discussed from two research perspectives: (a) motivation research and (b) conceptual change research.

Research on Student Motivation

In the present study, *attitudes* and *interest* are used in combination to indicate affective orientations, including liking, interest, curiosity, and enjoyment in science. *Attitudes* is the term most widely accepted as denoting affects (Laforgia, 1988; Koballa, 1988), although *interest/curiosity* is preferred in some research (Yager & Penick, 1986; Yager & Yager, 1985). Others use *interest/curiosity* to indicate intrinsic motivation (Berlyne, 1966 in Condry, 1987) or its component (Harter, 1980, 1981). Still others use the two terms as equivalent (Oliver & Simpson, 1988; Simpson & Oliver, 1985; Wilson, 1983) or widely different (Haladyna & Shaughnessy, 1982; Harty, Samuel & Beall, 1986). In a factor analytic study, Harty, Samuel, and Beall (1986) reported that "attitudes toward science, interest in science, and science curiosity are similar and might be a single construct" (p. 57).

Most previous research on students' affective orientations toward science examines the relationship between attitudes and achievement in science. Research suggests that attitudes and achievement in science are significantly related when the subjects are homogeneous within certain grade levels or the variables examined are specific (Welch, Walberg & Fraser, 1986). Yet, research findings are inconclusive about the relationship between attitudes and achievement in science (Gardner, 1975; Haladyna & Shaughnessy, 1982; Ormerod & Duckworth, 1975; Wilson, 1983).

Further, theoretical and empirical evidence suggests that the relationship between students' affective orientations and task engagement might not be systematic. An important implication in the conceptualization of student motivation to learn (Brophy, 1983, 1987) is its focus on cognitive aspects of motivation, not just its affective aspects. Brophy (1987) states: "whether or not they (students) find a particular task interesting or enjoyable, students who are motivated to learn strive to understand content or master skills" (p. 182).

This suggests that motivation to learn is independent from attitudes or interest. For example, students who like and enjoy science might not be motivated to learn science, while others who do not like or enjoy science might actually be motivated to learn science.

In fact, this was supported by empirical evidence. In an experimental study in middle school social studies classes, teachers received training on how to use various motivational strategies to stimulate student motivation to learn (Brophy & Merrick, 1987). The results suggest that after a period of instruction, students in the motivation (experimental) group tended to report more cognitive dispositions indicative of student motivation to learn, whereas students in the traditional teaching (control) group tended to report more affective aspects of intrinsic motivation (e.g., liking, interest or enjoyment). Thus, Brophy and Merrick (1987) concluded that "motivation to learn may be even more cognitive and less affective than we have interpreted it to date, and even more different from (perhaps even somewhat negatively correlated with) intrinsic motivation that we had anticipated" (p. 64).

Research on Conceptual Change in Science

The distinction between students' affective orientations and task engagement seems to be particularly relevant in science classrooms. As discussed earlier, scientific understanding is demanding and confusing for many students. Faced with such difficulty, mere liking or interest is not sufficient. To achieve scientific understanding, students need to expend high quality of effort and remain persistent in task engagement, whether they like science or not.

Further, students' affective orientations toward science might not be related to the nature of science learning or enjoyment of scientific understanding. Instead, affective orientations might depend on insignificant aspects of science learning or science class (e.g., fun experiments or interesting reading materials). Then, students' affective orientations are not related to their task engagement.

In sum, research on both student motivation and conceptual change in science suggests that students' affective orientations toward science might not be significantly related to the quality of their task engagement. Whether students like science or not, those who are motivated to learn science will expend effort to achieve scientific understanding. Thus, students' task engagement seems to be independent from their affective orientations toward science.

Summary: Factors Related to Patterns of Task Engagement

The second part of this chapter discussed four key factors related to the quality of students' task engagement from the perspectives of two research traditions. Those factors represent cognitive as well as affective aspects of student characteristics, ranging from task-specific to more general situations in science classrooms. The purpose of this study was to examine whether each of these factors is related to students' task engagement. Of particular interest was whether there is any systematic difference between students who are motivated to learn science and those who are not. Eventually, the study would identify key conditions under which students expend high quality of effort with the goal of achieving scientific understanding during task engagement in science classrooms. .

Part III: Achievement after Unit Instruction and Changes in Students' Goal Orientations and Affective Orientations

The relationship between achievement and motivation or affect has always been an important issue. Research efforts have focused not only on correlations but also on potentially causal relationships. For example, does success or failure in achievement after a period of instruction lead to any changes in motivation/affect, and vice versa? The assumption is that if the two are causally related, changes in one also lead to changes in the other, hopefully in a desired direction.

This study examines one such question: When students have achieved or failed to achieve scientific understanding after a period of instruction, is there any change in their cognitive aspects of motivation (i.e., general goal orientations) or affective orientations? This question is addressed in particular to the nature of the research context, in that the present study was conducted in classroom settings where there was strong support to promote scientific understanding for students. Does such support for students' achievement also enhance their motivation and affect after a period of instruction?

The discussion covers two topic areas. The first presents some empirical evidence suggesting a causal relationship between achievement and motivation/affect. The second examines the relationship between achievement of scientific understanding and changes in students' goal orientations and affective orientations in terms of both student motivation research and conceptual change in science research.

Achievement and Motivation/Affect: Causal Relationship

Research suggests that success or failure in achievement leads to changes in students' motivation and attitudes, more so than the reversed direction. Steinkamp and Maeher (1983) were concerned with the question of: "whether one should stress the development of proficiency in the hope that motivation will follow, or stress the development of positive feelings in the hope that this will encourage the development of proficiency" (p. 369). After reviewing correlational studies on achievement and attitudes in science, they concluded that: .

> It appears that as students acquire and demonstrate knowledge and proficiency they are most likely to develop a positive attitude toward science .... one is perhaps most likely to feel positively toward science as one actualizes one's ability through science achievement .... it is primarily the acquisition of proficiency that leads to positive attitudes (p. 389).

A similar conclusion was also advanced by Wilson (1983) in a meta-analytic review of achievement-attitude correlational studies in science. The findings suggested that achievement caused changes in attitudes, with the tendency increasing with time. Further, instrumental competence (achievement) seemed to be necessary to virtually all positive affect. In contrast, the correlation between time of delay and magnitude of association for attitude causing achievement was low. From these results, Wilson concluded: .

> Positive affect will follow success in science achievement. Perhaps science curricula should concentrate on achievement and let the affect follow without curricular emphasis .... they (science educators) should care about the attitude of children after their science experience. Successful achievement cause positive attitude ..(p. 849).

Peterson and Swing (1982) suggested that student attitudes toward elementary mathematics were sensitive to their learning experience and achievement only after a two-day instructional session dealing with a specific mathematics concept (i.e., probability theory). For example, before instruction of probability theory, one student (Paul) was initially low in attitude and medium in ability in mathematics. During the instructional period, Paul was actively engaged in thought processes that could facilitate understanding the lesson content and, subsequently, he achieved a perfect score on the achievement post-test. When instruction was completed, Paul showed an increase in his attitude toward mathematics. In contrast, another student (Melissa) was initially high in both attitude and achievement. However, during the instructional period, Melissa was not engaged in thought processes related to the lesson content much of the time and, later, performed below the average score on the post-test. When instruction was completed, Melissa showed some decrease in her attitudes toward mathematics.

Research also suggests that achievement leads to changes in motivation. Carr and Evans (1981) were interested in the relationship between skill and motivation in the early stages of reading instruction. They raised a basic question: "It *may* be that one of these two critical components of instruction, skill building or the encouragement of self-motivation, is more critical than the other in the early stages of learning to read" (p. 68, original emphasis). They compared reading achievement and engagement in reading activities between groups of first and second-grade children, one group in a traditional teacher-centered curriculum focusing on skill building and the other in a student-centered curriculum focusing on motivation. The results showed that children in the teacher-centered curriculum performed better on both achievement and motivation measures than those in the student-centered curriculum. Carr and Evans suggested that mastery of basic components of reading skills to a minimum level of competence is important not only for achievement but also for motivation.

Thus, research suggests that success or failure in achievement leads to changes in attitudes and motivation. As students experience success achievement, their attitudes and motivation also seem to increase. In contrast, as students experience failure achievement, their attitudes and motivation tend to decline. Further, the magnitude of achievement causing changes in attitudes and motivation seems to increase with time. .

Achievement and Changes in Students' Goal Orientations

This research question examines whether students' success or failure to achieve scientific understanding after a period of instruction leads to changes in students' goal orientations in science class or affective orientations toward science on a more long-term basis. Of particular interest is whether students who have achieved scientific understanding after completing unit instruction internalize understanding as a major goal in science class as well as develop more positive attitudes and interest than they posessed before unit instruction.

Students' Goal Orientations in Science Class

Conceptual change research suggests that a critical problem with the goal of understanding in science class is the fact that many students do not have a conception of scientific understanding. Further, traditional curriculum materials and instruction which tend to stress trivial learning of science, such as vocabulary words or technical details, do not help students realize the nature of science and science learning. However, when students have experienced success in achieving scientific understanding, they seem to develop a conception of scientific understanding. For example, Roth (1985) found that many students realized the process of conceptual change sense-making after reading an experimental textbook developed to promote scientific understanding for students. Although the students often expressed confusion and frustration, they eventually experienced the achievement of scientific understanding as rewarding and satisfying. After such a significant learning experience, some of them might have come to internalize scientific understanding as their reading goal, which would be substantially different from the ones they used to believe (C. Anderson & Roth, in press).

According to expectancy x value theory of motivation, after success achievement students come to place high value as well as high expectancy of success in achieving understanding (Brophy, 1983, 1987; Dweck & Elliot, 1983; Feather, 1982). Further, the value of understanding may be sufficient for some students with a reasonable expectancy of success to emphasize scientific understanding as their major goal in science class (Brophy, 1983, 1987). In terms of goal structure (Pervin, 1982), the students have established a new goal structure in which the goal of scientific understanding takes a high position. In contrast, students with failure achievement would not have the opportunity to experience the value of scientific understanding or develop the expectancy of success. Thus, these students are not ikely to realize understanding as a major goal in science class.

Unfortunately, research on student motivation suggests that as students advance in grade, they seem to become more concerned about task-exogeneous goals, such as getting good grades, pleasing their parents or teachers, or even trying to avoid classroom work. Marked changes in student goals and achievement behavior seem to occur during the transition from elementary to middle school. Blumenfeld and Pintrich (1982) asked second and sixth grade students about why they worked in school. The students, especially the older ones, gave extrinsic reasons most frequently. Research suggests that such changes might be influenced by students' long-term experiences in school environments which place heavy emphasis on evaluation of ability, social comparison, and competition rather than on task engagement for content understanding or skill mastery.

Students' Affective Orientations Toward Science

Conceptual change research in science suggests that success or failure to achieve scientific understanding leads to changes in students' affective orientations toward science, but only if achievement and affect are related. Students who have achieved scientific understanding enjoy expanding their scientific understanding. Research findings show that meaningful understanding of science leads to more positive attitudes or increased interest in science among non-science major elementary teachers (Appleman, 1984; D. Smith, 1987).

On the other hand, if students' affective orientations are related to some insignificant aspects of science learning, success or failure achievement may not be related to changes in attitudes or interest in a systematic manner. For example, even students who have experienced difficulty and failed in achievement still report positive attitudes and high interest because of certain aspects of science class, such as hands-on experiments, social interactions during group activities, or interesting reading materials.

Unfortunately, research on student motivation suggests that students' attitudes toward science steadily worsen as they advance in grade (Cannon & Simpson, 1985; Huefle, Rakow, & Welch, 1983; James & Smith, 1985; Schibeci, 1984; Simpson & Oliver, 1985; Welch, 1985). In a similar manner, students' interest in science and curiosity also decline (Yager & Penick, 1986; Yager & Yager, 1985; also see Eccles, Midgley, & Adler, 1984; Harter, 1981; Stipek, 1984 about steady decline of students' affects toward school in general). Findings generally show that elementary students have positive, although steadily declining in strength, attitudes toward science and high interest. Marked deterioration occurs during the transition from elementary to middle school grades. After this period, students tend to develop negative attitudes and little interest in science, which continues until the end of high school.

Several explanations have been advanced for the sudden, marked decline of students' attitudes toward science during the early period of middle school years. One explanation is that the first year in middle school is often the first time that science is taught as an independent, required subject (James & Smith, 1985). Another cites the stricter systems for grading or more emphasis on external evaluation in middle school than in elementary school (Eccles, Midgley, & Adler, 1984; Stipek, 1984). Still another explanation is that since elementary school students receive minimal instruction in science, they enter their first series of science courses with mixed feelings and inadequate backgrounds about the nature of science knowledge (Simpson & Oliver, 1985). Finally, students may be forced to engage in class activities that do not promote meaningful understanding of science (C. Anderson & Roth, in press; C. Anderson & E. Smith, 1987; Roth, C. Anderson & E. Smith, 1987).

Finally, there seems to be a relationship in the changes between cognitive and affective aspects of motivation. Students' attitudes and interest change as they develop different conceptions of what science is and, thus, change their goals in science class. It seems that cognition and affect are related for students who experience meaningful learning and come to enjoy true understanding, but not for those who fail to develop a conception of scientific understanding.

Summary: Achievement and Changes in Student Goals and Affect

Success or failure to achieve scientific understanding seems to lead to changes in students' goal orientations in science class. The literature suggests that students who have experienced meaningful understanding of science can develop a conception of scientific understanding and internalize it as a major goal in science class. Also, these students develop high expectancy of success and high value in the goal of scientific understanding. On the other hand, success or failure achievement seems to lead to changes in students' affective orientations in a systematic manner only when attitudes/interest are related to significant aspects of science learning.

Implications for This Study

This study is an attempt to develop an integrated theory of student motivation in science classrooms. The study addresses three basic questions. First, what are the types of goals and strategies while students engage in science classroom tasks? Second, what are the key factors related to patterns of students' task engagement? Finally, how are students' cognitive and affective aspects of motivation influenced by their achievement of scientific understanding on a long-term basis?

Part I of this chapter examined the conceptualization and operationalization of student motivation to learn science, a process which occurs when students engage in classroom tasks with the goal of achieving scientific understanding and activate strategies associated with such learning. Despite its significant potential to help us better understand the nature of student motivation in science classrooms, no systematic effort to integrate the conceptualization of student motivation to learn and conceptual change in science has yet been undertaken.

In research on classroom motivation, several empirical studies have been conducted within the conceptual framework of student motivation to learn (Brophy & Merrick, 1987; Marshall, 1987a, 1987b, 1987c). All these studies examined the effects of teachers or teaching strategies on stimulating student motivation to learn in classrooms. In an experimental study, Brophy and Merrick (1987) provided eighth grade social studies teachers with motivational strategies and examined their effectiveness after a period of instruction. In a series of naturalistic studies, Marshall (1987a, 1987b, 1987c) examined how elementary teachers influenced student motivation to learn. In addition to such studies, it is important to understand why and how students engage in classroom tasks in the first place. In fact, understanding of students' choice of goals and strategies during task engagement can suggest better ways to associate teaching strategies with various needs or problems of student motivation.

Research on conceptual change in science, on the other hand, has focused on issues of student learning and achievement and how to develop curriculum materials and instructional strategies to promote scientific understanding. Research has often been based on the assumption that when students succeed in scientific understanding, they find it rewarding in and of itself, so that motivation problems take care of themselves. Only recently has it been proposed that research on conceptual change be expanded to issues of student motivation and affect (White, 1987).

Thus, one of the research questions in the present study examines why (goals) and how (strategies) students engage in academic tasks in naturalistic science classrooms, based on the frameworks of student motivation to learn and conceptual change in science (Research Question 1). The results of the study show different patterns of students' task engagement in science classrooms.

Further, research suggests that students' choices of goals and strategies are related to various factors, including features of curriculum materials, quality of instruction, and student characteristics. It is important to understand key factors that are related to patterns of students' task engagement. In particular, under what conditions are students motivated to learn science? What are the key barriers blocking student motivation to learn science?

The primary focus of this study is student characteristics (Research Question 2). Literature on student motivation suggests several explanations for why students work (or do not work) hard to achieve scientific understanding. This study examines how each of four key factors (or hypotheses) is related to students' choices of goals and strategies during task engagement in science classrooms.

After a period of instruction, what happens to cognitive and affective aspects of student motivation if they succeed or fail to achieve scientific understanding? Is there any change in students' goal orientations in science class or affective orientations toward science (Research Question 3)? Conceptual change research in science suggests that when students have achieved meaningful understanding of science, they develop a conception of scientific understanding, internalize that understanding in science class, and eventually learn how to learn science independently (C. Anderson & Roth, in press). Also, research on classroom motivation suggests that student motivation to learn science over specific task situations stimulates the development of a generalized disposition of motivation to learn (Brophy, 1983, 1987). This question seems particularly relevant in the present study, as this study was conducted in classrooms where the curriculum and instruction provided extensive support for students to achieve scientific understanding.

Finally, a secondary interest of the study is the features of the curriculum materials and instructional strategies which were developed according to a conceptual change approach.

The results suggest how features of the curriculum materials and instructional strategies influence students' choices of goals and strategies during task engagement (with regard to Research Question 1) as well as changes in motivation on a long-term basis (with regard to Research Question 3). The results also suggest how features of curriculum materials and instructional strategies interact with aspects of student characteristics (with regard to Research Question 2). Further, the results inform conceptual change researchers about the validity of their assumption about student motivation and, if disconfirmed, suggest how to modify or elaborate that assumption.

CHAPTER THREE

BACKGROUND FOR THIS STUDY

Student motivation is a complex phenomenon related to various aspects of classroom settings, including features of curriculum materials, quality of instruction, and student characteristics. As a primary interest of the present study, chapter 2 discussed major aspects of student characteristics. Yet, understanding of student motivation is not complete without considering features of curriculum materials and instruction. After conditions of curriculum and instruction for student motivation are made clear, issues of student characteristics need to be examined. How effective were the curriculum materials and instruction in helping students expend high quality of task engagement in the present study? Did the curriculum and instruction in this study represent an *ideal* situation according to conceptual change research in science?

Issues of curriculum materials and instruction in this study have important implications (to be discussed in the final chapter of this report). Theoretically, the results provide some answers for the assumptions about issues of student motivation in conceptual change research. If the curriculum and instruction approximate the ideal research situation (as suggested by conceptual change researchers), but problems of student motivation still exist, then the assumptions are wrong. Problems of student motivation are then attributable to other factors, most likely to student characteristics as motivational research suggests. On the other hand, if the curriculum and instruction perform better than traditional practices but the research context does not fit the ideal specifications, then the study's appropriateness for testing the assumptions of conceptual change research is limited, allowing attribution of motivation problems both to features of curriculum and instruction as well as to student characteristics. Practically, as sources of the problems of student motivation are identified, the results will have implications for designing curriculum and teaching strategies that help students become motivated to learn science.

In addition to its conceptual importance, chapter 3 fulfills a practical purpose for the documentation of this study. It bridges chapters 2 and 4. It extends the discussion of understanding issues of student motivation in science classrooms begun in Chapter 2, approaching the question from a different perspective. Chapter 2 focuses on aspects of student characteristics, and chapter 3 on aspects of curriculum materials and instruction. At the same time, the ideas expressed and examined in here lead directly into chapter 4 (Methods) by introducing the research context (i.e., curriculum materials and instruction) in which the present study was conducted.

Three major discussions are presented in this chapter. The first examines how traditional science curriculum materials and instruction generally fail to help students achieve scientific understanding. The second concerns current efforts in conceptual change research to improve curriculum materials and instructional strategies in order to promote scientific understanding for students. The third investigates the special features of the curriculum materials and quality of instruction in the present study.

Failure in Traditional Curriculum and Instruction

As discussed in chapter 2, the process of scientific understanding is demanding and difficult, and many students fail to achieve scientific understanding in science classrooms. To what extent does science curriculum and instruction promote students' scientific understanding that meets both the structural and functional criteria?

Science Curriculum

Research in science education reports consistently that curriculum materials fail to help students achieve scientific understanding (C. Anderson, 1987; C. Anderson & E. Smith, 1987; Mergendoller, Marchman, Mitman & Packer, 1988; Roth, 1985). Most textbooks emphasize technical details and vocabulary, rather than focusing on central science concepts. For example, some textbooks contain several hundreds of new vocabulary words in bold-faced print (probably to attract students' attention), and technical details are presented in reference to these words (Gallagher, 1986; Lee & Gallagher, 1986). Most science textbooks, including some of the effective activity-based programs, are developed from the perspective of scientists or the scientific community without any consideration of students' personal knowledge in content domains (C. Anderson, 1987; Berkheimer, C. Anderson, & Blakeslee, 1988a).

A more basic problem in science curriculum materials is the traditional view of the nature of science and student learning as consisting of two independent components, content knowledge and science process skills (C. Anderson, 1987). The traditional view sees science curricula as being composed of two separate parts: (a) a body of scientific knowledge, containing definitions, facts, laws, and theories; and (b) the scientific method, which provides procedures for developing new knowledge. According to this view, new knowledge which is generated by the scientific method is simply added to a current body of knowledge.

However, our current understanding of the nature of science and student learning suggests that this traditional view of curriculum development has several major shortcomings (C. Anderson, 1987). In particular, this view ignores the dynamic interplay between the body of current scientific knowledge and the development of new knowledge. This view also ignores that students (scientists as well) take an active role in building new knowledge by integrating their personal knowledge with scientific knowledge and, in this process, modifying or restructuring their existing knowledge. Further, this view ignores the fact that, rather than simply being a body of knowledge and the method for developing new knowledge, science serves basic functions of describing, explaining, predicting, and controlling the world around us.

<u>Science Instruction</u>

Research also suggests that science instruction often fails to help students achieve scientific understanding (C. Anderson, 1987; C. Anderson & Roth, in press; C. Anderson &

E. Smith, 1987). Many teachers fail to encourage students to integrate their personal knowledge with the scientific knowledge being taught. For instance, some teachers present scientific information in the textbook, with little conceptual integration within or between topics. These teachers also show little awareness of or interest in students' personal knowledge. Thus, they teach science to students as a collection of isolated facts or skills, without connection to students' personal knowledge. Other teachers present rich, conceptually integrated knowledge of science and demonstrate considerable awareness of students' prior knowledge. Even these teachers, however, do not incorporate students' prior knowledge as an important component of instruction. They present well-integrated knowledge which is conceptually coherent, but its relevance to students' personal knowledge is difficult for students to recognize themselves (Hollon & C. Anderson, 1987).

Further, many teachers do not provide students with opportunities to practice scientific description, explanation, prediction, and control. Many teachers instruct students about conceptual tools of science—vocabulary words, facts, concepts, and theories—but do not teach them how to use those tools. In these classrooms, students are expected to memorize large numbers of vocabulary words and facts and, later, to reproduce them upon request. Students are evaluated to understand the content when they recall the words or facts correctly, for instance, on tests (Eaton, C. Anderson & E. Smith, 1983, 1984; Hollon & C. Anderson, 1987; Stepans, Beiswenger, & Dyche, 1986).

Even some skilled, experienced teachers do not engage students in description, explanation, and prediction; instead, the teachers themselves engage in those activities. They demonstrate to students how to make scientific descriptions, explanations, and predictions, while their students participate in a limited way. In these classrooms, only a few students can successfully engage in these activities themselves, whereas most of the others can produce only the simpler parts or disconnected segments of the activities (Hollon & C. Anderson, 1987; Roth, 1984, 1987; E. Smith & C. Anderson, 1984).

Thus, many science teachers engage students in a passive mode of learning by simply transmitting knowledge to be acquired by students, rather than help students construct their own knowledge by integrating personal knowledge with scientific knowledge and applying scientific knowledge to understand and explain the world around them. As a result, science is perceived by many students as a collection of facts or skills which has little relevance to their personal life, while only a few students develop meaningful learning of science.

Current Efforts in Curriculum and Instructional Development

As research findings repeatedly show that students in science classrooms fail to achieve scientific understanding, efforts have been undertaken to help students with their learning difficulties. Such efforts can be grouped into two categories: (a) improvement of curriculum materials and (b) effective instructional strategies.

Curriculum Development

Recent research efforts have focused on developing curriculum materials that encourage students to achieve scientific understanding (C. Anderson & E. Smith, 1983; Berkheimer, C. Anderson, & Blakeslee, 1988a; Driver, 1987; Nussbaum & Novick, 1982; Roth, 1985). The research shows that such curriculum materials can be effective, especially for non-science major teachers or with minimum teacher training. Such curriculum materials omit much technical detail and vocabulary, stress basic science concepts, incorporate extensive knowledge about students' personal knowledge in content domains, and emphasize the use of scientific knowledge to understand and explain real-world phenomena. This approach toward curriculum development is consistent with the structural and functional criteria of scientific understanding.

Curriculum development sometimes involves teaching materials only, excluding texts for students. Teaching materials generally provide teachers with four types of knowledge to teach for conceptual change learning: (a) knowledge about the particular topic being taught, including knowledge about main ideas, subordinate ideas, and relationships among these ideas; (b) knowledge about specific students' misconceptions that are common among students and likely to be problematic for them; (c) knowledge about instructional strategies that are effective in helping students modify or abandon these particular misconceptions; and (d) a general orientation to conceptual change teaching and learning (Roth, 1987; Shulman, 1986; D. Smith, 1987). For more information about current efforts in curriculum development, see C. Anderson (1987), C. Anderson and Roth (in press), C. Anderson and E. Smith (1987), Berkheimer, C. Anderson and Blakeslee (1988a), Driver (1987, in press), and Nussbaum and Novick (1982).

Instructional Strategies

Several conceptual change models of instruction have been proposed (Nussbaum & Novick, 1982; Pines & West, 1986; Posner et al., 1982). For example, Posner et al. (1982) stress that four conditions must be fulfilled if students are likely to achieve conceptual change: .

> 1. There must be dissatisfaction with existing conceptions.
> 2. A new conception must be intelligible.
> 3. A new conception must appear initially plausible.
> 4. A new conception should suggest the possibility of a fruitful research program (p. 214).

The conceptual change models of instruction proposed by Nussbaum and Novick (1982), Pines and West (1986), and Posner et al. (1982) all suggest that effective instruction must provide extensive support for students as they go through four major learning steps: (a) awareness of students' personal knowledge, (b) recognition of conceptual conflict between personal knowledge and scientific knowledge, (c) accomplishment of conceptual change learning, and (d) application of newly acquired scientific knowledge in diverse task contexts.

More specific guidelines and suggestions for effective instruction have also been attempted (C. Anderson, 1987; C. Anderson & Roth, in press; C. Anderson & E. Smith, 1987; Blakeslee, C. Anderson, & E. Smith, 1987; Brook, Driver, & Johnston, 1988; Driver, 1987). For instance, C. Anderson, E. Smith and his colleagues suggest specific instructional strategies that seem to be particularly effective in teaching for conceptual change under three broad categories: (a) strategies for presenting information, (b) strategies for questioning and discussing, and (c) strategies for using phenomena (laboratories, demonstrations, and applications) (C. Anderson & E. Smith, 1987; Blakeslee, C. Anderson & E. Smith, 1987; Roth, 1987).

Curriculum and Instruction for This Study

The curriculum materials and instructional strategies that provided the research context for the present study were developed by Science Achievement Project funded by National Science Foundation (Berkheimer, C. Anderson & Blakeslee, 1988a). The primary goal was to develop meaningful curriculum materials and identify effective instructional strategies to promote scientific understanding for students. In particular, the curriculum and instructional development was guided by conceptual change approach and cognitive apprenticeship or scaffolded teaching (C. Anderson, 1987; C. Anderson & Roth, in press; Collins, Newman, & Brown, in press).

An entire pool of 15 sixth grade science teachers in a midwestern urban school district participated in the Science Achievement Project during its two-year period. Most had no formal training in science. Among the 15 , four teachers who were recommended as exemplary teachers from each of the four schools in the school district worked closely with the Project as collaborating teachers. Two of these collaborating teachers participated in the present study.

Curriculum Unit

The curriculum unit "Matter and Molecules" included various aspects of kinetic molecular theory for sixth grade science students. Four kinds of curriculum materials were developed: a text and an activity book for students, and teachers' guides for the student text and the activity book, respectively (Berkheimer, C. Anderson & Blakeslee, 1988b; Berkheimer, C. Anderson, Lee, & Blakeslee, 1988).

The curriculum unit consisted of nine lesson clusters (L.C.), each dealing with a key concept:

L.C. 1	L.C. 2	L.C. 3	L.C. 4	L.C. 5	L.C. 6	L.C. 7	L.C. 8	L.C. 9
States of Water	Other Solids, Liquids & Gases	The Air Around Us	Compressing & Expanding Air	Explaining Dissolving	Heating/ Cooling Expanding/ Contracting	Explaing Melting & Solidi-fying	Explaining Evapora-tion & Boiling	Explaining Conden-sation

Two basic assumptions guided the curriculum development (C. Anderson, 1987; C. Anderson & Roth, in press; Berkheimer, C. Anderson & Blakeslee, 1988a). First, to be adaptable to the complexities and constraints of learning environments as they presently exist in the classrooms, the curriculum materials were made as conventional as possible, especially in terms of teachers' expectations about classroom management and time commitments. The curriculum unit did not include activities that demanded extensive preparation time, expensive equipment, or non-traditional forms of classroom organization. Second, detailed information about specific students' misconceptions as well as a general introduction to the conceptual change teaching approach were built into the teachers' guides. This course of action was taken in response to research findings that most teachers lack the knowledge base necessary to teach for conceptual change learning (Hesse & C. Anderson, 1988; Hollon & C. Anderson, 1987; Roth, 1987; D. Smith, 1987). Thus, these curriculum materials could be used by teachers with little background in science.

The curriculum unit minimized factors that lead to trivial learning. Unlike most traditional textbooks, the unit carefully eliminated much technical detail and vocabulary. It stressed central science concepts, rather than coverage of content that does not allow students to engage in meaningful learning of science (C. Anderson, 1987; C. Anderson & Roth, in press; Blumenfeld & Meece, 1988; Blumenfeld, Mergendoller, & Swarthout, 1987, Doyle, 1983; Mergendoller, Marchman, Mitman, & Packer, 1988; Roth, 1985).

In addition to differing from most traditional textbooks, the curriculum unit contained distinctive features specially designed to help students achieve scientific understanding. The readers are encouraged to compare these features, to be discussed below, with major shortcomings typical in curriculum materials and instruction in science education, as already discussed.

The curriculum development was guided by a *tasks by conceptions chart* and an associated *preconceptions by goal conceptions chart* for kinetic molecular theory developed by the Science Achievement Project (C. Anderson, 1987; Berkheimer, C. Anderson & Blakeslee, 1988a; Eichinger&Lee, 1988; Lee, et al., 1989). The two charts are presented in tables 3.1 and 3.2, respectively.

The tasks by conceptions chart consists of two parts: (a) a list of phenomena that we want students to describe, explain, predict and control; and (b) a list of scientific conceptions that we want students to use for their descriptions, explanations, predictions, and attempts to control those phenomena. These correspond to the structural and functional criteria of scientific understanding. The conceptions represent scientific knowledge that students are to master (structural criteria), and the tasks are the contexts in which that knowledge is mastered and used (functional criteria). As shown in table 3.1, the tasks and conceptions are interrelated, in that each task requires the understanding of several scientific conceptions, and each scientific conception is needed for several tasks. The X's marked in the cells in table 3.1 identify the conceptions that are particularly important and likely to be problematic for students to perform that particular task. (They do not identify all the knowledge that is necessary for the performance of the task.).

The preconceptions by goal conceptions chart lists common students' misconceptions, as opposed to the scientific conceptions they are to accomplish after instruction. This extensive knowledge base was obtained through clinical interviews and paper-and-pencil tests with sixth grade science students (Lee et al., 1989).

The curriculum unit emphasized to students the structural and functional components of scientific understanding. To help students recognize their misconceptions and conceptual conflicts, the student text and the activity book presented common students' misconceptions as opposed to scientific conceptions. Also, students were encouraged to use scientific knowledge to describe, explain, predict, and control natural phenomena. In

Table 3.1

Tasks by Conceptions Chart for Kinetic Molecular Theory

Tasks	Conceptions: Macroscopic								Molecular										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Describe/contrast/ classify matter vs. non-matter	x	x				x													
2. Describe states of matter	x	x				x		x		x	x	x				x	x		
3. Explain process and rate of dissolving		x	x	x						x	x	x	x	x			x		
4. Explain thermal expansion		x			x						x	x		x	x	x	x		
5. Explain expansion of gases		x						x								x	x		
6. Explain melting and freezing	x	x								x	x	x		x		x	x		
7. Explain evaporation and boiling	x	x	x			x			x	x	x	x		x		x	x	x	x
8. Explain smells	x	x	x	x			x			x	x	x				x	x	x	
9. Explain condensation	x	x	x	x		x			x	x	x	x		x		x	x	x	

Table 3.2

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"; <u>or</u> 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 <u>in</u> 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 explanation 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.

the first three lesson clusters of the unit, basic scientific conceptions of kinetic molecular theory were emphasized. In the remainder of the unit, students were requested to engage in scientific activities to describe, explain, and predict natural phenomena. Initially, students were asked to explain relatively simple phenomena (e.g., expansion and compression of air; thermal expansion). As the unit advanced, students had to combine several scientific conceptions that had already been presented in order to explain progressively more complicated phenomena (e.g., changes of state involving melting, solidifying, evaporation, and condensation).

The curriculum unit was structured as a process of *cognitive apprenticeship* in three steps: modeling, coaching, and fading (Collins, Brown & Newman, in press). The text presented students with a few questions or problems involving natural phenomena familiar to them in daily life. The purpose was to elicit students' conceptions and make them aware of their own conceptions for the topics to be studied. The text then presented scientific conceptions along with extensive explanations or demonstrations about how to use these conceptions to solve the problems already presented. As knowledge was situated, students were not expected to transfer what they had learned in one task context to other contexts. Instead, important conceptions were presented in several different task contexts within the same lesson cluster as well as over the entire unit. This, in turn, provided students with repeated opportunities to use scientific knowledge in diverse contexts. Also, the importance of these major conceptions was explicitly communicated to students. As they gained mastery, the degree of assistance (i.e., prompts or probes) were gradually withdrawn, until they were finally capable of working independently.

To encourage students to actively construct their own knowledge, the curriculum materials included a variety of class activities. For example, reading and writing were more prominent here than in traditional curriculum materials, where they tend to be ignored (C. Anderson, 1987; C. Anderson & Roth, in press). For students to make sense from reading, the curriculum unit contained sufficient information that could hang together. Writing activities were stressed, requiring students to construct their own answers in the activity book. Hands-on experiments involving everyday phenomena were scheduled at least once for each lesson cluster (i.e., more than once a week). Class discussion was also stressed, in order to provide opportunities for students to make explanations and exchange their ideas with those of other students in the class.

Further, to encourage students to focus on the task content, the forms of classroom tasks were carefully arranged. Research suggests that procedurally complicated tasks direct too much student attention to how to carry out the tasks, distracting them from task content (Blumenfeld & Meece, 1988; Blumenfeld, Mergendoller, & Swarthout, 1987; Doyle, 1979, 1983). To minimize such potential learning difficulties for students, the curriculum unit included tasks that seemed to be simple and easy to follow procedurally. When procedurally complex tasks were necessary to present important concepts, those tasks were conducted through teacher demonstrations and explanations. Research also suggests that when the cognitive purpose of classroom tasks is not clear, students are likely to be confused and tend to employ inappropriate learning strategies. Thus, the curriculum unit made explicit to students the content objectives of classroom tasks (see the discussion, "Students' interpretations of Science Classroom Tasks", in Chapter 2).

The teacher's guides for both the student text and the activity book contained two additional sources of information. First, when presenting a certain concept or idea, the teacher's guides directed teachers to pay special attention to those places where students' misconceptions were expected to be problematic. Second, the teacher's guides provided instructional strategies, along with specific guidelines for implementation. Examples included: what kinds of problems could be anticipated during a hands-on experiment and how to manage the classroom; when a small-group activity might be effective; how to structure the sequence of class activities in a lesson for most desirable learning outcomes; how to prepare and set-up laboratory equipment or facilities; how to evaluate student performance.; etc.

Quality of Instruction

Effective curriculum materials are necessary but not sufficient to promote meaningful learning of science for students. Most students also require the support of well implemented instruction (C. Anderson, 1987; C. Anderson & Roth, in press; C. Anderson & E. Smith, 1985; Blakeslee, C. Anderson, & E. Smith, 1987). Through their lengthy involvement in the Science Achievement Project, the two teachers in the present study developed an extensive knowledge base for teaching for conceptual change. This included (a) knowledge about central concepts in kinetic molecular theory, (b) specific students' misconceptions about aspects of matter and molecules, (c) effective teaching strategies, and (d) a conceptual change orientation toward science teaching and learning.

The teachers taught the unit in accordance with the purpose of the curriculum materials, paying attention to students' misconceptions and closely following instructional strategies suggested in the guides. Theyemphasized to their students how the students' personal knowledge could often be in conflict with scientific knowledge, and they encouraged students to use scientific knowledge to understand and explain natural phenomena in diverse task contexts. To promote scientific understanding for students, the teachers also encouraged students to be actively involved in a variety of class activities.

The nature of instruction was characterized as a process of cognitive apprenticeship, involving modeling, coaching, and fading (C. Anderson, 1987; C. Anderson & Roth, in press; Collins, Brown, & Newman, in press). Initially, the teachers and the students together established problems to be solved through scientific thinking. Instruction started with teachers asking students a few questions, using natural phenomena in everyday life and eliciting students' conceptions about a certain concept or idea to be studied (e.g., How is water different from ice? How can we explain when water changes into ice?). This served several important functions: (a) Students became aware of their prior knowledge and its limitations; (b) teachers became familiar with students' conceptions, especially common misconceptions, and their reasoning; and (c) students and teachers together established problems that were commonly understood.

Once problems were established, the teachers and the students engaged in instructional activities to solve these problems through scaffolded instruction. The teachers initially presented scientific conceptions through modeling. This usually occurred as the teachers demonstrated to students whether their prior knowledge was consistent or in conflict with scientific knowledge and then showed how to use scientific knowledge to make scientific explanations for these problems.

After presenting scientific knowledge to students, the teachers gave them opportunities to use the new scientific knowledge to make explanations. The teachers provided extensive support for the students with their initial attempts in various ways. The teachers reduced the demands of classroom tasks on students by clarifying the tasks or simplifying them into smaller steps, facilitated classroom dialogue in which students were encouraged to express and exchange their ideas, and provided feedback to students to correct or elaborate their reasoning. Thus, instead of presenting information directly to students, the teachers tried to help students construct their own knowledge through active engagement.

Finally, as students achieved basic understanding of scientific conceptions, the teachers gradually withdrew support until students were ready to perform independently. While fostering independent student work, the teachers emphasized to students the power and precision of scientific knowledge in diverse task contexts.

Thus, the teachers implemented this curriculum unit using conceptual change strategies suggested in the teacher's guides. Nevertheless, there was much to be desired in the quality of instruction in order to represent an approximation of ideal circumstances. This involved aspects of teaching that were not addressed in the curriculum but existing in the social context of classrooms. Two of these seemed particularly apparent: pacing of instruction and accountability system.

The teachers kept on schedule to complete the unit as planned. Even though some students did not understand the content early in the unit, the teachers did not vary the pacing of instruction according to the needs of individual students. There was little discussion of individual work; instead, the class progressed at the same time.

Further, the teachers did not hold the students accountable for really thinking and not just finishing the work assigned. Even when students did not complete tasks or did them poorly (e.g., student answers in the activity book or tests), the teachers did not closely monitor students' performance. and provide adequate geedback for individual students to realize their learning deficiencies. Task completion was often accepted, although students could have exerted effort to achieve scientific understanding with reasonable standard of accountability system placed on them. In sum, the teachers implemented the curriculum unit as planned in the unit according to a conceptual change approach. Yet, the teachers did not interact with individual students in ways that would have led to greater students' engagement within the social contexts of classrooms. Thus, the extent of support in the instruction could be sufficient for some students, but not for others.

Effectiveness of Curriculum and Instruction

The effectiveness of the revised"Matter and Molecules" unit to promote students' scientific understanding was compared to the commercial textbook unit "Models of Matter," found in the sixth grade version of the Houghton Mifflin Science series (Berger, Berkheimer, Neuberger & Lewis, 1979), which provided the basis for the curriculum revision (see Berkheimer, C. Anderson, & Blakeslee, 1988a about major contrasts between the two sets of curriculum materials). The data were collected through students' paper-and-pencil tests administered in classrooms taught by the 15 teachers in the Science Achievement Project.

The results show that 50% of the students who were taught by the "Matter and Molecules" unit demonstrated adequate scientific understanding of kinetic molecular theory, in comparison to 26% of students taught by the commercial materials (see Lee et al., 1989 for details). Thus, the "Matter and Molecules" unit was significantly more effective in promoting students' scientific understanding. As indicated in the 50% of success rate, however, many students still failed to achieve adequate scientific understanding.

Summary and Discussion: Curriculum and Instruction

Traditional science curriculum and instruction generally do not provide opportunities for students to engage in classroom tasks in meaningful ways and, thus, they fail to promote scientific understanding for students (Berkheimer, C. Anderson & Blakeslee, 1988a; Roth, 1985). Traditional textbooks and instruction tend to emphasize technical details and vocabulary, rather than scientific understanding. Further, many teachers are not trained in, or even aware of, the conceptual change approach and related instructional strategies (Hesse & C. Anderson, 1988; Hollon & C. Anderson, 1988). These problems in science curriculum and instruction seem to be a major cause of students' failure to achieve scientific understanding.

There have been renewed efforts to develop effective curriculum materials and instructional strategies, based on current theories about human cognition and the nature of science and student learning. The focus in this study was on helping students integrate personal with scientific knowledge and apply scientific knowledge to understanding and explaining the world around them. This approach is represented by research on conceptual change in science.

The curriculum and instruction in the present study was an attempt to help students achieve scientific understanding according to research on conceptual change in science and scaffolded instruction. The curriculum materials and instruction in the study demonstrated significant advancement over traditional practices. Yet, the quality of instruction in the study did not seem to be sufficient to provide needed support for individual students.

The research context used here has important implications. First, the context did not approximate the ideal conceptual change research context. Thus, the results of the study can test conceptual change assumptions about issues of student motivation only in part.

Second, the research context did provide an opportunity to examine how features of curriculum and instruction interact with student characteristics. Some students were motivated to learn science with minimal support from the curriculum materials and instruction. Others took advantage of the extensive support designed into the materials and became motivated to learn science. Still others were not motivated to learn science, despite extensive support of curriculum materials and instruction. These results should have significant implications for curriculum development and classroom teaching in science.

CHAPTER FOUR

METHODS

Since this study was to examine several research questions, various kinds of data were collected at various phases of investigation. This chapter consists of four sections: (a) subjects and research setting, (b) curriculum and instruction, (3) data collection procedure, and (d) data analysis procedures.

Subjects and Setting

This study involved two schools from a midwestern urban school district with an ethnically mixed student population: 25% black, 10% Hispanic, 3% Asian, 2% American Indian, and 60% white students. The two schools were part of the larger Science Achievement Project. One sixth grade science class was selected from each school. Both classrooms were selected as representing average, regular sixth grade science classes in the school district in terms of student achievement, behavioral conduct, and other social and cultural aspects.

The study chose six students per each classroom from three achievement levels: high, middle, and low. Other criteria for the selection of students included gender and ethnic backgrounds. Based on these criteria, 12 students were selected from a pool of students who agreed to participate in the study. The 12 students consisted of four students from each achievement level; seven female and five male students, or eight white, two black, and two Hispanic students.

Two male science teachers at the sixth grade level participated in this study. Recommended as exemplary teachers from each school, both also worked as collaborating teachers in the Science Achievement Project for the two-year period.

They developed the extensive knowledge base necessary to teach for conceptual change learning. One teacher was a science major, and the other was a science department chairperson.

Curriculum and Instruction

As already described in detail in chapter 3, the curriculum materials and instructional strategies developed by the Science Achievement Project provided the research context for the present study. To promote scientific understanding for students, the curriculum materials incorporated extensive knowledge of students' misconceptions about aspects of matter and molecules. The curriculum materials encouraged students to develop scientific understanding that both integrates personal knowledge with scientific knowledge and is useful for describing, explaining, and predicting natural phenomena. Further, to help teachers accomplish this curricular goal, the materials suggested instructional strategies that seemed effective in helping students develop scientific understanding.

The two teachers taught the unit in accordance with the general goal of the curriculum materials. They paid attention to students' misconceptions, helped students solve conceptual conflicts between personal and scientific knowledge, and provided opportunities for students to use scientific knowledge to understand and explain natural phenomena. Thus, the quality of instruction in both classrooms was superior to conventional classroom teaching, although not ideal to meet the needs of individual students.

The two classrooms provided comparable research settings as the two teachers closely followed the instructional sequences and strategies suggested in the teachers' guides. Yet, there were some differences in the ways they implemented instructional activities. The teacher in Classroom 1 devoted a significant portion of class time to individual or small-group activities (e.g., experimentation and writing). In comparison, the teacher in Classroom 2 allocated less time to individual or small-group activities and, more time to whole-class activities (e.g., class discussion and reading aloud). In a similar vein, the teacher in Classroom 1 exercised less control over students during class activities than the teacher in Classroom 2. For example, when a lesson contained a hands-on experiment accompanied by questions in the activity book, Teacher 1 allowed a certain amount of time for students to complete the experimentation and answer questions in the activity book and, then, engaged in class discussion. Teacher 2 started with answering questions in the activity book in class, allowed students to work on important segments of the experiment, and continued class discussion on the remaining questions in the activity book.

Data Collection Procedures

The research questions addressed in this study rendered it necessary to collect various types of data at different phases of instruction of the "Matter and Molecules" unit. The data were collected by two observers/interviewers who worked with six target students in the two classrooms, respectively. The types of data and the methods for data collection along the timeline of before, during, and after instruction of the unit are summarized in Table 4.1. In both classrooms involved in the study, the beginning and end of data collection as well as the duration for instruction of the unit were almost identical.

In this section, the types of data and methods for each of the research questions are discussed with focus on: (a) kinds of data necessary to answer the research questions and (b) rationales for using certain instruments or observation schedules.

1. Patterns of students' task engagement (R.Q. 1)

Information about the quality of students' task engagement in terms of their choice of goals and strategies in specific situations was collected. Students were observed and engaged in informal conversations during class activities over the period of instruction of the "Matter and Molecules" unit. Three issues of data collection are discussed here: (a) development of classroom observation schedules, (b) specific questions guiding classroom observations and informal conversations with target students, and (c) procedures for data collection and major sources of data.

Table 4.1

Types of Data and Methods along the Timeline of Unit Instruction

	Before Instruction October 1987 (2-3 weeks)	During Instruction October-December 1987 (9-10 weeks)	After Instruction January 1988 (2-3 weeks)	
Data:		quality of task engagement		R.Q. 1
		interpretation of classroom tasks		R.Q. 2-a
	content understanding	progress in scientific understanding	content understanding	R.Q. 2-b R.Q. 3
	goal orientations in science class		goal orientations in science class	R.Q. 2-c R.Q. 3
	affective orientations toward science		affective orientations toward science	R.Q. 2-d R.Q. 3
Methods:	formal (clinical) interview	classroom observation and informal conversation during class activity	formal (clinical) interview	

Classroom observation schedules. The study developed schedules for classroom observations on the basis of the structure and sequence of lesson content and class activities in the "Matter and Molecules" curriculum unit. This unit consists of nine lesson clusters (abbreviated as L.C.), each dealing with a key science concept (see the list on page). Each lesson cluster contains three or four lessons, each one designed to last approximately one class period. Based on the structure of the curriculum unit, it was decided to observe each target student at least once in each lesson cluster. Further, the study used event sampling to observe various aspects representing the quality of students' task engagement for a meaningful segment of time.

The unit of observation was *class activities* during instruction. According to the curriculum unit's organization, there were generally three class activities contained in each lesson (e.g., reading – writing – class discussion, or reading – experiment – class discussion). It was predicted that three students could be observed in one lesson, one during each class activity, and the researcher selected the activities and lessons for observation accordingly. Based on the importance of dealing with lesson content and the high frequency of appearance, the study design first identified four major class activities: (a) reading the text, (b) writing answers in the activity book, (c) hands-on experimentation, and (d) class discussion. Then, to facilitate observation of all six target students in a classroom during a lesson cluster, the researcher chose two lessons from each lesson cluster, using the criteria of: (a) main ideas of the lesson cluster; and (b) similar class activities. The final observation schedule included a total of 18 lessons from the entire unit, each containing some combinations of the above four class activities.

During classroom observations, an observer focused on one student during one class activity, another student during the next class activity, and so on. The observation of one target student lasted between 10 and 20 minutes, on average about 15 minutes. To produce comparable data across students, the study arranged observation schedules so that every student was observed the same number of times during each of the four class activities across the nine lesson clusters. This procedure also produced the result that each student was observed for an approximately equal amount of time in total. Considering the possibilities for unexpected student absences or changes in teaching schedules, observation decisions were made before each visit.

The final observation schedules in the two classrooms are shown in Table 4.2. Each student was observed 10 or 11 times throughout the entire unit, totaling 130 observations in this study. Although 18 lessons were originally decided, actual classroom observations included 20 lessons. The changes were to adapt to modifications or unexpected class activities, differing from the structure of the curriculum unit. For example, when one lesson lasted for more than one class period, the observer continued observation the following day until the lesson was completed. Some lessons lasted for less than a class period. There were occasionally quizzes or presentation of films, which

Table 4.2

Classroom Observation Schedule

	Classroom 1:				Classroom 2:			
Activity L.C.	Read	Writ	Exp	Disc	Read	Writ	Exp	Disc
1.3	5			1.2	4.1.3	6		5.2
1.4	4	3		6				3.4.5
2.1	1	4		2.5	5.6			2
2.2		5		6.3.4				
3.1	2		6	2.5	2		1	3
3.3			3	4.1.5			4	6.2
4.2			1.3	4		5	3	1.6.3
4.3	6	6.2			6	4		
5.1	3		2.4	5			2.1	5.3.1
5.2			5	1.6		2	4	5.6
6.3	1	4	6.3	3			3.6	1
6.4		3	5.2.4		5	4	1	2
7.1					3	1		2.6
7.2				6.4				
7.3	1	5.2		3	4	5		4
8.1	3	6.2		4.1	2	1		4.3.5.6
8.2	5		1		5	3	6	4
9.1	2			1.4.5	1.6			
9.2					2.4			3.5
9.3		1		6.3		2		4

Total Number of Observations: 130

Classroom 1:
student #11: 11
student #12: 10
student #13: 11
student #14: 11
student #15: 11
student #16: 11

Classroom 2:
student #21: 10
student #22: 11
student #23: 11
student #24: 12
student #25: 11
student #26: 11

were not included as data sources in this study. When some activities continued longer than 20 minutes, the observer shifted attention to the next student.

Specific questions guiding classroom observations. After setting up the overall observation schedules, the researcher designed specific questions guiding classroom observations and informal conversations during class activities in advance, in order to collect systematic data across students. Different sets of specific questions were developed for each of the four class activities (see Appendix A). To examine the quality of students' task engagement in specific situations, the observers focused on two aspects: (a) behavioral engagement; and (b) cognitive engagement.

Data collection for behavioral engagement was rather easy in terms of students' observable behavior. The measures involved students' attentiveness in class and involvement in class activities. Major indicators of behavioral engagement included: (a) on- or off-task behavior, (b) completion of assigned tasks, (c) pace of task completion, (d) reactions to distractions, and (e) frequency of participation during whole class activities.

Because the focus of this study was on the quality of cognitive engagement, the observers paid particular attention to students' cognitive processes. The measures involved the two criteria of scientific understanding: integration of personal and scientific knowledge and application of scientific knowledge for scientific functions. Major indicators of cognitive engagement included: (a) help-seeking or sources of students' answers (e.g., copying from the text or other students, or independent work), (b) quality of students' answers (e.g., key vocabulary words, definitions, collection of facts, scientific knowledge), and (c) relevance of students' comments or questions to the content being taught (e.g., irrelevant, request for clarification, elaboration on someone's answers or comments, cognition going beyond lesson content).

Data sources and collection procedures. Each classroom visit yielded a set of observational data in narrative records, describing what the target students did and which instructional events occurred. Systematic procedures for data collection (to be described below) and specific questions to attend to (as described above) produced a semi-structured approach for qualitative, descriptive data collection.

Since two observers collected date in each of the two classrooms, comparability of data collection between the two observers was assured. Before the study, both observers practiced together for two lesson periods, once in each classroom. During the early stage of data collection, they exchanged observation notes and checked each other's notes with reference to the specific guiding questions for data collection. Throughout the data collection period, the two observers continued to check each other's notes occasionally, looking for completeness and consistency of data collection.

To examine the quality of students' task engagement., observers used four data collection procedures from different sources of data. With the first procedure, each observer kept narrative records of target students, focusing on one student during a single class activity. Attending to specific guiding questions, the observer recorded information, as complete as possible, about the focused student at that time. Throughout the class time, the observers noted significant events with any of the six target students in that classroom, even though this student might not be the current focus of observation, as long as that did not detract the observer's attention from the focusd student. For example, one observer noticed that a target student not currently the focus of observation was working on her mathematics assignment under her desk without being detected by the teacher for a significant amount of the class period. Observers recorded every lesson on audio tape to insure accurate data, and transcribed target students' responses during class discourse after each visit

For the second procedure, the observers engaged in informal conversations with target students. To examine the quality of cognitive engagement in specific task situations, observers asked target students specific questions, chosen before each lesson cluster, which covered the major concepts in that lesson. Observers conducted their informal conversations mainly during the individual or small group activities (i.e., writing or experimentation); they rarely gained access to target during whole-class activities (i.e., reading or class discussion). Informal conversations were also recorded, on a portable tape-recorder carried by the observer; they were transcribed after each visit.

Constraints in classroom settings limited opportunities for informal conversations with target students . This was especially problematic in Classroom 2, where the teacher allocated most of the class time for whole-class activities. Even during individual or small group activities, this teacher maintained tight control over the students. For this reason, informal conversations in Classroom 2 often occurred after class periods.

The third data collection procedure involved written information from the students.in their activity books and tests. After a reading assignment or experiment, students answered a set of questions in the activity books. At the end of each lesson cluster, they responded to review questions in their activity books. The target students' answers in the activity books were collecte.

Finally, observers kept brief descriptions of instructional events and content. These provided contexts for student responses during class. Observers noted which teaching strategies seemed to be effective, especially those from the teachers' own ideas rather than the teacher's guides. They also noted what went wrong during class or what failed to help students with their learning difficulties, such as, when the teachers failed to address critical students' misconceptions in class or clarify students' conceptual conflicts and confusions during discussion. Further, every lesson was tape-recorded in order to complete any missing data the observer failed to record during class. Each observer placed a second tape-recorder in front of the classroom to record instructional events and content, and selectively transcribed the content of instruction after each visit.

Obervers also recorded other relevant information in their observation notes. They noted the lesson cluster and lesson (e.g., L.C. 7.2 indicates the second lesson in Lesson Cluster 7), type of class activity (i.e., one of the four class activities), student code (e.g., #25 designates target student #5 in classroom 2), and passage of time. After each visit, the observers completed the day's notes, filling in information missed during class and briefly summarizing target students' responses for the day. They sometimes recorded impressions, emerging hypotheses, and other unplanned observations as well.

2. Factors Related to Patterns of Task Engagement (R.Q. 2)

For each of the four factors examined in this study, three main issues will be discussed: (1) data sources, (b) data collection procedures, and (3) specific questions guiding data collection.

a. Students' interpretations of classroom tasks (R.Q. 2-a)

Whenever observers found an opportune time to interact with their target students, they asked the students specific content questions (for Research Question 1) and then continued the conversations to inquire about their interpretations of the nature of classroom tasks they were currently engaged in. Specific questions guiding data collection were developed in advance for each of the four class activities (see Appendix A). First, the observer asked target students about how they understood the content objectives. The observer provided no feedback to students even when their understanding was inaccurate. Second, the observer asked the students about how they experienced the difficulty of the classroom tasks and why they felt so.

Since data could be obtained only through informal conversations with students, the opportunities occurred during individual or small group activities (i.e., writing or experimentation) in which the observer could gain access to students. In Classroom 2, where class time was spent mostly on whole-class activities, the observer often had to arrange for informal conversations with target students after class periods.

b. Progress in scientific understanding (R.Q. 2-b)

Data for students' progress in scientific understanding were collected through the entire span of the study: (a) prior to instruction of the unit, (b) over the period of unit instruction, and (c) after completion of instruction. Prior to and after instruction of the "Matter and Molecules" unit, the interviewers (who were also the classroom observers) conducted clinical interviews with each of the target students with regard to his/her understanding of aspects of matter and molecules. Over the period of instruction, the observers collected data from several sources, that could render the assessment of students' success or failure in scientific understanding in specific task situations.

Content understanding before and after unit instruction. Interviewers asked each of the 12 target students about aspects of matter and molecules, using the clinical interview protocol developed by the Science Achievement Project (see Appendix B, see Lee et al., 1989 for details). Interviewers used the clinical interview method (Codd, 1981; Posner & Gertzog, 1982), originally developed by Piaget and extensively applied in research on conceptual change, to examine the nature and extent of students' knowledge about aspects of matter and molecules. The method is highly flexible, allowing an interviewer to probe a person's knowledge structure in a content domain while the person speaks freely. The method is also effective for distinguishing the extent of conceptual understanding from factual knowledge (Finley, 1986; Roth, 1985; Stepans, Beiswenger & Dyche, 1986).

The development of the clinical interview protocol was based on a tasks by conceptions chart for kinetic molecular theory. The protocol included five major tasks: (a) the nature of matter and its three states, (b) expansion and compression of gases, (c) changes of state, (d) dissolving, and (e) thermal expansion. Each of these five tasks examined students' knowledge of matter and molecules at both the macroscopic level, (concerning observable properties of substances and physical changes) and at the molecular level (concerning properties of invisible molecules). Also, 19 major conceptions about aspects of matter and molecules were included: 8 conceptions at the macroscopic level and 11 conceptions at the molecular level.

Two interviewers completed the clinical interviews prior to and after unit instruction. Both were experienced in conducting clinical interviews, as they had worked extensively with the Science Achievement Project during the previous year, aiding in the development of the interview protocol, the implementation of clinical interviews, and the analysis of interview data. The two interviewers also followed standard procedures and decision rules to conduct clinical interviews. The interview protocol included both branch questions and main frame questions as means for responding to a variety of student responses and probing their reasoning.

Each interview took about a class period of 45 or 50 minutes with each targert student. During clinical interviews, the interviewers conducted hands-on experiments to represent natural phenomena to students (e.g., sugar dissolving, boiling water on a hot plate, melting ice cubes in a cup, evaporation of alcohol on a glass plate, condensation of water outside of a cold glass with ice cubes in it, etc.). The interviews were tape-recorded and later transcribed.

All the pre-instruction interviews in both classrooms took place about a week before instruction of the "Matter and Molecules" unit began. The post-instruction interviews started about two weeks after unit instruction (a delay due to Christmas vacation). This delay provided an opportunity to examine students' understanding of kinetic molecular theory at a long-range term, not easily amenable to memory effect immediately after unit instruction.

Progress in scientific understanding over the period of unit instruction. Various sources of data provided information for examining students' success or failure to achieve scientific understanding in specific task situations over the period of instruction. First, the observer engaged in informal conversations with target students during class activities (or after class periods in Classroom 2). To probe target students' understanding of the content being taught, the observer asked each of them specific content questions which had been formulated before beginning each lesson cluster. Second, verbatim student responses during class discourse were recorded in observation notes. Third, students' conversations with the teacher individually or with other students in small groups were also recorded as much as possible. Finally, students' answers in their activity books were collected. During classroom observations, the observer paid particular attention to whether target students copied answers from the textbook or other students.

c. Students' goal orientations in science class (R.Q. 2-c)

To understand students' goal orientations in science class, interviewers conducted formal interviews with target students prior to instruction of the unit. (The interviews were conducted again after unit instruction as part of the data for R.Q. 3.) These interviews were separate from the clinical interviews concerning content understanding that had already been completed.

A structured interview protocol was developed for the present study (see Appendix C). The protocol contained several important features to facilitate examination of the issues addressed in the study. First, the interview protocol included several opening questions concerning students' understanding of the nature of science and science learning. This was to elicit whether students were aware of the structural and functional components of scientific understanding.

Second, the protocol specified as many as 13 goals in science class. This specification of goals was designed as an exhaustive list of possible student goals in science class. Students would also be able to understand these specified goals more meaningfully than broadly defined goals. For example, the generic goal of *learning* was divided into four different kinds of learning, including acquisition of vocabulary words and definitions, memorization of facts, mastery of scientific conceptions, and use of scientific knowledge for scientific functions.

Third, the protocol consisted of four short sets of questions, each dealing with student goals from four different perspectives: (a) myself, (b) a good science student, (c) a science teacher, and (d) a scientist. These question sets examined students' perceptions of their goals in relation to various aspects of science and science learning: (a) the goals that the students perceived they were actually trying to achieve (i.e., from one's own perspective); (b) those they perceived as achievable, regardless of whether they personally tried or not (i.e., from the perspective of a good science student); (c) those they perceived as important in science class (i.e., from the perspective of a science teacher); and (d) those they perceived as the nature of science and science learning (i.e., from the perspective of a scientist).

Fourth, students' responses to these four sets of questions would also reflect external influences on their goals in science class. An additional set of questions from the perspective of parents was originally considered, although it was not included in the final interview protocol for several reasons. According to the results of pilot testing for the present study, most students perceived that their parents wanted them to get good grades as the first priority. Also, students' perceptions of their parents' expectations seemed to reflect student goals in school in general, not specifically in science class. In contrast, the four sets of questions in the final protocol were all closely related to aspects of science, science learning, and science class.

Finally, to understand how student goals were hierarchically organized into a goal structure, students were asked to rate each goal on a five-point scale. After completing ratings on each of the four question sets, students were asked to report three primary goals in order and explain why they responded in the way they did.

Since social desirability response tendencies pose a problem in self-reports, the interviewers tried to minimize this concern by informing target students in advance that their responses would be kept confidential, particularly from their teachers and parents. To avoid the problem of superficiality in student responses, the interviewers probed students about their underlying reasoning. The interviewers also asked students to be honest in their responses, so that they could be representative of other sixth graders in the school district. During the interviews, students seemed to be serious and enthusiastic in expressing their thoughts and feelings in response to questions.

All the interviews were conducted by the two interviewers outside the two classrooms, respectively. To ascertain consistency between the two interviewers, each followed the guidelines and questions in the interview protocol. Each interview took 20–25 minutes, including the time spent for the first part of the interview for R.Q. 2-d concerning students' affective orientations toward science. This allowed for two students in one classroom to be interviewed during a class period. The interviews were tape-recorded and later transcribed. The two nterviewers completed all the pre-instruction interviews in both classrooms several days before instruction of the unit. The post-instruction interviews started about a month after completion of unit instruction (i.e., two weeks for Christmas vacation and another two weeks for clinical interviews).

d. Students' Affective Orientations Toward Science (R.Q. 2-d)

To understand students' attitudes and interest, formal interviews were conducted prior to instruction of the unit. (The interviews were conducted again as part of the data for R.Q. 3.) A structured interview protocol was developed for the present study (see Appendix C).

Each interview began with the interviewer explaining to the students the purpose of interviewing. Then, the interviewer asked students an opening question concerning their general affective orientations toward science. After this opening, the interviewer presented to the students a set of three questions about attitudes (i.e., like or dislike), interest (i.e., interested or bored), and curiosity (i.e., curious or do not care to learn about science). These questions were modified from the questionnaire on intrinsic versus extrinsic motivation in the classroom developed by Harter (1980, 1981)

Using a sample question, the interviewer demonstrated to students how to respond to these questions. For each of the three questions, students rated themselves on a four-point scale that was designed to reduce social desirability response tendencies (Harter, 1980, 1981). After students finished answering the questions, the interviewer asked them to explain why they responded in the way they did. This explored the nature of students' affective orientations.

Because the affective orientation interviews were conducted at the same time as those concerning students' goal orientations in science class (R.Q. 2-c), the procedure used was identical to that for the student goal interviews.

3. Achievement after Unit Instruction and Changes in Students' Goal Orientations and Affective Orientations (R.Q. 3).

This question examined whether achievement of scientific understanding after completion of unit instruction was related to changes in students' goal orientations in science class and affective orientations toward science. For this purpose, several sources of data were required: (1) achievement of scientific understanding after unit instruction; (2) students' goal orientations in science class prior to and after instruction; and (3) students' attitudes toward and interest in science prior to and after instruction. Sources of data as well as data collection procedures had already been discussed for Research Questions 2-b, 2-c, and 2-d.

Data Analysis Procedures

Two main issues of data analysis will be discussed. The discussion of a general approach in data analysis will emphasize how this approach differs from the conventional hypothesis testing approach and how this approach attempts to establish objectivity based on empirical and theoretical evidence. Second, specific procedures in data analysis for each of the research questions will be discussed.

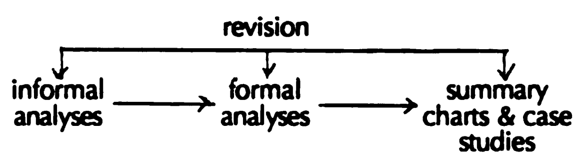
General approach in data analysis

The purpose of data analysis in this study was to construct a theoretically and empirically defensible account of the data. The data analysis approach used here had two distinct features differing from the conventional hypothesis testing approach. First, unlike the pre-planned procedures for data analyses in the hypothesis testing approach, this was a post-hoc procedure. Analytical frameworks for the research questions emerged or became apparent as data analyses proceeded. Second, instead of using the pre-planned coding systems of the hypothesis testing approach to guard for objectivity, the approach in this study combined both informal analyses (i.e., observers' intuitive reasoning) and formal analyses (i.e., coding systems using ratings or frequency counts).

This approach, however, did not consist simply of ad hoc descriptions. Although the process of analysis involved intuitive reasoning and post-hoc theory development, an attempt was made to establish systematicity and objectivity in the final analysis according to the following criteria:

1. The accounts should be theoretically coherent and grounded in the literature;
2. It should produce accounts of student behavior and cognition that are systematic across students, across occasions of observation, and across data sources; and
3. The relationship between observable student behavior and covert cognitive and/or affective processes should be clearly specified.

The data analysis process involved three main stages: (a) informal analyses based on the observers' intuitive reasoning from a thorough reading of data, (b) formal analyses based on coding systems using ratings or frequency counts; and (c) development of summary charts and case studies. This three-stage process took more than one cycle (i.e., revision) until the final summary charts and case studies were formalized.



First, during the stage of informal analyses, the readers (who were also classroom observers/interviewers) read the entire data set thoroughly for individual students. When the readers became familiar with students' characteristics with regard to the research question to be examined, they informally classified individual students into groups based on common patterns among students in the same group but distinct contrasts across students of different groups. This classification was conducted on the basis of the readers' intuitive reasoning from their in-depth understanding of students. At the same time, the readers also identified key issues that seemed to serve as the basis for a formal classification system. These issues should be theoretically coherent and grounded in the literature. Thus, this first stage of data analyses combined the readers' intuitive reasoning with theoretical and empirical rationale.

Second, for more formal analyses, coding systems were developed on the basis of the key issues identified for each research question. Using ratings or frequency counts in the coding systems, systematic analyses of data across students, across occasions of observation, and across data sources were conducted. In this way, the original, informal classification was validated by more objective evidence. The final classification system was based on the results of consistency or inconsistency between the informal and more formal classification. Then, students were classified into new categories.

Finally, based on the results using the new classification, summary charts were developed. The summary charts, which were organized under the key issues for each research question, featured common patterns among students in the same category and distinct contrasts across students of different categories. The summary charts also specified the relationship between behavioral, cognitive, and affective variables.

Further, case studies were developed, which best represented characteristics of students in a category and which were well supported by a sufficient data base. The case studies provided detailed, rich descriptions of students' characteristics in the category that were concisely presented in the summary charts.

Data analysis for each research question

Within the framework of a general approach in data analysis, specific procedures were developed to analyze the data for each research question.

1. Patterns of task engagement (R.Q. 1)

The entire data set for the 12 target students across the nine lesson clusters included a total of 130 episodes, each including narratives of students' behavior and cognitive responses during class activities, transcripts of informal conversations, and student answers in the activity book.

Theoretical rationale and the observers' intuitive reasoning after thorough readings of student data identified three key aspects of students' task engagement. First, *self-initiated cognitive engagement* occurred when students explained their thinking or expressed ideas that were not solicited by the teachers but revealed cognition going beyond lesson content. On their own initiative, students actively constructed their own knowledge as they tried to integrate their personal knowledge with scientific knowledge and apply scientific knowledge to understand and explain the world around them. Second, *cognitive engagement* occurred when students, within the scope of the lesson content being taught in class, tried to integrate their personal knowledge with scientific knowledge and produce scientific descriptions and explanations of natural phenomena. Finally, *behavioral engagement* occurred when students were attentive and involved in class activities, such as listening to the teacher or other students during class discussion, not talking to others inappropriately, and following the teacher's directions.

The coding system, which incorporated states of existence, ambiguity, and non-existence for each of the three aspects of task engagement, included seven categories:

Category 1: (a) existence of self-initiated cognitive engagement,
(b) existence of cognitive engagement, and
(c) existence of behavioral engagement;

Category 2: (a) existence of cognitive engagement, and
(b) existence of behavioral engagement;

Category 3: (a) ambiguity of cognitive engagement, and
(b) existence of behavioral engagement;

Category 4: (a) non-existence of cognitive engagement, and
(b) existence of behavioral engagement;

Category 5: (a) ambiguity of cognitive engagement, and
(b) non-existence of behavioral engagement;

Category 6: (a) non-existence of cognitive engagement, and
(b) non-existence of behavioral engagement;

Category 7: (a) non-existence of cognitive engagement, and
(b) disruptive behavior . .

There are several points to be clarified regarding the coding system. First, existence of self-initiated cognitive engagement occurred only for Category 1. Second, a possible combination of (a) existence of cognitive engagement and (b) non-existence of behavioral engagement was not included in the coding system, as this occurred only once out of 130 episodes. Third, ambiguity of behavioral engagement was not included;

the assessment of behavioral engagement was generally clear. Also, eliminating this category made the coding system more manageable. Finally, the assessment of cognitive engagement was not always clear and recorded as *ambiguity* for various reasons: no student response during class discussion; no answers in the activity book; no opportunity for the observer to interact with students during class activities; and ambiguous or irrelevant response during class discourse or in the activity book.

Each episode was the unit of analysis. The episode was analyzed as representing one of the seven coding categories based on the overall quality of students' task engagement described in an that episode. To examine general patterns of students' task engagement across task situations, the results of assessment in specific task situations were aggregated over the period of instruction.

Two coders (who were also the observers/interviewers) completed the data analyses. After practicing with a sample of episodes, the two worked independently. The reliability between the two coders was 81%; the remaining 19% of disagreements involved mostly differences within two bordering categories (e.g., Category 2 or 3) or occasionally the assessment of behavioral engagement (e.g., Category 3 or 5). These disagreements were resolved through discussion between the two coders.

2. Factors related to patterns of task engagement (R.Q. 2)

a. Students' interpretations of classroom tasks (R.Q. 2-a)

Due to the constraints in classroom settings (especially in Classroom 2), the two interviewers could collect data only in a total of 33 cases of informal conversations with target students. Student reports of the content objectives were coded as representing one of three categories: (a) adequate, (b) moderately adequate, and (c) vague. Students' responses were assessed as *adequate* when they demonstrated understanding of the content objectives intended in the curriculum unit; *moderately adequate* when they showed partial understanding of the curricular objectives; and *vague* when they did not seem to understand the curricular objectives.

In a similar manner, student reports of perceived task difficulty were coded as representing one of three categories: (a) easy, (b) medium (i.e., not easy but not difficult), and (c) difficult. The analysis of student responses was straightforward. The data were analyzed by two coders. Because of the small number of cases, reliability between the two coders was not obtained. The two coders showed overall a high rate of agreements. Occasional disagreements were resolved through discussion between the two coders.

b. Progress in Scientific Understanding (R.Q. 2-b)

The data set for students' progress in scientific understanding included: (a) clinical interviews concerning content understanding before and after instruction of the unit and (b) achievement of scientific understanding in specific task situations over the period of instruction. Students' actual performance before, during, and after unit instruction was the basis for developing profiles of progress in scientific understanding for individual students. The list of scientific goal conceptions as opposed to common students' misconceptions for each of the 19 conceptions was the basis for the assessment of student performance (see Appendix D).

Analysis of clinical interviews. The data set included a total of 24 clinical interviews, i.e., pre- and post-instruction interviews for each of the 12 target students. Student responses were analyzed using the tasks by conceptions chart for kinetic molecular theory. Two steps were involved in data analysis: (a) analysis of student responses for each task and (b) assessment of student performance for each conception.

The tasks-by-conceptions chart identifies several scientific conceptions that are particularly important and likely to be problematic for students for each particular task. The chart indicates them with blank cells (see Appendix E). Students' responses for each of these conceptions represented one of the following categories: (a) scientific goal conception, (b) partial understanding of scientific conception, (c) misconception, or (d) ambiguous responses Thee judgments were recordedin each of the blank cells for this particular task in the chart. The analyses of students' responses continued for all the tasks included in the clinical interviews.

After completing the analyses for all the tasks, the coders assessed each student's performance for each conception, based on the results of assessment across several relevant tasks, as representing one of the four categories: (a) scientific goal conceptions, indicating adequate understanding of the scientific conception across several tasks; (b) mixed responses, indicating a mixture of scientific conceptions for some tasks and misconceptions for other tasks; (c) commitment to misconceptions; and (d) ambiguous responses, including irrelevant responses, inconclusive data, or "I don't know" responses. The final data analysis tallied students' performance for all the 19 conceptions for the relative frequency of the four coding categories.

The data analysis was completed by two coders, one interviewer, and a staff member from the Science Achievement Project. Through involvement in various phases of the Project, both coders had extensive knowledge of students' misconceptions as well as scientific conceptions about aspects of matter and molecules. Based on the system of four coding categories, decisions of agreement between the two coders included four sets: G-G (Goal conception), N-N (Naive conception), M-M (Mixed response), and A-A (Ambiguous response). All the other possible combinations were decided as disagreements. The reliability coefficient of agreement between the two coders was 88%.

Assessment of scientific understanding in specific task situations. The data set included a total of 130 episodes, each including student responses during class discourse, informal conversations with students during class activities, and student answers in the activity book. The extent of students' scientific understanding in specific task situations was assessed as representing one of three categories: (a) success in achieving scientific understanding, (b) failure to achieve scientific understanding, and (c) ambiguity or inconclusive data. The assessment *ambiguity or inconclusive data* was made for various reasons, such as no student responses during class discourse, no answers in the activity book, no informal conversations during class activities, or ambiguous or irrelevant responses during class discourse or in the activity book.

To examine general patterns of progress in scientific understanding across task situations, the results of assessment in specific task situations were aggregated over the period of unit instruction. The data were analyzed by two coders (the same observers/interviewers); the reliability between the two was 85%.

c. Students' goal orientations in science class (R.Q. 2-c)

The data set included 24 formal pre- and post-instruction interviews for each of the 12 target students. The data were analyzed using ratings and analyses of verbal reports.

First, the 13 specific goals in the interview protocol were grouped into six goal clusters:

Cluster 1: Understanding
- (a) use science to understand the world
- (b) have scientifically correct ideas

Cluster 2: Fact acquisition
- (a) learn vocabulary and definitions
- (b) memorize facts and information

Cluster 3: Performance in class
- (a) get work done on time
- (b) do well in class activities
- (c) get good grades
- (d) do better than other students

Cluster 4: Expectations of others
- (a) please my parents
- (b) please my teacher
- (c) show that I am a smart person

Cluster 5: Extrinsic rewards
- (a) receive rewards from parents (e.g., extra money or gifts)

Cluster 6: Task avoidance
- (a) do as little work as possible

Then, three primary goals on each of the four question sets (i.e., from four different perspectives) were analyzed into relevant goal clusters. Some students reported three primary goals that represented three different goal clusters, while others reported two of their primary goals belonging to the same goal cluster. The results of students' goal clusters from the four perspectives (i.e., myself, good science student, science teacher, and scientist) were aggregated as a summary chart. Finally, students' reports were analyzed to examine their perceptions of the nature of science and science learning and whether they understood the structural and functional components of scientific understanding.

d. Students' affective orientations toward science (R.Q. 2-d)

The data set included 24 formal pre- and post-instruction interviews for each of the 12 target students. The data were analyzed using numerical scales and analyses of verbal reports. The scales for each of the three affective orientations (i.e., attitude, interest, and curiosity) included: +2 and +1 (positive) and –1 and –2 (negative). Further, students' verbal reports were analyzed to examine the nature of their affective orientations toward science.

3. Achievement after Unit Instruction and Changes in Students' Goal Orientations and Affective Orientations (Research Question 3).

The entire data set for each student included two sets, one before and one after unit instruction, of: (a) clinical interviews concerning content understanding about aspects of matter and molecules, (b) formal interviews concerning students' goal orientations in science class, and (c) formal interviews concerning affective orientations toward science.

With regard to students' goal orientations, he study examined the relationship between achievement and changes in student goals by simultaneously comparing the extent of content understanding after unit instruction, on one hand, and changes in goal orientations after instruction as compared to before instruction, on the other hand. The focus was on changes in students' perceptions of (a) the nature of science and science learning and (b) the goal of understanding in science class. In a similar manner, the relationship between achievement and changes in affective orientation toward science was examined. The focus involved changes in the nature of students' affective orientations toward science. The final analysis examined changes in students' goal orientations and changes in affective orientations for any systematic relationship.

CHAPTER FIVE

FINDINGS AND DISCUSSION

This chapter describes research findings for each of the three research questions addressed in the study. The descriptions involve common characteristics among students of the same category but distinctive differences from students of other categories. Also, exceptional cases are noted. Following the description of the findings for the research questions is a discussion of those findings from the perspectives of the student motivation and conceptual change in science research traditions (discussed in Chapter 2). The discussion addresses the question of whether issues of student motivation in science classrooms can be explained in terms of motivational variables of students or their content knowledge in science.

Patterns of Students' Task Engagement (R.Q. 1)

Research Question 1 examined patterns of task engagement in science classrooms in order to answer the question: What types of goals do students try to achieve and which strategies do they activate while engaging in science classrooms tasks? The quality of students' task engagement was used as the measure which incorporated three key aspects of students' task engagement: (a) self-initiated cognitive engagement, (b) cognitive engagement, and (c) behavioral engagement.

Ratings of the quality of task engagement in each task situation for individual students across the nine lesson clusters (L.C.) of the "Matter and Molecules" unit are shown in Table 5.1. Results of ratings across the 12 students in the study are grouped into six categories:

Category 1 represents students who demonstrated self-initiated cognitive engagement in many task situations by expanding their thinking beyond the lesson content being

Table 5.1

Ratings of the Quality of Students' Task Engagement

	L.C./Student	1	2	3	4	5	6	7	8	9	Mean Rating
1	#11 (Ken)	1	2	1.1	1	2	2	2	1	2	1.5
	#21 (Jason)	1	x	2	1	1.1	2.1	1	1	1	1.2
2	#13 (Sara)	3	4	2	2	5	4.3.2	3	2	2	2.9
	#14 (Dan)	4	3.2	2	2	3	2.2	3	2	2	2.5
	#22 (Ann)	2	1	3.2	x	2.2	2	3	2	3.2	2.2
	#25 (Maria)	2.2	2	x	2	2.3	2	4	2.4	2	2.5
3	#16 (Neil)	6	1	1	1.2	6	2	5	1	1	2.6
4	#24 (Sean)	2.2	x	3	2	5	2	4.4	3.3	4.3	3.5
5	#12 (Thea)	5	6	4	4	4	2	6	4.6	3.6	4.5
	#15 (Lin)	2	6	5.6	x	6.2	2	6	6	4	4.4
	#26 (Kim)	2	6	5	4.2	5	6	2	6.5	4	4.3
6	#23 (Nora)	2.4	x	6	7.6	5	6	6	7.6	7	5.6

*Six students (#11 through #16) were from Classroom 1; the other six (#21 through #26) were from Classroom 2.

**The mark, x, indicates that data were not available.

***Table 5.1 can be understood in connection with Table 5.4 presenting the results of students' actual chievement of scientific understanding in specific task situations over the period of unit instruction taught. They were also attentive and actively involved in class activities. The quality of their task engagement is indicated by the high frequency of Scale 1 (i.e., existence of self-initiated cognitive engagement and existence of behavioral engagement) of the 7-coding system in Table 5.1.

Category 2 represents students who demonstrated cognitive engagement in classroom tasks, although their thinking was limited to the lesson content actually being taught. They were also attentive and actively involved in class activities. Unlike those in Category 1, however, these students did not demonstrate any thinking going beyond the lesson content. The quality of their task engagement is indicated by the majority of Scale 2 (i.e., existence of cognitive engagement and existence of behavioral engagement).

Category 3 represents a student who demonstrated self-initiated cognitive engagement in some task situations in which he was intrinsically interested, but was not even attentive in other task situations. Thus, the quality of his task engagement seemed to depend on his intrinsic motivation, which was inconsistent across task situations. This is indicated by the combination of Scale 1 (i.e., existence of self-initiated cognitive engagement and existence of behavioral engagement) and Scale 6 (i.e., non-existence of cognitive engagement and non-existence of behavioral engagement).

Category 4 represents a student who appeared attentive and involved in class activities, but was not really engaged in classroom tasks cognitively. The quality of task engagement is indicated by Scale 4 (i.e., non-existence of cognitive engagement and existence of behavioral engagement) and Scale 3 (i.e., ambiguity of cognitive engagement and existence of behavioral engagement).

Category 5 represents students who were often inattentive or uninvolved in class activities as well as not cognitively engaged in classroom tasks. The quality of their task engagement is indicated by Scale 6 (i.e., non-existence of cognitive engagement and non-existence of behavioral engagement) and Scale 5 (i.e., ambiguity of cognitive engagement and non-existence of behavioral engagement).

Finally, Category 6 represents a student who demonstrated disruptive behavior in class and active resistance to engaging in classroom tasks. This student was not engaged in classroom tasks either behaviorally or cognitively. The quality of her task engagement is indicated by Scale 7 (i.e., non-existence of cognitive engagement and disruptive behavior) and Scale 6 (i.e., non-existence of cognitive engagement and non-existence of behavioral engagement).

Based on the results shown in Table 5.1, six patterns of students' task engagement in terms of their choice of goals and strategies are summarized in Table 5.2:

Table 5.2

Patterns of Students' Task Engagement

Pattern	Goals		Strategies	
		Self-initiated cognitive engagement	Cognitive engagement	Behavioral engagement
1.	Intrinsically motivated to learn science	yes	yes	yes
2.	Motivated to learn science	no	yes	yes
3.	Intrinsically motivated, but inconsistent	yes sometimes	yes sometimes	no sometimes
4.	Task completion	no	no	yes
5.	Work avoidance	no	no	no
6.	Disruptive behavior	no	no	no & active resistance

Several points regarding the nature of the goals and strategies in Table 5.2 need to be made clear before describing the major characteristics of each pattern of task engagement,. First, these goals and strategies are based on observations of the quality of students' task engagement, rather than on the students' self-reports of their goals and strategies during task engagement.

Second, goals and strategies are not clearly distinguishable from each other. Students with a particular goal activated strategies associated with the achievement of this goal. Thus, goals and strategies are inextricably related (Brophy, 1983, 1987).

Third, causal independence between goals and strategies may be artificial (Vallacher & Wegner, 1987; Wegner & Vallacher, 1986). Instead of setting the goal and subsequently selecting strategies to achieve this goal, students often may choose a goal in an attempt to identify a particular course of action after the action or, at best, concurrently with the action. Conversely, the relationship of goals to stragegies may be cyclical, rather than unidirectional in either way.

Fourth, students did not engage in task situations with any particular goal or strategies consistently; rather, they varied in their choice of goals and strategies for different task situations. Even students across different types of motivation shared some common characteristics, which was especially true for students in adjacent categories. Yet, distinctive patterns of goals and strategies across different types of student motivation seemed to emerge.

Finally, the measure of student motivation involves the process of learning during task engagement rather than later performance. Assessment of student achievement in scientific understanding was not considered here; it was reserved for Research Question 2-b, which addresses students' progress in scientific understanding.

As a result of the small sample size (12 students) in the present study, there was only one student for three of the six patterns of task engagement (Patterns 3, 4 and 6). Despite a great caution to interpret research findings based on only one case, it was decided to maintain these three patterns, as the one student in each pattern demonstrated distinctive differences from those of the other patterns of task engagement.

A detailed account of major characteristics for each pattern of task engagement follows. The discussion focuses on two issues: (a) goals and strategies during task engagement for each pattern and (b) distinctive differences across patterns of task engagement. Specific examples are provided.

Pattern 1: Intrinsically Motivated to Learn Science

Self-initiated cognitive engagement distinguishes the two students in this category from those in all the other categories. Without solicitation by the teachers, these students initiated thinking which was relevant to the content being taught and went beyond the lesson content. They seemed to engage in classroom tasks primarily because they wanted to learn science. They seemed to find classroom tasks intrinsically enjoyable and take satisfaction in expanding and increasing their scientific understanding. The modifier, *intrinsically*, denotes that the students seemed to display a general disposition of motivation to learn science.

Their intrinsic motivation to learn science was uniquely different from other patterns of task engagement. On their own initiative, the students actively constructed their own knowledge as they tried to integrate personal knowledge with scientific knowledge. They also took initiative in engaging in scientific functions of describing, explaining and predicting natural phenomena. Their self-initiation in cognitive engagement not only satisfied their own desire to learn science, but also contributed to class discussion and helped other students in the class expand their thinking.

While engaging in classroom tasks, these students demonstrated various learning strategies, indicating their intrinsic motivation to learn science. *They seemed to be inquisitive about understanding and explaining natural phenomena.* In their effort to explain novel events that had not been discussed in class, they extended the lesson content to relate to their prior knowledge or personal experience. For example, both Ken (#11) and Jason (#21) in two different classrooms asked similar questions in several task contexts. There was an occasion in each classroom when the teacher explained to the class that evaporation occurs without heating, as opposed to a prevalent student misconception that evaporation requires a heat source. Jason in Classroom 2 asked the teacher, "Can it (water) evaporate even when it's below freezing?" In Classroom 1, the teacher was setting up a solar still on his desk as a demonstration activity for evaporation and condensation of water. Ken asked, "What will happen if you set it up in snow? You can get pure liquid out of snow .... Even it's ice, evaporation is still coming out of ice."

On another occasion, the lesson designed to help students explain that exhaled air contains more carbon dioxide than normal air involved students in hands-on experimentation. They breathed into bromothymol blue (BTB) solution and observed the solution changing from blue into yellow (as a result of the increased presence of carbon dioxide). After the experiment, both Ken in Classroom 1 and Jason in Classroom 2 asked whether it was possible to change BTB yellow back to the original BTB blue. This question expanded the lesson content, leading to class discussion about the molecular bondage between a liquid (BTB solution) and a gas (carbon dioxide). Students in both classes reached the conclusion (and later observed) that if they left BTB blue with carbon dioxide in it for a while, the carbon dioxide would escape from the solution and BTB yellow would turn back to the original blue color.

On still another occasion, Ken and Jason used the idea of magnet attraction to explain properties of molecules. In Classroom 1, when the teacher was explaining that molecules are constantly moving and that there is empty space between molecules, Ken responded, "It is like the feel of pressure, like two of the same magnets. They don't go together. I was wondering about what the force is." When the teacher in Classroom 2 was explaining about attraction between molecules, Jason suggested a magnet attracting a paper clip as an analogy.

The Pattern 1 students seemed to think about science outside science class and expanded class activities to connect to their science experiences outside class. For instance, students in Classroom 2 were engaged in hands-on experimentation on dissolving, using sugar as an example. Jason commented in class that he was currently growing sugar crystals on a paper clip at home. He had watched the activity on a TV science program and decided to try it himself. When the teacher in Classroom 2 was explaining that every substance has its own unique freezing or melting temperature, Jason urged the teacher to explain his question from the previous day, "I asked you a question yesterday and you said you'd know by the end of the day. If you put whiskey in a freezer, why doesn't it freeze?" The teacher responded to Jason that they would get to that issue in the day's lesson.

The students fought for their ideas until they convinced the teacher of their ideas or were themselves convinced by the teacher's explanations. For example, to a quiz question asking whether there is anything (e.g., air or water) between the molecules of liquid water (Lesson Cluster 1 introducing molecules), Jason responded, "No. Water molecules are the liquid water itself." The teacher gave a half-credit for this answer. In the following lesson period, Jason asked the teacher in class about the half-credit. He said, "I know that there is nothing between the molecules. Water is the water molecules." The teacher responded that he knew what Jason was saying. However, since it was the beginning of the unit, the teacher wanted students to be more accurate and exact in their answers. Only students who gave answers explicitly in terms of empty space received a full credit, but Jason's answer deserved a half-credit. Jason stopped his argument with the teacher.

The students paid close attention to the content being taught in class and pointed out mistakes, ambiguities, or places for further elaboration in the textbook or the teachers' explanations. For example, one question in the activity book asked students to draw the molecules of air before and after air was compressed in a syringe (Lesson Cluster 4 on compression and expansion of air). Then, the next question asked students to draw the molecules of air on a high mountain as opposed to those in a scuba tank. During class discussion, Jason commented that compared to the molecules of air on a high mountain, the molecules of the non-compressed air in the syringe (i.e., normal state of air) should be closer together. He explained that he drew more molecules (9 molecules) for the non-compressed air in the syringe, compared to the number of molecules of air on the high mountain (6 molecules). His answers indicate that Jason had integrated the two apparently separate but conceptually related questions.

The students frequently worked ahead of the rest of the class in class activities. They often used this extra time to check or elaborate their answers in the activity book, listen to teacher explanations or other students' answers during discussion, or help other students during hands-on experiments. However, this caused minor problems for Jason; he was reminded by the teacher several times to engage in certain activities as the rest of the class or not to talk to his neighbors when he was helping them with their answers. In response, Jason sometimes asked the teacher for permission to move on to the next activity ahead of the class.

Pattern 2: Motivated to Learn Science

The students in this category engaged in classroom tasks with the goal of achieving scientific understanding and activated strategies associated with the accomplishment of their goal. While engaging in classroom tasks, they tried to integrate personal knowledge with scientific knowledge and use scientific knowledge to describe, explain, predict ,and control natural phenomena. They often displayed a state of motivation to learn science in specific task situations.

Although the students of both Patterns 1 and 2 were motivated to learn science, there was one critical difference. Compared to the students of Pattern 1 task engagement, the students of Pattern 2 rarely showed evidence of self-initiated cognitive engagement. Instead, their cognitive engagement existed within the lesson content being taught. It was not clear, at least based on classroom observations and informal interviews during class, whether they found classroom tasks intrinsically enjoyable or whether they engaged in classroom tasks primarily because they wanted to learn science. In other words, although they often displayed a state of motivation to learn science in specific task situations, they did not demonstrate a general disposition of motivation to learn science.

The quality of their task engagement revealed that the students activated strategies to achieve the goal of scientific understanding in specific task situations. It should be noted that most of these strategies (to be described below) were also shared by the students of

Pattern 1. On the other hand, the kinds of strategies demonstrated by the students of Pattern 1 (described above) were not observed with the students of Pattern 2 task engagement.

The students tried to integrate their personal knowledge with the scientific knowledge being taught. In the process of undergoing conceptual change, they recognized their misconceptions and tried to modify these misconceptions into scientific conceptions. The following example shows how Sara changed her misconception into a scientific conception and also illustrates her awareness of the process of her conceptual change learning. During Lesson Cluster 1 on three states of water, the teacher introduced a scientific conception of "empty space between molecules" and emphasized to the class that there is nothing but empty space between molecules of water. Sara failed to understand the scientific conception, as indicated in her answer to the observer:

Sara: There is water around water molecules .... There is nothing between molecules because molecules are all bunched and close together.

In Lesson Cluster 3 on the molecular composition of air, Sara was still confused about the scientific conception of empty space between molecules:

O (Observer): What do you think is between the molecules?
Sara: There is air in between them.
O: Do you think there is air in between them?
Sara: Well, something is in between them. There is space between them.
O: Is the space filled with anything or is it empty?
Sara: Air molecules. No, air without molecules.
O: So there is space between molecules, and in the space there is air?
Sara: Air without molecules .... There is space between the molecules. So it's really air space.

During the study on compression and expansion of air in Lesson Cluster 4, Sara finally demonstrated an understanding of the scientific conception:

O: What is between the molecules (of air)?
Sara: There is just space between them.
O: Is the space empty or is there anything in the space?
Sara: Well, there is like smoke in the air. But there is just space, nothing between the molecules.
O: So is it empty?
Sara: Yeah.
O: Do you remember your answer a while ago when I asked you the same question?

Sara: I think I said water or something.
O: So you have changed your idea now?
Sara: Yeah. A lot

The students displayed several patterns of task engagement, suggesting *their effort to engage in scientific functions of describing, explaining, predicting, and controling natural phenomena.* In classroom environments in which the teacher encouraged students to express their thinking, these students were usually among the first to volunteer explanations in class discussion. They also tried to make complete, although not always accurate, explanations in the activity book or during class discussion. The teacher, in turn, provided feedback to correct their confusions, elaborate their answers, or promote further understanding.

For example, an question in the activity book asked students to explain how ice melts: Molecules break out of their rigid pattern when ice is warmed up. Ann was among the first to raise her hand and volunteer to give her answer in class. She provided an explanation in terms of molecular arrangements and movements during changes of states, "The molecules are moving farther apart and vibrating and then they move into another pattern." This answer, however, indicated that she was confused about the movements of molecules in liquids as opposed to solids. As feedback to the answer, the teacher tried to correct her confusion by probing her reasoning, saying, "Moving farther apart and vibrating sound opposite to me," and "In which state do molecules vibrate?" Ann later changed *vibrating* in her original answer into *moving faster.* Clearly, active participation in class discussion helped Ann develop a better understanding of scientific conceptions.

These students *actively sought help from the teacher or the textbook in order to resolve learning difficulties or enhance their scientific understanding.* They often expressed to the teacher in class, "I don't understand what you just said (or a question in the activity book)" and asked the teacher for clarification or further explanation. In the following example, Maria had difficulty understanding how smell reaches her nose. To resolve her learning difficulty, Maria asked the teacher to explain it again:

Maria: I don't understand that. How does that happen?
Teacher: When perfume dries up, where does it go?
Maria: Into the air.
Teacher: Right, the molecules go into the air. . .

During individual class activities, such as conducting hands-on experiments or working on questions in the activity book, the students sometimes asked the teacher individually to check their ideas or answers. For instance, while students in Classroom 2 were working independently on a question about water cycle in the activity book, Ann finished her answer, then approached the teacher for verification of her answer.

The students were attentive in class and actively involved in class activities. They demonstrated several unique patterns of behavioral engagement, which also seemed to indicate the quality of their cognitive engagement. For example, they sometimes used a finger or a pencil to point in the textbook as they followed reading aloud in class. They sometimes reread sections of the textbook which the class had just finished reading aloud. They usually completed answers in the activity book before class discussion started, instead of waiting for other students to give their answers fist. They generally kept pace with the rest of the class or were slightly ahead.

Pattern 3: Intrinsically Motivated but Inconsistent

The quality of task engagement of the one student in this category suggests that he was engaged in classroom tasks to satisfy his intrinsic motivation, although his engagement was inconsistent across different task situations. In those classroom tasks that he found interesting, this student demonstrated his own initiative in cognitive engagement. He successfully integrated his personal knowledge with scientific knowledge and applied new, scientific knowledge to explain natural phenomena. In tasks that he did not find interesting, however, he was inattentive in class or uninvolved in class activities. The quality of his task engagement seemed to depend on his intrinsic interest across task situations.

The quality of task engagement in this category showed both similarities to and demonstrated self-initiated cognitive engagement in certain tasks and engaged in those tasks primarily because he was intrinsically motivated. Unlike the students of Patterns 1 and 2, however, he was not consistently engaged in classroom tasks with the goal of achieving scientific understanding. Further, he was not even attentive or involved in several task situations.

Three characteristics of task engagement seemed to emerge across the different task situations. *In task situations which the student found interesting, he seemed to engage in those tasks primarily because he wanted to learn science.* For example, the first lesson in Lesson Cluster 3 was designed to help students understand that air is a form of matter that has certain definite properties, such as occupying space. Students in Classroom 1 engaged in discussion about whether air is something or nothing. The teacher introduced the hands-on experiment for the day, which involved blowing air through a hose into a cup placed upside down in a container of water and then sucking the air out of the cup. Then, the teacher said, "If you ride a boat, and the boat overturns..." Neil suddenly interrupted the teacher and commented in class, "Oh, that's right! You can breathe inside the boat underneath. We did that riding a row boat. We went underneath and there is air you can breathe around the seats." His comment led to adiscussion on air pockets in a boat as a source of evidence that air is something and takes up space. Further, the teacher emphasized that it is important to understand scientific knowledge for practical reasons in daily life, citing Neil's example that people can survive if they know the scientific principle of an air pocket in an overtunred boat. Later, Neil was actively involved in the experiment, leading the activity for his group members.

Neil also seemed intrinsically interested in evaporation (L.C. 8) and condensation (L.C. 9). During the first lesson in Lesson Cluster 8, the teacher introduced evaporation and engaged the class in a discussion. Neil made two brief comments during class discussion, suggesting his interest in the concept as well as his understanding of scientific conceptions. After class discussion, the teacher told the class to work on the questions in the activity book in small groups. Neil and his group called the observer for help to answer the question, "If you want your towel to dry out quickly after you have used it, should you leave the bathroom door open or closed? Why?" Neil tried to convince the other group members of his idea, "I think you should leave it open because that way humidity or whatever can get out of the bathroom. In the bathroom, after you take a shower, humidity is always inside the bathroom. The mirror is all fogged up. When you open the door it starts to clean up." One group member asked Neil how one knew that the towel was wet. Neil responded, "It is a bathroom!" The group finally agreed with Neil's idea.

In contrast to his interest and cognitive engagement in some classroom tasks, however, *the student was neither attentive nor involved in other task situations.* Instead, he played with things (e.g., pencil or rubber eraser), talked quietly to his neighbors, looked around or smiled at other students, and did not volunteer to answer or make comments in class. For example, the observer noticed that Neil and two of his group members were not involved in a hands-on experiment on dissolving of sugar in Lesson Cluster 5 (although Neil was not one of the three target students for the day). Near the end of the class period, the observer approached Neil and his group:

O: May I take a look at your answers?
Neil: That's OK, you don't have to.
O: Let me help you.
Neil: Help X (pointing at one of his group members). He needs help. (Then, he went away from the observer.)
Member X: They (including Neil) didn't do it, either. So, you better call them back, too.

Immediately after this conversation, the class was over and Neil left the room. The observer later noticed that Neil answered some of the questions mindlessly and left the others unanswered in his activity book. In the following class period, while the class discussed the results of the experiment from the previous day, Neil was not attentive and did not engage in class discussion.

The quality of his task engagement seemed to depend on his interest or enjoyment in certain task situations, rather than being guided by the goal of achieving scientific *understanding*. Compared to the students of Types 1 and 2 motivation who tried to achieve their goal of scientific understanding, Neil seemed to be more concerned whether or not he enjoyed certain tasks or activities. For example, Neil commented to the observer several times on what parts he liked in the unit and why he liked them. While the class was studying evaporation, Neil told the observer, "The water, that was fun. Like when we turn the water into the water vapor and back into the water again." Neil also commented, "I think this (condensation) is my favorite one...Because it is fun, like trying to build the solar thing."

Although Neil repeatedly said that "it's fun when we get to do experiments," he experienced some activities "not fun." During the experiment on the expansion and compression of air (L.C. 4) in which he was interested and also cognitively engaged, he told the observer, "I like the experiment. But I don't like writing on the (activity) book." In fact, despite the teacher's continual reminders to the class to complete the questions in the activity book, Neil did not finish some parts of his activity book and left them unanswered.

If the quality of Neil's task engagement depended on his interest, what caused his interest in certain situations and lack of interest in others? Although the findings do not provide a clear answer, he seemed to be interested in hands-on experiments or topics of class discussion that he could relate to his prior knowledge or experience and were, therefore, personally meaningful to him (Floden & Buchman, 1984). In contrast, he seemed to dislike activities that required sustained effort, such as writing answers in the activity book. The quality of Neil's task engagement poses an interesting question about what triggered his interest inconsistently across classroom task situations.

Pattern 4: Task Completion

The one student in this category seemed to be concerned about completing classroom work, not necessarily with scientific understanding, and activated strategies that allowed him to achieve his goal of task completion. This student generally appeared attentive in class and involved in class activities. In contrast to his seeming behavioral engagement, however, the student failed to demonstrate cognitive engagement. Thus, rather than expending effort to try to achieve scientific understanding, he settled for the goal of meeting the minimum requirements generally accepted in classroom settings, i.e., completion of classroom work.

The quality of his task engagement displayed major differences from the previous patterns of task engagement. Unlike the students of Patterns 1 and 2, this student was not cognitively engaged in many task situations, although he seemed to be attentive and involved in class activities. Further, unlike the students of Patterns 1 and 3, he did not show any evidence of self-initiated cognitive engagement or interest in classroom tasks. Thus, the quality of his task engagement would be described as "failure in cognitive engagement, although success in behavioral engagement" (Peterson & Swing, 1982).

While engaging in science classroom tasks, *the student relied on his prior knowledge, although incorrect, instead of trying to connect scientific knowledge to his prior knowledge.* Thus, he often failed to recognize his misconceptions or conceptual conflicts. In the following example, the observer asked Sean to explain evaporation (L.C. 8) at the end of a class period:

O: We were talking about evaporation in your class today. What do you mean when we say the air is humid? What does that mean to you?
Sean: We got a lot of water vapor in it, in the air.
O: OK. Is the air always humid? Is there always the same amount of water vapor in the air?
Sean: No...
O: When you use the word evaporate, what do you mean by that?
Sean: It means, uh, it's changing to the air, going to the air.
O: So when we say water evaporates, what happens?
Sean: Water will break up, water will go into the air, change into the air.
O: It will change into the air?
Sean: Yeah.
O: So, water will become air? Is that what you mean?
Sean: Yeah.

This conversation shows that Sean was not cognitively engaged. By the time the students were studying evaporation later in the unit, they had already studied the conservation of matter and the nature of air several times throughout the unit. Yet, Sean failed to connect the content taught earlier in the unit with the content being taught presently. Further, even during the conversation, Sean gave inconsistent responses. He responded in the beginning that there is water vapor in the air (i.e., air contains water vapor); but he later said that liquid water becomes air. Eventually, Sean relied completely on his incorrect prior knowledge and maintained his initial misconceptions even after instruction.

The student was not actively engaged in those class activities that provided opportunities to promote scientific understanding. Sean did not participate in class discussion, although students were strongly encouraged to provide their explanations in class and, subsequently, receive feedback and help from the teacher. Nor was Sean among the first group of students who volunteered to give their answers in class. Instead, he usually waited until after other students provided and then started to raise his hand. In fact, since Sean was not active in class discussion, the teacher called on him to check his understanding more often than Sean volunteering to provide his explanations or seeking help for his learning difficulties from the teacher.

Although generally attentive, the student occasionally did not pay attention in class or participate in class activities. For example, when the class engaged in a hands-on experiment on dissolving of sugar, he teacher forgot to assign Sean to a group. While other students were engaged in the experiment in small groups, Sean just sat at his desk and, then, moved into one group. Instead of taking part in the group activity, he just stood apart and looked around the other groups until the end of the activity (all this took place for about 4 minutes). Sean sometimes did not answer questions in the activity book, even when the teacher told the class to do so, but waited until class discussion started. When Sean finished classroom work earlier than the rest of the class, he just sat back at his desk and waited, looking at the teacher or his neighbors, until the class started the work together.

Pattern 5: Task Avoidance

The quality of task engagement of the students in this category showed that they avoided engaging in classroom work. They were not cognitively engaged in classroom tasks. Further, they were not even attentive or involved in class activities. They seemed to be mainly concerned about getting the work done with a minimum of effort.

The quality of their task engagement showed distinctive differences from the previous four Patterns. Unlike the students of Patterns 1 and 2, these students were not engaged in classroom tasks with the goal of achieving scientific understanding. Unlike those of Patterns 1 and 3, they did not demonstrate any initiative in cognitive engagement. Even unlike the student of Pattern 4, these students were evidently not attentive or involved in class activities.

The students used various strategies to minimize their effort in completing classroom work. In the following example, Kim made no effort to engage in the classroom task and, yet, successfully completed the work by copying her neighbor's answer. This example also shows how the quality of Kim's task engagement differed markedly from that of her group partner Maria (Pattern 2 engagement). The teacher in Classroom 2 told the class to work in small groups on a question about evaporation (L.C. 8) in the activity book:

> (Bonus question) (a) Evaporation occurs when fast moving water molecules escape from liquid water and leave the slower-moving molecules behind. What do you think happens to the temperature of the liquid water?

While the observer was watching the group activity, each of the four group members showed different reactions: One student believed that the temperature would go down; another student insisted that the temperature would stay the same; Maria was not sure, although she seemed to think that the temperature would go down; and Kim had not yet made any comments. At this moment, the observer took part in the group conversation:

O: You have very different ideas. Some students say that the temperature will go up, and some say it will go down. You say that it will stay the same, right?

Student 1: I think it will stay the same, because if you take the cup outside, it is going to turn to that temperature. It will stay the same as it evaporates.

(While Student 1 was responding to the observer, Kim talked to Maria briefly about a school event and said that one of her friends needed a black skirt for that occasion.)

Kim (to Maria): Do you have a black skirt that she can borrow?
Maria: Come on. We are thinking about science today. Just answer the question.
O (toward Maria): What do you think?
Maria: I think it will go—. Evaporation occurs when fast-moving—, so it has to go up, because molecules move when it is hot. Catch my drift?
O: But there is something you learned in the last lesson. If you have a cup of water, are all the molecules of water moving at the same speed?
Student 1: No, it can go higher or lower, and it will evaporate.
Maria: Yeah.
O: If you have molecules moving at different speeds in the same cup of water, which ones are the ones that are going to evaporate?
Student 2: The ones at the higher speed.
Maria: Because—.
Kim (interrupted): So the temperature would go higher.
O: When the fast-moving molecules leave?
Maria: There will be two different kinds of molecules in the water. They move at different speeds. They are not in a rigid pattern, they are moving around freely.
Student 2: The temperature will go down.
Kim: It will go down. I will put it down. I like it.
Student 2: Because the fast-moving molecules go away, leaving the slow-moving molecules to stay behind. So the temperature will go down.
Kim (toward Student 2): What are you writing?
(Kim copied Student 2's answer in her activity book.)
Student 2: We are not supposed to copy....
O: Do you think that is right what he (Student 2) said? Do you agree with what he said?
Maria: Just a little.
O: Do you think his answer makes sense?
Maria: Yeah.
Kim: Yeah.

Following the group activity, the class engaged in discussion. Kim was called on by the teacher to give her answer in class. She said, "The temperature will go down, because the fast-moving molecules leave the slow-moving molecules behind." The teacher praised her, "Excellent! A very good answer."

This example illustrates several characteristics of Kim's task engagement. First, Kim was not actively involved in the group activity; her participation in class activities was generally minimal. To encourage Kim to participate more in class, the teacher praised her for any indication of good performance, as evidenced in the above example. Second, without thinking, Kim impulsively accepted another student's idea and copied his answer (perhaps partially because Student 2 was a good science student in class). This is a significant contrast to the case of Maria, who was struggling with her idea. Third, Kim was imore nterested in social matters than engaging in the academic activity. Maria, in contrast, urged Kim to engage in the task. Finally, the nature of Kim's task engagement suggested her passive attitude during task engagement. Kim rarely seemed to ask herself whether or not something made sense to her. Further, she did not seek help from the teacher in class or individually.

The students avoided, even when provided with opportunities, engaging in scientific activities in class. They rarely volunteered to give their explanations in class discussion. Instead, the teachers encouraged them to be more active in class participation. When called on by the teachers to give their explanations in class, they often responded, "I don't know."

When guided by the teachers with prompts or probing questions, however, they could provide adequate, scientific explanations. For example, after the hands-on experiment using BTB blue solution, students engaged in discussion about why the original blue color changed into yellow. The teacher called on Kim to give her answer in class:

Kim: It shows that there is CO_2 in the air.
Teacher: Which air are you talking about, air you breathe in or breathe out?
Kim: Air going in.
Teacher: What about air going out?
Kim: None. I don't know.
Teacher: What do you think causes the solution to turn color?
Kim: The CO_2 in your breath when you breathe out.
Teacher: That's very good. You do know. . .

In several other occasions, Kim showed inconsistencies or even contradictions in her answer. For example, to examine the difference between compression of air (gas) as opposed to water (liquid), students performed individual hands-on experiments which involved pushing a syringe filled with air and then with water. While Kim was working at her desk, the observer engaged in a conversation with her. Kim told the observer that she could compress the water in the syringe (which is incorrect), as she could the air in it. Kim explained that there was no difference between what happened with air and water (i.e., she could compress water as well as air in the syringe). Upon hearing this conversation, her neighbor interrupted and said that there was a difference in the results. Right after, the class engaged in discussion, and the teacher called on Kim to give her answer. Contrary to what she told the observer, Kim answered that the plunger in the syringe did not move at all with air in it, just like it did not move with water in it. She put down in her activity book, "I wasn't able to push it (air) at all."

Thea and Lin in Classroom 1 were relatively more active in class participation than Kim. When Thea and Lin sometimes made comments in class, their responses were based on personal experiences irrelevant to the content being taught in class. For example, to explain the different arrangements and movements of molecules in three states of matter, the teacher used rock salt as an example. Thea raised her hand and made a comment in class, "We saw in the fourth grade. We went to Chicago and picked up rock salts." While Thea was commenting, Lin kept her hand raised until being called on by the teacher, "My sister collects rocks, and she has some of it."

Of the three students of Pattern 5, Lin was the only one who sometimes volunteered to give her answers in class. Even on those occasions, Lin relied on her common-sense explanations, rather than trying to use scientific knowledge being taught in class. For example, one of the questions in the activity book asked students to explain, "Bonus question (b): Why does your head get cold if you go outside without drying your hair?" (L.C. 8). The teacher had already explained evaporation in terms of molecules, and the class jhad ust finished discussing a similar question (Bonus question ([a], described earlier). Further, the teacher reminded the class to think about the idea of individual fast-moving molecules. While the teacher was talking, Lin kept her hand raised until being called on. Lin responded, "I say that when you dry your hair and walk out of the bathroom, you are not used to dry air. You were used to humid air. It makes you feel cold because you used to be warm."

A most critical aspect of students' task engagement involves *their lack of attention or* *involvement in class activities, which also suggests their failure to engage cognitively.* For example, although quiet, Kim did not pay attention in class. Instead, she had an empty gaze, looked around the room, focused outside the window, or played with things. Thea constantly moved at her desk, looked around, or quietly talked to her neighbors. In three lesson periods over the course of this study, Lin worked extensively on her mathematics assignments under her desk without being detected by the teacher. On several other occasions, Lin drew pictures, wrote on sheets of paper, put her head down on the desk, or talked to her neighbors. She was admonished by the teacher several times to pay attention in class, with such remarks as, "I guess you haven't paid attention for 10 minutes."

The students also failed to follow the instructions or directions in class activities, and did not complete their work as did the rest of the class. For example, despite the teacher demanded that the class finish questions in the activity book before engaging in class discussion, Kim usually waited until class discussion started. Lin failed to follow procedures during several experiments, although the teacher provided specific directions before the experiments or the instruction in the activity book was fairly easy to follow. Lin sometimes did not engage in classroom tasks with the rest of the class, so by the time the teacher told the class to finish their work, she had barely started it. Further, she left the questions in her activity book unanswered.

Pattern 6: Disruptive Behavior

The one student in this category displayed two major patterns of task engagement: active task avoidance and disruptive behavior. Compared to the less obvious task avoidance by the students of Pattern 5, this student actively avoided engaging in classroom tasks or participating in class activities. She also seemed to resist engaging in classroom tasks, and often displayed disruptive behavior or disciplinary problems in class.

The student actively avoided engaging in classroom tasks. For example, students in Classroom 2 had finished a hands-on experiment on how to dissolve sugar faster. When called on by the teacher to give her answer during class discussion, Nora provided a very elaborate, scientific explanation. However, it turned out that she copied the answer from the textbook. On two other occasions, when called on by the teacher to give her answers in class, she started reading her answers in her activity book for the questions that had already been discussed in class. For instance, Nora started reading her answer, "Paper towel", then stopped and asked her neighbor, "Which question am I supposed to answer?" Her neighbor pointed to her that she should answer the next question. On another occasion, the teacher, while walking around the room during class discussion, pointed out to Nora that she was on a wrong page.

The student seemed to resist engaging in classroom tasks. While walking around the room, the teacher passed by Nora and reached to pick up her activity book to read the answer for her in class (as the teacher sometimes did for other students). Nora suddenly grabbed her activity book, refused to let the teacher read her answer, and hid her book behind her back. On another occasion, during class discussion and a hands-on experiment on thermal expansion of liquids using a thermometer as an example, Nora was playing with her thermometer instead of writing her answers in her activity book or engaging in discussion. At one point, she put her hand on the bulb of the thermometer for a while, although both the activity book (in an underlined passage) and the teacher stressed to the class before the experiment that this was not to be done. Noticing her behavior, the teacher reminded Nora, "I want to talk to you because you are holding the bulb." On still another occasion when the teacher was explaining water cycle, Maria (Pattern 2) insisted to the teacher that when water evaporates, it starts from the ocean and goes up. The teacher tried to correct Maria's confusion, explaining that the water cycle starts from anywhere there is water, not necessarily from the ocean. Looking at Maria, Nora sarcastically commented, "Just believe it, Maria."

The student often displayed disruptive behavior or disciplinary problems in class. The teacher told her to change her seat during class, because she was disrupting her neighbors and not attending to class discussion. The teacher also required her to remain after class several times because of her disciplinary problems. In one class period, Nora was talking to her neighbor and not involved in class activities. When instructed to pay attention, Nora excused her problem by accusing her neighbor, saying that this neighbor kept asking her for the answers in the activity book. On two occasions, Nora made faces at the teacher behind his back while he was writing on the blackboard. Several other times, Nora disrupted the class in a more subtle manner, by yawning or coughing loudly, reading her answer in class loudly and quickly, or making faces at other students.

Summary: Patterns of Task Engagement in Science Classrooms

The study identified six patterns of students' task engagement. Students across different patterns engaged in classroom tasks with different goals and activated different qualities of cognitive or behavioral engagement.

Patterns 1 and 2 task engagement represent students who engaged in classroom tasks with the goal of achieving scientific understanding, as they tried to integrate scientific knowledge with personal knowledge and apply scientific knowledge to describe, explain, predict, and control the world around them. The two patterns, however, differed in one major aspect. The students of Pattern 1 seemed to be motivated to learn science as a general disposition; they found classroom tasks intrinsically enjoyable and interesting. In comparison, the students of Pattern 2 often displayed a state of motivation to learn science in specific task situations but failed to demonstrate a general disposition of motivation to learn science.

In contrast to the students of Patterns 1 and 2, the remaining students were not motivated to learn science while engaging in science classroom tasks. They settled for less than trying to achieve the goal of scientific understanding. The quality of task engagement by the student of Pattern 3 seemed to depend on his intrinsic interest which was inconsistent across different task situations, instead of being guided by the goal of achieving scientific understanding. The student of Pattern 4 seemed to be concerned with completing classroom work, not necessarily with scientific understanding. Although he generally appeared to be engaged, he was not cognitively engaged in many task situations. The students of Pattern 5 avoided engaging in classroom tasks and activated strategies that minimized their effort in getting done with classroom work. Finally, the student of Pattern 6 actively resisted engaging in classroom tasks altogether. This student often showed disruptive behavior and disciplinary problems in class.

Factors Related to Patterns of Task Engagement (R.Q. 2)

The second research question examines four key factors that seem to be related to patterns of students' task engagement: (a) students' interpretations of the nature of classroom tasks, (b) success or failure to make progress in scientific understanding, (c) students' goal orientations in science class, and (d) students' affective orientations toward science.

The descriptions of the findings proceed by examining how each of these factors is related to students' choice of goals and strategies during task engagement. In particular, the discussion examines whether each of these factors can distinguish students who are motivated to learn science from those who are not. After the descriptions of findings for each factor, those findings are discussed from the perspectives of two research traditions: (a) student motivation and (b) conceptual change in science.

To develop an extensive, complete profile of student characteristics for each pattern of task engagement across all the four factors, a detailed account of one student from each pattern is presented:

Pattern 1 engagement: Jason (#21)
Pattern 2 engagement: Sara (#13)
Pattern 3 engagement: Neil (#16)
Pattern 4 engagement: Sean (#24)
Pattern 5 engagement: Kim (#26)
Pattern 6 engagement: Nora (#23)

Two main criteria were used for the selection process: representativeness of the student for the particular pattern of task engagement and sufficient data for the student across all four factors:

Students' Interpretations of Classroom Tasks (R.Q. 2-a)

The first key factor concerns whether students' task engagement is related to the way they interpret the content objectives and difficulty of classroom tasks while (or, sometimes, after) engaging in those tasks. Do students who are motivated to learn science interpret academic tasks differently from those who are not motivated to learn science?

Four issues of research findings were examined. First, how did the students understand the content objectives of classroom tasks? Second, how did the students perceive difficulty of classroom tasks? Were they aware when they had learning difficulty and why they did so? Third, how did the students' subjective judgment of task difficulty compare with the observer's assessment of their actual achievement in that particular task situation? Finally, how were the students' interpretations of classroom tasks related to their goals and strategies during task engagement?

Table 5.3 presents a summary of three sources of data: (a) students' understanding of content objectives (i.e., accurate, moderate, or vague); (b) students' perceptions of task difficulty (i.e., difficult, medium, or easy); and (c) actual achievement of scientific understanding (i.e., success, ambiguous, or failure , to be discussed in detail for R.Q. 2-b). To examine the consistency (or inconsistency) between subjective task difficulty and actual achievement, data from these two sources are connected with dotted lines.

As shown in Table 5.3, the results suggest there were significant differences between students of the first three patterns and those of the remaining three patterns. The students of Patterns 1, 2 and 3 show common characteristics: (a) They generally had accurate understanding of the content objectives; (b) they were aware when they had learning difficulties, and why they did so; (c) their subjective judgment of task difficulty was consistent with the observer's assessment of their actual achievement; and (d) their interpretations of classroom tasks were related to the goal of scientific understanding and strategies during task engagement in those situations.

There seems to be, however, one significant difference among the students of the first patterns of task engagement. The students of Pattern 1 seemed stricter in their judgment of

Table 5.3

Students' Interpretations of the Nature of Science Classroom Tasks

		Understanding of content objective	Perception of task difficulty		Achievement of scientific understanding	Number of incidents
1.	Intrinsically motivated to lern science	accurate	easy medium difficult	— — —	success success ambiguous	6
2.	Motivated to learn science	accurate, occasionally moderate	easy medium difficult	— — —	success ambiguous/failure failure	10
3.	Intrinsically motivated, but inconsistent	accurate	easy difficult	— —	success failure	5
4.	Task completion	moderate vague	easy	—	success/failure	2
5.	Task avoidance	vague moderate accurate	easy medium difficult	— — —	failure/success failure failure	8
6.	Disruptive behavior	accurate	easy medium	— —	failure failure	2
Total						33

task difficulty than those of Patterns 2 and 3. When they perceived a certain task as medium (moderately difficult), they still achieved scientific understanding. Even when they perceived a certain task as difficult, they demonstrated partial understanding of scientific conceptions. In fact, when they perceived certain tasks as difficult or moderately difficult, those tasks tended to be inherently complicated (e.g., explaining dissolving or condensation). Thus, they seemed to be very sensitive when something did not completely make sense to them.

In contrast to the first three patterns of engagement, the students of the remaining three patterns (except Lin of Pattern 5) show a different set of common characteristics: (a) Their understanding of the content objectives was sometimes inaccurate or vague; (b) they were sometimes unaware of their learning difficulties; (c) their subjective judgment of task difficulty was sometimes inconsistent with the observer's assessment of actual achievement; and (d) their interpretations of classroom tasks were related to their goals, such as simply completing classroom work or trying to avoid the work, and the activation of strategies to achieve these goals.

Since two sets of common characteristics across the six patterns of task engagement seem apparent, discussion here will not exhaust findings for each pattern of engagement. Instead, four cases are presented. The first case, Jason (Pattern 1) ,represents accurate interpretations of classroom tasks by the students of Patterns 1, 2 and 3. Two cases, Sean (Pattern 4) and Kim (Pattern 5), represent different types of inaccurate interpretations of classroom tasks by the students of the last three patterns. The final case, Lin (Pattern 5), illustrates an exception to the two sets of common characteristics.

Case A: Accurate interpretations. Jason (of Pattern 1) usually had a good understanding of what the classroom tasks were intended to teach. For example, the class had just started Lesson Cluster 5 on dissolving of sugar in water: Molecules of water hit the grains of sugar and break off sugar molecules, and sugar molecules mix with the water molecules. When asked by the observer about the main idea of a hands-on experiment on dissolving, Jason responded, "Like if somebody asked you why is it dissolving, then you have an answer if you have known it."

Further, Jason was aware of his learning difficulties. When the observer asked him to explain how sugar in a tea bag dipped in a container of water dissolved in the water, Jason tried to apply his prior knowledge about properties of molecules (e.g., the arrangements and movements of molecules in different states of substances). Yet, he seemed to be confused:

Jason: Molecules of the water started mixing molecules of the sugar and escaping from the tea bag.
O: What do you mean, molecules of water started mixing with molecules of sugar? Do you have any idea how that happens?
Jason: Sort of like the movie said. I didn't include as much as the movie said. Umm. The molecules—There was almost the same—It was just—Umm. The sugar molecules started—I can't say—Umm. They started sliding and bumping past each other, like they started taking the same action as the

water movement.
O: What makes them start doing that?
Jason: The movement of the water molecules are different than the solid of the grains. The movement of water molecules mixes the movement of sugar. Instead of the movement, the molecules themselves try to break them up.

The observer continued the conversation, asking Jason whether he experienced the task as easy or difficult, and why:

O: Did you think these questions (in the activity book) were hard to answer?
Jason: Difficult, yeah.
O: Why were they hard for you?
Jason: I couldn't just gather my thoughts. I couldn't think, you know. It is pretty confusing, sort of. Umm. It was sort of hard.
O: Cause the material, the stuff you are learning was hard?
Jason: No. The stuff that I am learning, it's interesting, you know. And it is sort of fun being and science and stuff, but it wasn't hard at all. It was difficult, difficult.

Thus, Jason's subjective judgment of task difficulty was consistent with the observer's assessment of his actual performance. As Jason expressed that the task was difficult for him, he had not constructed a complete scientific explanation for dissolving, although his explanation included some components of scientific conceptions (e.g., molecules breaking up or mixing). In contrast, when he perceived certain tasks as easy, he achieved scientific understanding in those situations.

Finally, Jason's interpretations of classroom tasks seemed related to his choice of goal and strategies during task engagement. Even when he experienced certain tasks as difficult, he expended sustained effort to achieve the goal of scientific understanding. For example, in the following lesson period, the class continued discussion of the questions in the activity book from the previous day. Jason frequently raised his hand to volunteer his answers, although he was not called on by the teacher. Before moving on to the next lesson, Jason finally had a chance to ask a question: "Like my pencil, why doesn't it dissolve? Molecules are hitting it, too." Jason's question indicated that he adequately understood scientific conceptions for dissolving. This question led the teacher to explain to the class that pencil and sugar are different substances and that their molecules behave differently.

Case B: Inaccurate interpretations. Sean (of Pattern 4) sometimes did not accurately interpret the content objectives of classroom tasks. For example, the teacher emphasized a new, complicated idea to the class that evaporation occurs when individual fast-moving molecules break away attraction of the other molecules and escape from the surface of a liquid (L.C. 8). During a conversation with the observer, Sean responded:

O: Why do you think you were studying this stuff today?
Sean: Because I think it was to refresh our memory, because people thought we knew it but people don't, and teach them.
(Note: Sean told the observer that he had studied evaporation in the fifth grade.)

Further, Sean failed to understand scientific conceptions for evaporation:

O: You talked about the water escaping from the towel today (a question in the activity book). Can you talk about that in terms of substance and molecules?
Sean: The substance is water, and the water on the towel. And then when there is not as much as humid, as humid, then they sort of escape and break. I mean the molecules sort of escape and break up and go to the air and evaporate.
O: When you say the molecules escape, what makes them escape?
Sean: Umm. They, probably because of evaporation?
O: OK. What do you mean by because of evaporation?
Sean: Like, sort of, evaporates on the towel, then it breaks off and then evaporates.

This example shows that Sean failed to construct a molecular explanation of evaporation. He repeated *escape* and *break up* without understanding how those ideas were related to the process of evaporation. He seemed to pick up these familiar expressions without trying to make sense of them in the context of scientific knowledge.

Nevertheless, Sean thought the task was not difficult for him:

O: Was this stuff new for you, what you were talking about today?
Sean: Um, no, not really.
O: Have you talked about evaporation before?
Sean: Yeah, in the fifth grade.
O: Did you? Was anything difficult for you?
Sean: No, not really.

Thus, Sean's subjective judgment of task difficulty was inconsistent with the observer's assessment of his actual achievement. Although Sean perceived the classroom task as rather easy, he did not understand scientific conceptions of evaporation.

Finally, Sean's interpretations of classroom tasks seemed to be related to his goal of task completion and choice of strategies during task engagement. As described above, Sean failed to understand the content objectives of classroom tasks. He interpreted the task based on his inaccurate or insufficient prior knowledge Since he thought that he already knew the content of the lesson, the task appeared rather easy to him and there was nothing new. While engaging in the tasks, Sean tried to complete the classroom tasks according to the way he interpreted them, which was not compatible with scientific understanding.

Case C: Inaccurate interpretations. Kim (of Pattern 5) usually failed to understand the content objectives of classroom tasks. For example, students engaged in a hands-on experiment in which they warmed up a cold soda bottle with a dime on the neck and observed the dime popping up and down (i.e., thermal expansion of air in L.C. 6). When asked by the observer to explain the objective of this activity, Kim did not respond:

O: Why do you think you did this activity today? What do you think the purpose of the activity was?
Kim: (pause)
O: You don't know? Any idea?
Kim: No.

Further, Kim could not explain why the dime popped up and down in the activity:

O: Can you tell me anything about molecules? What was happening to the molecules of air?
Kim: They were moving closer together, cause when you makesomething warm, when you heat something, the molecules get close together. So when you put your hands around it, the bottle got warm, so it caused the dime to jump up and down.
O: OK. You said that when you heat something, the molecules get closer together. I think it might be the other way around. When you heat something—
Kim: They move farther apart.
O: Anything else?
Kim: (pause)

Even when the observer tried to help Kim make scientific explanations, she almost refused (although covertly) to engage in the task:

O: Right. When you heat them, they start moving faster and they also start moving farther apart. When you cool something, that is when they start moving slow and get close together, too. OK? So, can you tell me what happened? Can you talk about molecules in your answer?
Kim: (pause)
O: No? What happened to the molecules of air when the air got warm?
Kim: (pause)

O: Do they move farther apart or close together?
Kim: They move farther apart.

Although the observer assured Kim that her explanation was incorrect, she said that the task was not difficult for her:

O: Did you find anything difficult about today's activity?
Kim: No.
O: Or the questions? Were the questions hard at all?
Kim: No.

Finally, Kim's interpretations of classroom tasks seemed to be related to her task engagement. She did not understand what the classroom tasks were intended to teach, and she was unaware of her learning difficulties. Yet, she expressed the opinion that the tasks were not difficult for her. She did not seek help from the teacher in class or individually. Instead, she tried to avoid engaging in classroom tasks and chose strategies that minimized her effort.

Exception: Lin's case. Unlike the students of Patterns 4, 5 and 6, Lin was usually aware when she had learning difficulties, and why she did so. Further, she sometimes accurately understood the content objectives of classroom tasks. In the face of tasks she perceived as difficult, she seemed easily discouraged or frustrated and quick to terminate task engagement.

For example, the class studied how substances melt or solidify (freeze) at different temperatures (L.C. 7). To explain this concept, the textbook told a story of taking a trip through a tunnel, "Adventure into the Hot Zone and Cold Zone." After the lesson, the teacher told the class to answer the questions in the activity book for the remaining of the class period (about fifteen minutes). About the end of the class period, Lin waived her hand to the observer:

Lin: I need help on this one (question 5). I don't understand the question.
Question 5: "How is freezing liquid oxygen like freezing water? How are they different?"

O: Think about the today's lesson. What was the lesson about today?
Lin: (pause)
O: What was the main idea of the lesson today?
Lin: It was about taking trips through tunnels.

O: OK. What were the trips about?
Lin: (pause)

Further, Lin could not formulate a scientific explanation for the question in the activity book:

O: What state is both liquid oxygen and water?
Lin: Liquid.
O: When you freeze liquids, how do they change?
Lin: They become ice.
O: Ice?
Lin: I mean, solid.
(Then, Lin started writing in her activity book, "They both become solids.")
Lin: I don't know how they are different.
O: Think about the temperature. What did you learn about temperature today?
Lin: I will write down, "I don't know." I am finished.
O: Wait. Do they become solids at the same temperature?
Lin: No.
(Then, Lin wrote down, "But at different temperature.")
Lin's answer to Question 5: "They both become solids. But at different temperature."

In the example above, Lin realized that she had difficulty answering a question in the activity book and sought help from the observer. Instead of engaging in cognitive strategies to overcome her learning difficulty, Lin tried to have the observer give the answer for her. Eventually, she got discouraged and terminated her engagement in the task. In several other occasions, Lin told the observer that she had difficulties carrying out experiments or answering questions in the activity book. However, she was not persistent in task engagement or not willing to put effort to achieve scientific understanding.

Summary and Discussion: Task Interpretations

The findings suggest two distinctive sets of common characteristics in students' interpretations of classroom tasks. Further, students' interpretations seemed to be related to their choice of goals and strategies during task engagement. Students who were motivated to learn science accurately understood the content objectives of classroom tasks and realized when they had learning difficulties. In contrast, those who were not motivated failed to understand the content objectives and did not realize their learning difficulties. Thus, accurate understanding of the content objectives and learning difficulties seems to be a critical factor for student motivation to learn science. When students do not know the problems that should be solved through scientific reasoning and monitor their learning difficulties, they do not expend high quality of effort to solve those problems and overcome their learning difficulties while engaging in classroom tasks.

Why did students display different characteristics of task interpretations? Research on conceptual change in science finds explanations in the scientific knowledge being taught. Jason and the other students of Patterns 1, 2 and 3 understood what the classroom tasks were designed to teach. They realized there were conceptual conflicts between their prior knowledge and the new, scientific knowledge and, thus, experienced difficulty understanding the scientific knowledge. In contrast, Sean and some other students of Patterns 4, 5 and 6 interpreted scientific knowledge based on their incorrect prior knowledge and, thus, did not realize there were conceptual conflicts or learning difficulties.

The conceptual change approach, however, does not seem sufficient to explain other characteristics of task interpretations. For instance, although Lin often interpreted the nature of classroom tasks adequately, she did not expend sustained effort to achieve scientific understanding. Kim did not even attempt to understand what the tasks were about in the first place. For these students, problems of task interpretations seemed to be attributed to motivational factors. According to research on student motivation, Lin's behavior seemed to indicate learned-helpless pattern of motivation, and Kim's behavior indicated her indifference to classroom work altogether or a defense mechanism.

Progress in Scientific Understanding (R.Q. 2-b)

A second factor of this investigation concerns how students' task engagement is related to their success or failure to make progress in scientific understanding. Do students who are motivated to learn science show different patterns of progress in scientific understanding than those who are not motivated to learn science? The discussion focuses on three aspects of students' progress in scientific understanding: (a) background knowledge in kinetic molecular theory prior to instruction of the "Matter and Molecules" unit; (b) progress in scientific understanding over the period of unit instruction; and (c) achievement of scientific understanding after unit instruction.

a. Students' background knowledge prior to unit instruction. To examine the degree of students' background knowledge prior to instruction, researcherrs conducted clinical interviews on aspects of matter and molecules. Of the 19 issues identified for kinetic molecular theory, the frequencies of students' conceptions representing each of the four categories are counted: (a) scientific understanding, (b) mixed response (partially scientific and partially misconceptions), (c) ambiguous respons, and (d) misconception. The results are summarized in Table 5.4, below:

Table 5.4

Students' Background Knowledge Prior to Unit Instruction

Pattern of engagement		scientific understanding	mixed response	ambiguous response	misconception
1.	Ken	3	7	3	6
	Jason	6	6	2	5
2.	Sara	0	0	0	19
	Dan	6	6	1	6
	Ann	1	4	4	10
	Maria	0	3	6	10
3.	Neil	1	3	0	15
4.	Sean	2	2	4	11
5.	Thea	0	2	3	14
	Lin	0	3	2	14
	Kim	1	2	6	10
6.	Nora	0	3	8	8

Prior to instruction of the unit, only three students seemed to have some understanding about aspects of matter and molecules. The sources of knowledge differed among the three students: Ken learned from a science TV program; Jason learned from his father who was an engineer; and Dan learned in elementary school. Although Thea (Pattern 5) studied about molecules in elementary school, her knowledge was grossly incorrect. The remaining students had almost no understanding about aspects of matter and molecules, or had not even heard of the term *molecules*.

Thus, students started instruction of the "Matter and Molecules" unit with varying degrees of background knowledge. In particular, the two students of Pattern 1 seemed to have greater amount of knowledge than the other students except Dan of Pattern 2. Interestingly, both students learned about molecules outside science class.

<u>b. Progress in scientific understanding over the period of instruction.</u> The results of student achievement of scientific understanding in specific task situations over the period of instruction are shown in Table 5.5, below. To assess student achievement in specific task situations, a 3-scale rating system was used: success (S), ambiguous (A), or failure (F) in scientific understanding. Then, overall assessment of student achievement for the entire unit is summarized in the last column.

TABLE 5.5

<u>Achievement of Scientific Understanding in Specific Task Situations Over Period of Unit Instruction</u>

Pattern	L.C. Student	1	2	3	4	5	6	7	8	9	Overall Assess-ment
1.	Ken	S	A	S..	S	S	S	S	S	S	consistent
	Jason	S	x	S	S	A.S.	S.S	S	S	S	success
2.	Sara	F	F	S	S	F	F.A.S	A	A	A	overall
	Dan	F	A.S	S	S	F	S.S	A	S	S	success
	Ann	S	S	A.S	x	A.S	S	A	S	S	
	Maria	F.A	S	x	S	F.F	F	F	F.F	F	*exception
3.	Neil	F	S	S	S.S	F	S	A	S	S	overall success
4.	Sean	S.F	x	S	S	A	S	F.F	F.F	F.A	mixture
5.	Thea	S	F	F	F	F	S	F	F.F	A.F	
	Lin	S	F	A.F	x	A.F	S	F	F	F	overall
	Kim	F	F	S	F.S	F	F	F	F.A	A	failure
6.	Nora	S.F	x	F	F.F	F	F	F	F.F	F	consistent failure

*Table 5.5 can be understood in connection with Table 5.1

The results suggest that students displayed different rates of progress in scientific understanding over the period of unit instruction. The results seem to be generally consistent with the quality of students' task engagement. The students of Pattern 1 demonstrated consistent progress in scientific understanding over the period of instruction. The students of Pattern 2 (except Maria) and the student of Pattern 3 were successful overall, with some occasions of failure. The student of Pattern 4 showed mixed performance, with more occasions of failure. The students of Pattern 5 showed overall failure, with a few occasions of success. Finally, the student of Pattern 6 displayed consistent failure.

In particular, the students of Patterns 4, 5 and 6 showed consistent failure achievement later in the unit, as compared to some success earlier in the unit. It is noteworthy that none of them demonstrated adequate, scientific understanding in Lesson Clusters 7, 8, and 9. In fact, the science tasks in these clusters involved inherently complicated phenomena during changes of state, requiring students to integrate several components in order to make adequate scientific explanations.

The results above present a sharp contrast to the students of Patterns 1 and 2 (except Maria). Although some of them failed to achieve scientific understanding in Lesson Cluster 7 (which introduced the idea of changes of state), all the students demonstrated success in scientific understanding in Lesson Clusters 8 and 9. Considering the inherently complicated nature of the tasks, their achievement indicates significant accomplishment.

The student of Pattern 3 displayed achievement consistent with the pattern of his task engagement. Neil achieved scientific understanding in task situations in which he was interested, but failed in other task situations in which he was inattentive in class. Thus, Neil's achievement seemed to depend basically on his intrinsic motivation, which was inconsistent across task situations.

The cases of Sara and Sean present a great contrast. Sara's case (Pattern 2) illustrates successful progress in scientific understanding over successive task situations Sean's (Pattern 4) case illustrates failure to make progress. Both cases indicate how students' progress in scientific understanding is related to their task engagement: (a) success in progress and the goal of scientific understanding during task engagement; and (b) failure in progress and the goal of task completion.

Case A: Success in making progress. Students were engaged in a hands-on experiment in which they observed that the colored liquid in a thermometer went up (expanded) when the bulb of the thermometer was placed in hot water and, then, went down (contracted) in cold water (i.e., thermal expansion of liquids in L.C. 6). The scientific conception for thermal expansion is: When a substance is heated, its molecules move faster and farther apart, causing the substance to expand. During the experiment, Sara had difficulty explaining the phenomenon:

O: Why does the liquid go up in hot water? What happens to the molecules?
Sara: They are being pushed up.
O: Why?
Sara: Because of the heat. It rises.
O: Heat rises?
Sara: Yeah, so it pushes the molecules up. And the molecules push the liquid up.
O: You say that molecules are pushed up. Do you mean that molecules move from the bottom up to this point?
Sara: No. Mine was on 29 (Celsius scale). It went all the way up there. And then it dropped way back here.
O: Why does the liquid go up and down? What happens to the molecules?
Sara: They are getting colder and hotter.
O: Do molecules get colder and hotter?
Sara: Yeah, they are warming up. The liquid is. And that warms, kind of, just a little bit, kind of warms up.
O (to other group members): Molecules get colder and hotter. Do you agree?
Group member 1: Molecules get spread apart.
Sara: Oh, yeah!
O: There is one more point, when a substance is heated—
Group member 1: They move faster.
Sara: They move faster, yeah.
O: Now, can you explain why the liquid goes up and down in terms of molecules?
Sara: They go down. When you cool it, the liquid goes down and molecules can go down, too. And then they go back up again.
O: Think about in terms of the movement of molecules. When you heat a substance, molecules move faster—
Sara: And slower. And then they move slower and closer together.

In the conversation above, Sara tried several explanations, most of them misconceptions. She thought that molecules were pushed up, because heat rose. She also thought that molecules got colder and hotter. Basically, she hypothesized that what happened to the observable substance also happened to its molecules. Although Sara realized scientific conceptions with the help of her group member, she was still having difficulty giving an adequate, scientific explanation.

During the rest of the class period after the hands-on experiment, students discussed the results of the experiment and read the textbook aloud in class. Sara did not volunteer her answers or make comments in class. Instead, she was very attentive to the teacher and class discussion throughout the remaining 20 minutes.

In the subsequent lesson period, the class engaged in another hands-on experiment in which they warmed a cold soda bottle with a dime on the neck and observed the dime popping up and down (i.e., thermal expansion of gases). Sara could give a scientific explanation for this phenomenon:

O: What substance are we talking about here?
Sara: Air inside.
O: What happened to the air when you warmed it?
Sara: When you heat it, it expands.
O: When you cooled the air, then what happened?
Sara: It contracts.
O: When you warmed the air, what happened to the molecules of air?
Sara: They spread farther apart.
O: Something else?
Sara: Faster.
O: Then what happened to the air?
Sara: It spreads farther apart, it expands. It tries to get farther and farther apart.
O: Do you think air is moving from the bottom to the top, or does it expand?
Sara: It expands.

The observer continued the conversation to see whether Sara still had difficulty explaining the colored liquid in a thermometer from the previous day's lesson. Sara demonstrated scientific understanding of thermal expansion of liquids:

O: Let me ask you some questions about the activity you did yesterday. When you put the thermometer in hot water, what happens to the colored liquid?
Sara: The liquid gets heated. It expands, and goes faster and up.
O: What happens to the molecules?
Sara: They are getting farther apart and going faster.
O: Then, where do they go?
Sara: Wherever they can. They can go up.
O: What happens if you put the thermometer in cold water?
Sara: It falls down. It contracts.
O: What happens to the molecules of the liquid?
Sara: They are going slower and getting closer together.

Further, Sara was aware of how she resolved her learning difficulty and came to achieve scientific understanding:

O: Was this activity difficult yesterday?
Sara: Kind of, kind of hard for me to understand until he (the teacher) really explained it.
O: But can you understand it now?
Sara: Yeah. When you understand it, it is simple because you know exactly what happens.

<u>Case B: Failure to make progress</u>. During the first lesson in Lesson Cluster 7 on melting and solidifying (freezing), the textbook introduced a new concept: attraction of molecules. In a sense, Lesson Cluster 7 was an extension of Lesson Cluster 6, thermal expansion and the effects of heating on molecular movements and arrangements. In addition, the textbook emphasized molecular attraction to explain how a substance changes its state (e.g., from a solid to a liquid during melting). The textbook also presented a model explanation, accompanied by a drawing, for melting and freezing of water.

Despite the emphasis in the textbook and by the teacher, Sean failed to understand the concept of molecular attraction and did not use this concept in his explanations:

O: When ice melts into water, what happens?
Sean: Heat is getting into it, and molecules are trying to spread apart and move faster.
O: OK. Do you remember that you learned one more concept in the lesson today, besides the two points?
Sean: (pause)
O: What happens to the pattern when ice melts?
Sean: They move all over, not in a certain pattern, not like in a solid.
O: Why does the pattern change?
Sean: (pause)
O: There is one more concept you learned today.
Sean: (pause)
O: Let me show you in the book (opens the textbook). Do you remember?
Sean: They stick together and push apart

Further, Sean failed to understand how molecular attraction is related to molecular movements and arrangements during changes of state, producing an incoherent and illogical explanation. The scientific explanation for melting is: When ice melts, molecules move faster and farther apart, and there is less attraction between molecules to break of a rigid pattern:

O: When ice changes into water, are the molecules more or less attracted?

Sean: They are more attracted.
O: What about when water changes back into ice?
Sean: They are less attracted, because they are getting cold.
O: Do you mean that molecules are getting cold?
Sean: No, getting slower.
O: Now, would you try to give me a complete explanation? When ice changes into water, what happens to molecules?
Sean: They move faster and they attract more to each other.
O: What about the space between molecules?
Sean: They are farther apart.

Throughout Lesson Cluster 7, Sean failed to demonstrate scientific understanding of molecular attraction. Sean never included the concept of molecular attraction in his explanations, as shown in his answers in the activity book over two subsequent lessons:

Question 5 (L.C. 7.2): Pick one kitchen substance and explain what happens when it solidifies.

Sean's answer: Ice cream changes from a solid to a liquid. In a solid, the molecules are closer together. In a liquid the molecules are farther apart.

Question 2 (L.C. 7.3): Why do molecules of a solid break of their pattern if the solid is heated enough?

Sean's answer: becaus (sic) when you heat them the molecules go faster or speed up and spread out or expand.

Question 3 (L.C. 7.3): Why do molecules of a liquid forma rigid pattern if the liquid is cooled enough?

Sean's answer: becaus (sic) the molecules get closer or contract, then go slower.

<u>Exception: Maria's case</u>. Maria's performance (Pattern 2) presented an exception. She was engaged in classroom tasks with the goal of achieving scientific understanding and expended sustained effort in task engagement. Yet, she failed to achieve scientific understanding. The case illustrates that the process of learning is not necessarily consistent with later performance.

There seem to be several reasons for why Maria failed to achieve her goal of scientific understanding. Although Maria tried to connect her personal knowledge with scientific knowledge, she was not easily convinced of scientific knowledge being taught. For example, earlier in Lesson Cluster 1, the class discussed the differences among three states of water, i.e., ice (solid), water (liquid), and water vapor (gas). To demonstrate to the class that liquid water and water vapor are two states of the same substance, the teacher distilled water in an apparatus. Although the teacher emphasized that water vapor is invisible but still exists, Maria insisted that she could see bubbles and water vapor in the distillation apparatus. In the next lesson period, the teacher introduced the concept of molecules to the class and explained that water, for example, is made of molecules, although molecules are too small to be seen. Maria fought for her ideas: When water boils, there are bubbles; bubbles are the molecules; and, thus, molecules can be seen. The teacher tried to help her confusion by stressing that molecules are not bubbles and that there are millions of millions of molecules in a bubble. Maria was not convinced and asked the teacher, "If you see bubbles in the water, why can't we see the molecules? " Several days later, Maria still showed her confusion when she asked the teacher in class, "If I can't see water molecules, how can we see water? "

Even when Maria knew that she was confused or had learning difficulty, she could not easily resolve her difficulty. For example, she had difficulty explaining evaporation and condensation of water. She was confused about whether evaporation involves the process of change from a liquid to a gas or in the reversed way. Maria was also confused about whether molecules move faster or slower during condensation. She told the observer, "That always confuses me. I am still kinda confused when we take our test. I try to concentrate so hard, and I get messed up because I always think that molecules of cold water move faster and molecules of hot water go slower." .

c. Achievement of scientific understanding after instruction. The results of student achievement after instruction of the unit are summarized in Table 5.6. Of the 19 issues identified for kinetic molecular theory, the frequencies of students' conceptions representing each of the four categories are listed: (a) scientific understanding; (b) mixed response (partially scientific and partially misconception); (c) ambiguous response; or (d) misconception.

The results show that students developed different degrees of achievement in scientific

Table 5.6

Achievement of Scientific Understanding After Unit Instruction

Pattern of engagement		scientific understanding	mixed response	ambiguous response	misconception
1.	Ken	19	0	0	0
	Jason	18	1	0	0
2.	Sara	18	1	0	0
	Dan	16	2	0	1
	Ann	17	2	0	0
	Maria	6	7	2	4
3.	Neil	14	4	0	1
4.	Sean	13	3	2	1
5.	Thea	7	5	0	7
	Lin	9	4	4	2
	Kim	2	7	1	9
6.	Nora	7	6	1	5

understanding after unit instruction. The students of Patterns 1 and 2 (except Maria) had successfully developed a general understanding of kinetic molecular theory. A major difference between the first two groups, however, is that the students of Pattern 1 gave more spontaneous, elaborate explanations without being probed by the interviewers than the students of Pattern 2.

The students of Patterns 3 and 4 were both moderately successful. Yet, they displayed several major difficulties. The student of Pattern 3 had difficulties understanding some basic, scientific conceptions and also tended to fall back on misconceptions in his initial attempts to give explanations. The student of Pattern 4 maintained several misconceptions to explain complicated phenomena involving changes of state.

Finally, the students of Patterns 5 and 6 generally failed to achieve scientific understanding. Even after instruction, they maintained many of their misconceptions and had difficulty giving adequate, scientific explanations.

In the following, a more detailed account of students' achievement of scientific understanding for each of the six patterns of task engagement will be presented.

Pattern 1 (intrinsically motivated to learn science). The students successfully developed scientific understanding of kinetic molecular theory. Further, they spontaneously gave elaborate, scientific explanations without being probed by the interviewers. For example, when asked to explain boiling, Jason expanded the question by explaining how boiling, evaporation, and condensation are all related:

I (interviewer): OK. And when you say it's boiling, what do you mean by that?
Jason: Ah, the molecules—well, the heat from the hot plate is heating up the water, and it's making the molecules move faster—they move farther apart, um, lose attraction and the molecules, when they move faster, they rise and escape from the surface of the water and evaporate. And when they hit the—when it hits the cold air, it condenses into water droplets and goes up into steam....
I: Now I put that (a glass plate) over the top of the beaker of boiling water. Do you see anything happening?
Jason: Yeah. The water vapor's condensing on the glass.
I: OK. And when you say it's condensing, what do you mean?
Jason: The water molecules are—they are—once they change into water vapor, it reaches the glass which is cooler than the—the substance—the water vapor.
I: Um hum.
Jason: And it slows down the water vapor molecules and turns the water vapor into water.

Pattern 2 (motivated to learn science). All students (except Maria) demonstrated adequate, scientific understanding of kinetic molecular theory except Maria. Although successful, their explanations were not as spontaneous or elaborate as those given by the students of Pattern 1. In the following example, Sara gave an adequate, scientific explanation for condensation with the support of probing questions by the interviewer:

I: If we leave the ice cubes in the glass for, say, thirty minutes or so, what do you think will happen outside the glass?
Sara: The glass will become cold because the ice is in there and the ice is cold. And so the air will condense.
I: OK. So, what do you expect to see outside the glass?
Sara: Water....
I: Where does this water come from?
Sara: The air.
I: When you say the air, do you mean that the air changedinto water?
Sara: No. It condensed.
I: What condensed?
Sara: The water that is in the air.
I: How do you call that?
Sara: Water vapor.
I: OK. So when you say condenses, what change of stateis occurring?
Sara: From gas to a liquid.

I: Can you explain what's happening here in terms of molecules?
Sara: Well, the molecules are moving closer together and slowing down.
I: OK. When molecules slow down, then what happens?
Sara: As they get closer together, together, they become water droplets that form outside the glass.
I: OK. Do you remember one thing you learned in the unit, attraction of molecules? Do you remember that?
Sara: No.

Pattern 3 (intrinsically motivated, but inconsistent). The student developed a reasonably good understanding of kinetic molecular theory. Yet, his explanations show some major difficulties. First, Neil failed to understand some of the basic conceptions for kinetic molecular theory, including molecular constitution of matter, empty space between molecules, and the size of molecules. For example, Neil thought that there must be "something" between molecules, as if something that could hold the molecules together in substances (continuous model), instead of substances are made of only molecules:

I: OK. You just draw the molecules here (in the water). Is there anything between the molecules?
Neil: Well, there has to be. You don't see spaces in water.
I: So is there space between the molecules?
Neil: Well, yeah, there's space but there's got to be something in it .... There's got to be something. I mean you don't see open spaces in water.
I: OK. What will that be?
Neil: I don't know....
I: Is there anything in this space between molecules (in the rock)?
Neil: There is something .... Because you don't just see open spaces with nothing in a rock....
I: Is there anything between the molecules (in the air)?
Neil: There's something in all of them. . .

Second, the student tended to fall back on his misconceptions in several task situations. He attempted to give explanations in terms of his misconceptions, noticed inconsistency in his responses, and then gave scientific explanations. For example, Neil started to explain, in terms of his misconceptions, why the balloon on top of a cold bottle blew up when the bottle was warmed (i.e., thermal expansion of gases):

I: What is happening to the balloon?
Neil: It's starting to fill up with air.
I: Can you tell me why?
Neil: Well, warm air rises, and warming up the bottle is warming up the air molecules inside, and molecules are rising up and going into the balloon.

Over the course of interviewing, Neil changed his incorrect ideas and made a scientific explanation:

I: So the warm air goes up to the balloon?
Neil: Right.
I: Can you tell me in terms of molecules?
Neil: Well, the molecules get faster and farther apart.
I: Uh huh.
Neil: Spread out up into the balloon.
I: You just told me that hot air rises to the top?
Neil: Well, the molecules get farther apart.
I: Uh huh.
Neil: So there's more space in between the molecules, and they need somewhere to go, so they go up into the balloon.
I: How about the hot air?
Neil: It's not really. Just the molecules spreading farther apart ....
I: OK. Is it because air spreads farther apart or air rises to the top?
Neil: Because they are spread farther apart .... It doesn't really rise. It just spreads apart.

Pattern 4 (task completion). The student was moderately successful in developing a scientific understanding of kinetic molecular theory. He failed to provide scientific explanations for complicated phenomena during changes of states of matter, including melting and freezing, evaporation and boiling, and condensation. For science tasks involving these phenomena, Sean either gave inadequate explanations based on his misconceptions, or simply said, "I don't remember," apparently without even trying:

I: Is there anything inside those bubbles (of boiling water)?
Sean: Yeah, water vapor.
I: OK. What is water vapor?
Sean: It's—it's, um it's water but it's in a gas.
I: OK. So, how does the, ah, water gets into a gas form?
Sean: Um, by the heat.
I: OK. What does the heat do?
Sean: The heat will make them, um....I, um, can't remember that.

As another example, when asked to explain why there was water outside a glass container with ice cubes in it (i.e., condensation), Sean gave a scientific explanation in terms of substances: "Because the glass would be cold and the, and, um, and—and water vapor is attracted to cold and then it'll go on the glass and it changes to water." However, when asked to explain condensation in terms of molecules, Sean gave an inadequate explanation based on his misconceptions:

Sean: Um, because of the cold of the glass, it'll sort of make the molecules hard.
I: Hum.
Sean: And they change back to water.
I: OK. When you say it'll make the molecules hard, what do you mean by that?
Sean: Um, that, um, it'll change them.
I: So the coldness of the glass will change the molecules?
Sean: Yeah. . .

Patterns 5 (task avoidance) and 6 (disruptive behavior). The students failed to develop scientific understanding of kinetic molecular theory. They maintained many of their misconceptions and failed to make scientific explanations. They often had to be supported by the interviewers with encouragement, prompts, and probing questions.

Kim's (Pattern 5) explanations were often one-line responses, "yes", "no", or "I don't know." For example, the interviewer asked Kim to explain how sugar dissolved in water:

I: OK. And then what happens? You said something about the water molecules hitting the sugar. Is that right?
Kim: Yeah.
I: OK. Can you tell me more about that?
Kim: No.
I: So if the water molecules hit the sugar, what happens then?
Kim: I don't know.
I: What would happen to the sugar?
Kim: It dissolves.
I: OK. Then what?
Kim: Then it goes into the bottom of the cup.
I: When you say dissolves, can you tell me anymore about that? What that means?
Kim: No.

Kim sometimes gave contradictory responses within the same task context. For example, the interviewer showed Kim that he could easily pull a metal ball through a metal ring. When the ball was heated, he could not pull the ball through the ring anymore; but when the ball cooled, he could pull the ball through the ring again. Asked to explain this phenomenon in terms of molecules (i.e., thermal expansion of solids), Kim gave contradictory responses based on her misconceptions:

I: Why can't you pull the ball through the ring?
Kim: Because the molecules expanded and caused it to get bigger, so it wouldn't go through the ring.
I: Does the movement of the molecules change at all? The movement of the molecules of the ball?
Kim: No.

I: That stays the same?
Kim: Yeah ....
I: OK. You just got it through. Why do you think you got it through now?
Kim: Because it cooled down and the molecules moved closer together and it went through.
I: You said it cooled down and the molecules moved closer together?
Kim: Uh huh.
I: Before when you were talking about it, when you couldn't get it through, you said the molecules got bigger, right?
Kim: Uh huh.
I: OK. And when the molecules get bigger, does the space between the molecules change?
Kim: No.
I: No? OK. But when it cools, the space between the molecules does change?
Kim: Yeah.

Exception: Maria's Case. Unlike the other students of Pattern 2 who successfully achieved scientific understanding, Maria showed overall failure in her achievement. As a result, her achievement after instruction was no better than students who avoided engaging in classroom tasks. Despite the similarity to the students of Patterns 5 and 6 in terms of failure achievement, the nature of Maria's responses revealed some distinctive differences.

On several occasions, Maria was aware when she had difficulty giving explanations and told the interviewer, "I am confused about that," or "I don't understand that." Yet, Maria did not readily give up and persisted making explanations, however unsuccessful they were. In the following example, the interviewer asked Maria to predict whether she could push on the plunger in a syringe with water in it, after having tried with air in it (i.e., compression of gases vs. liquids). Maria predicted incorrectly that she could compress water as she had done with air:

Maria: Um. At first if you just pull the water in, the molecules are far apart, but then when you try to push it together, it will just, um, do the same movement of the air. The molecules will go closer together so that then it will stop you from pushing the syringe down anymore. . .

When Maria actually tried to push on the plunger with water in the syringe, she found that she could not push the plunger down at all. Maria told the interviewer that she did not understand why that happened:

Maria: Because the molecules wouldn't .... Well, I didn't understand this, when you pulled it out, when you pushed, when you pulled the water in, wait

....When you pulled the water in.
I: Uh huh.
Maria: And I tried to push it down, and it would stay right there.
I: Uh huh.
Maria: But I don't, I don't understand why.

Despite her confusion and frustration, Maria kept trying:

I: OK. Why can you push it down with the air but you can't push it down with the water?
Maria: Um .... I'd say, because it's a liquid and it takes up more room, and the molecules, with the molecules being in there, you wouldn't be able to push it and make room for the molecules with the liquid and the molecules being in the same place. Got it?

Maria's struggle and persistence occurred on several other occasions. As another example, Maria failed to give an explanation about condensation, but hoped that she could be successful on the next task about thermal expansion of solids (i.e., the ball and ring experiment):

I: OK. Does that mean that the water came through the glass?
Maria: From the water vapor in the air? In—
I: OK. So how does the water vapor in the air get on the glass?
Maria: I'm confused about that.
I: Are you?
Maria: Yeah, pass.
I: OK. We will just forget about that one for now .... I have a bottle here—and it's cold. And what I'm going to do is, I'm gonna put the balloon on top of it.
Maria: Here. Maybe I can get it. . .

<u>Summary and Discussion: Progress in Scientific Understanding</u>

The results show that students who were motivated to learn science displayed distinctively different rates of progress than those who were not. Students who were motivated to learn science made continuous progress over task situations. When instruction of the unit was completed, they successfully constructed an integrated body of scientific knowledge for kinetic molecular theory. In contrast, students who were not motivated to learn science failed to make progress over task situations. Their performance deteriorated as instruction of the unit continued. Eventually, they failed to develop general understanding of kinetic molecular theory. Thus, the results suggest that students' success or failure to make progress in scientific understanding is a key factor related to their patterns of task engagement.

According to research on conceptual change, the students of Pattern 1 had greater background knowledge than other students when instruction of the science unit started. Based on such content knowledge to start with, the students were more likely to initiate scientific thinking independently than other students with little background knowledge.

Students who had little background knowledge to start with expended high quality of task engagement as they gained better understanding of scientific knowledge (e.g., the case of Sara). In contrast, when students failed to make progress in scientific understanding, that failure imposed an increased difficulty for the expenditure of high quality of task engagement (e.g., the case of Sean). Thus, their achievement deteriorated as instruction continued.

Research on student motivation, on the other hand, provides explanations in terms of motivational variables of students. The results suggest that students' content knowledge does not always explain the quality of task engagement. For instance, when instruction of the unit started, Dan of Pattern 2 had as much background knowledge as the students of Pattern 1 and, yet, did not demonstrate self-initiation of scientific thinking as did those of Pattern 1.

Motivation research also suggests that when students succeed or fail to achieve scientific understanding, their expectations of success or failure also change. This seems to be the case with Maria. She engaged in classroom tasks with the goal of scientific understanding and usually failed to achieve understanding in classroom tasks. Realizing her learning difficulties and failure achievement, she seemed to lower her expectations of success in achieving scientific understanding. .

<u>Students' Goal Orientations in Science Class (R.Q. 2-c)</u>

This research question examines how students' goal orientations in science class are related to patterns of task engagement. Do students who are motivated to learn science possess different goals in science class from those who are not motivated? Of particular interest here is students' perceptions of the goal of understanding in science class.

Three aspects of student goals in science class are discussed. The first aspect concerns students' personal goals in science class. The second concerns students' perceptions of various goals from the perspectives of: (a) myself (i.e., personal goals), (b) a good science student, (c) a science teacher, and (d) a scientist. The final aspect concerns students' perceptions of the nature of science and science learning.

a. Students' personal goals in science class. How did each student perceive his or her personal goals in science class? First, three priorities of individual goals reported by each student were identified. Then, these individual goals were classified into relevant goal clusters. Finally, major goal clusters for each student across patterns of task engagement were identified; they are summarized in Table 5.7, below. The number, 1, 2, or 3, indicates the priority of each goal cluster reported by each student.

Table 5.7

Students' Personal Goals in Science Class

		Understanding	Fact acquisition	Performance in class	Others' expectations	Extrinsic rewards	Avoidance
1.	Ken	1	2	3			
	Jason	1		2,3			
2.	Sara	3		1,2			
	Dan	1,2	3				
	Ann			1,3	2		
	Maria	2		1,3			
3.	Neil	2		1	3		
4.	Sean			1,2	3		
5.	Thea		2	1,3			
	Lin	3		2	1		
	Kim			1	2,3		
6.	Nora			1,2	3		

*Out of their first three priorities, some students reported two goals which belong to the same goal cluster

The results show similarities among the students in the study. First, none of them perceived extrinsic rewards or task avoidance as one of their primary goals in science class. Second, most students perceived performance in class (e.g., get good grades, do well in class activities, and get work done on time) as their top priority, except the two students of Pattern 1 and one student of Pattern 2 for whom this goal cluster was secondary to the goal of understanding. The result suggests that most students were concerned with good performance, especially good grades, in science class.

The results also show differences across students, especially between students who were motivated to learn science and those who were not. The students of Patterns 1, 2 and 3 (except Ann) all reported understanding as one of their primary goals. Some of them also reported fact acquisition as one of their primary goals. Thus, the students perceived *task endogenous* reasons, in terms of understanding and fact acquisition, as one of their major goals in science class.

Yet, there seemed to be some significant differences between the students of Pattern 1 and those of Patterns 2 and 3. The students of Pattern 1 reported the goal of understanding as their first priority and good performance in class as their second. In contrast, the students of Patterns 2 and 3 reported the goal of good performance as first priority and understanding as secondary. Thus, the priority of understanding versus good performance seemed to be reversed.

Among the students of the first three patterns of task engagement, Ann was the only one who did not report understanding as one of her primary goals. Yet, she indicated a strong orientation toward good work ethics in learning, suggesting a willingness to expend effort and persistence by a sense of duty (Brophy, 1987, p. 182):

> Ann: Sometimes I don't want to do it but I do it anyway .... Usually I'm not the type to not do your work or something because I've never got a zero yet and stuff. So I do the work no matter what .... And sometimes it's fun and sometimes I'd rather not do it, but I do it anyway. But other people may not do it just because, you know, they want to do something else, like if they want to watch their TV program, and so they say "Oh, I'll just do it later" and then they don't get to it, so they can't do it.

In contrast to the students of the first three patterns, none of the not-motivated-to-learn-science students (Patterns 4, 5, and 6, except Lin) identified understanding or even fact acquisition as one of their primary goals. Instead, most of them reported good performance in class as their first priority, and pleasing their parents or teachers as their second priority. These students were primarily concerned with *task exogenous* reasons in science class.

b. Students' perceptions of goals from different perspectives. To understand students' goal structures, we need to examine not only their personal goals but also external influences, such as expectations of parents, teachers, and peers. In addition, examining students' perceptions of goals from different perspectives can enrich our understanding of their goal structures in science class.

This approach seems to be particularly effective for examining why some students did not perceive the goal of understanding as one of their priorities in science class. Is this because: (a) The students did not realize that the goal of understanding exists in science and science learning (i.e., from a scientist's perspective); (b) they did not perceive that this is a major goal in science class (i.e., from the perspective of a science teacher); (c) they did not expect that this goal was achievable by students (i.e., from the perspective of a good science student); or (d) they decided not to try to achieve this goal, even when they perceived it within the reach of students (i.e., from one's own perspective)?

Table 5.8 presents the summary of three major goal clusters from each of the four perspectives across different patterns of task engagement. To develop this summary chart, relative frequencies of the first three priorities reported by students of the same pattern were tallied, following the format and procedure used for Table 5.7 above.

The results show some similarities among students. All the students reported understanding as the first priority in science class from a scientist's perspective, suggesting that they recognized its existence in science and science learning. Also, none of the students reported extrinsic rewards or task avoidance as a major goal from any of the four perspectives.

However, students' perceptions of goals from the perspectives of oneself, a good science student, and a science teacher varied widely across students, especially between students who were motivated to learn science and those who were not. The following discussion focuses on whether students placed high or low value on the goal of understanding, compared to other competing goals, in science class.

Pattern 1 (intrinsically motivated to learn science). The students reported understanding as the first priority from all the four perspectives. They perceived that understanding was a major goal in science class, that this goal was achievable by students,

Table 5.8

Students' Perceptions of Goals from Different Perspectives

	Perspectives→ Pattern	Myself	Good science student	Science teacher	Scientist
1.	Intrinsically motivated to learn science	1) understanding 2) performance 3) facts	understanding performance expectations	understanding facts performance	understanding facts
2.	Motivated to learn science	1) performance 2) understanding 3)	understanding performance	understanding performance	understanding facts
3.	Intrinsically motivated, but inconsistent	1) performance 2) understanding 3) expectations	performance expectations understanding	understanding performance	understanding facts
4.	Task completion	1) performance 2) expectations 3) .	understanding expectations performance	understanding facts performance	understanding facts
5.	Task avoidance	1) performance 2) expectations 3)	expectations performance	performance understanding facts	understanding facts
6.	Disruptive behavior	1) performance 2) expectations 3)	performance expectations	performance expectations	understanding expectations

*Out of their first three priorities, students sometimes reported two goals that belong to the same goal cluster.

and that they were actually trying to achieve this goal. Good performance in class was the second priority, and fact acquisition was the third priority. Pleasing parents or teachers was not perceived as a major goal cluster, except,to a certain extent, from the perspective of a good science student. The results suggest that the students placed high value on the goal of understanding, above any other competing goal in science class.

Pattern 2 (motivated to learn science). All the students except Ann perceived good performance in class as their first priority and, then, understanding as their second priority. Yet, understanding was perceived as increasingly more important in the order of myself, a good science student, and a science teacher. Pleasing parents or teachers was perceived as a major goal only by one student. The results suggest that although the students recognized understanding as a major goal in science class and also perceived this goal within the reach of students, they were personally more concerned with doing well in class to get good grades than understanding. Thus, the students placed reasonably high value on the goal of understanding, along with other competing goals in science class.

Pattern 3 (intrinsically motivated, but inconsistent). The student perceived good performance in class as his first personal priority. He listed understanding as first priority from the perspectives of a scientist and a science teacher, second priority from his own perspective, and third priority from the perspective of a good science student. Satisfying others' expectations was also one of his priorities. As the results suggest, although the student recognized understanding as a major goal in science class, this goal could not easily be achieved by students. Instead, students, including himself, would be more concerned with extrinsic reasons. Thus, although the student placed moderately high value on the goal of understanding, other competing goals were more salient to him.

Pattern 4 (task completion). The student perceived good performance in class as his first priority and satisfying the expectations of others as his second priority. However, he perceived understanding as the first priority from all the other perspectives. The results suggest that although he recognized understanding as a major goal in science class and perceived this goal to be within the reach of students, he did not try to achieve this goal personally. Thus, the student placed low value on the goal of understanding, despite his clear awareness of its importance in science class, and endorsed other competing goals.

Patterns 5 (task avoidance) and 6 (disruptive behavior). The students perceived good performance in class as their first priority and satisfying others' expectations as their second priority. Understanding was not perceived as one of their priorities, or even from the perspective of a good science student. Further, understanding was perceived only as the second priority from the perspective of a science teacher. As the results suggest, the students perceived that understanding was not a major goal in science class, this goal was not within the reach of students, and that they did not try to achieve this goal personally. Thus, the students placed low value on the goal of understanding, below any other competing goal in science class.

c. Perceptions of the nature of science and science learning. If students across patterns of task engagement perceived their goals in science class differently, how did they perceive the nature of science and science learning in the first place? The results show that there were significant variations in the way students from different patterns of engagement perceived the nature of science and science learning. Further, their perceptions seem to be compatible with their goal priorities in science class, discussed above.

Pattern 1. The students had a conception of the nature of science and science learning as understanding and explaining the world around them. For example, Jason told the interviewer:

> Jason: Um, every move you make, like, you know, if I just hold up this pencil, there is, like, an explanation why I could put the pencil on there. I want it high, I pick it up, and everything. Every move I make, there's, you know, there's a reason for it. In science class because it's a really important subject in school and it's interesting for me .... There's always somewhere there's science, and science, you know, explains things.

Pattern 2. The students had some understanding that science had something to do with the world around them, although it was very general. For example, Sara perceived science learning as follows:

> I: What does learning science mean to you?
> Sara: Well, some people just—if you didn't have science, you wouldn't know probably just about as much as trees and nature in science. That's all probably you wouldn't know about it.
> I: So, do you think science is important?
> Sara: Science is important to me, because there wouldn't be like nature and there wouldn't be, um, trees and stuff like that .... Because it helps me live.

Patterns 3 and 4. Both students showed some understanding that the nature of science and science learning had something to do with the world around them:

Neil: It (science) has a lot, science deals with just about everything that has to do around the world .... I want to know about what the world's doing because science has a lot to do with the world.

Sean: It (science) is mainly to learn about the things around us, like things about the earth or something about our planets and the solar system. That's why we do science. You learn different things in science, new things. . .

Pattern 5. The students (except Lin) did not seem to perceive the nature of science and science learning as understanding and explaining the world around them. Instead, they perceived science learning as something required in school or memorization of factual information:

I: Why do you study science?
Kim: So that when you go on next year, so that the teacher, they will teach it right over mostly. So when you go to the seventh grade next year, you will know more about what they gonna teach.

Thea: I guess it (science) is just something we have to learn .... Some things that we should really know, so we have to study them and read about them and answer questions about them. Because there are a lot of things in science that you need to memorize and know.

Both Kim and Thea gave low ratings to the goal, *to make sure my ideas are scientifically correct,* because they felt they were not competent in science learning:

Kim: Because all the work ain't going to be correct. It might be OK, but it isn't all going to be correct all of the time .... Because I know that I, most of them, I know that me, I, I ain't better than some of the students in my class. So you can't put five (scale) when you know that you're not better than some other students.

Thea: Because I am not that good in science and I guess my ideas are just ideas. I am not too good in science.

Unlike Kim and Thea, Lin had some understanding that science explains nature:

Lin: Sometimes I get questions in my mind, like, I wonder why something works like this. But science figures it out, I guess. . .

Pattern 6. The student seemed to have some understanding of the nature of science and science learning. However, she also seemed to actively deny its importance. In fact, she gave the lowest ratings to both goals, t*o use science to understand the world,* and *to* *make sure my ideas are scientifically correct.*

> Nora: I just don't like learning about the world because, I don't know, because like, when they talk about different states and stuff, it's like, because I don't care and stuff because I'm not living there so it's not happening. If I get my work done, I don't go back and make sure they (my ideas) are correct. If I get them wrong, then they're wrong. I don't like science.

<u>Summary and Discussion: Goal Orientations in Science Class</u>

The results show that there were definite differences between students who were motivated to learn science and those who were not. Students who were motivated to learn science perceived understanding as one of their primary goals in science class. They also had a conception that the nature of science and science learning is to understand and explain the world around them. In contrast, students who were not motivated to learn science did not perceive understanding as one of their primary goals in science class, or even did not recognize understanding as a major goal in science altogether. Further, some did not have any understanding of the nature of science and science learning.

The results suggest that students' goal orientations in science class are a key factor for patterns of task engagement. Students' general goal orientations in science class were generally consistent with their choice of goals and strategies during specific task engagement. Further, students' perceptions of the nature of science and science learning also seemed to be generally consistent with the quality of their task engagement.

According to research on student motivation, students who were motivated to learn science placed high value on the goal of understanding, above or along with alternative goals in science class. In contrast, students who were not motivated to learn science placed low value in the goal of understanding, compared to other competing goals in science class.

Conceptual change research, on the other hand, explains the results in terms of content knowledge of students. When unit instruction began, the only students who reported understanding as their primary goal were also the ones with greater background knowledge than any other student (Ken and Jason of Pattern 1, and Dan of Pattern 2).

Thus, the results suggest that having content knowledge was closely related to an awareness of what it means to understand in a content area. Further, the awareness of what scientific understanding involves seemed to be related to high quality of task engagement. In contrast, students with initially low content knowledge would not articulate or even have a conception of what understanding involves. Such lack of conception, however, did not seem to prevent them from expending high quality of task engagement (e.g., Sara and Ann of Pattern 2).

Students' Affective Orientations toward Science (R.Q. 2-d)

This research question examines how students' affective orientations toward science are related to their patterns of task engagement in science classrooms. Do students who are motivated to learn science possess different attitudes and interest than those who are not motivated?

Two issues of findings are discussed: (a) students' ratings of their attitudes toward and interest in science and (b) the nature of students' affective orientations toward science.

a. Students' Attitudes toward and interest in science. Students' reports of their attitudes toward science showed that 11 of the 12 students in the study had positive attitudes toward science (average rating +1.5 of maximum +2). On a scale ranging from minimum –2 to maximum +2, nine students reported +2, and two students reported +1. Only one student (Thea of Pattern 5) reported –2, negative attitudes.

In a similar manner, students' reports of their interest/curiosity in science also showed that 11 of the 12 students were interested in science and curious to learn about science (average rating +3.5 of maximum +4). On a scale ranging from minimum –4 to maximum +4, nine students reported +4, and two students reported +3. Only one student (again, Thea of Pattern 5) reported 0, neutral orientation.

The results suggest three major points. First, most students reported positive attitudes and high interest (curiosity) in science. Consistent with previous research findings, students in the present study showed positive attitudes toward and high interest in science when they started formal learning of science in middle school.

Second, students' reports of their attitudes and interest did not seem to be significantly related to patterns of task engagement. Although almost all the students reported positive attitudes and high interest, only some of them were motivated to learn science during task engagement. Further, even fewer students actually seemed to engage in classroom tasks with interest or enjoyment in learning science.

Finally, since students' reports of their attitudes and interest were almost identical, in terms of both magnitudes and directions of orientations, attitudes and interest might be a single construct or, at least, extremely highly correlated (Harty, Samuel & Beall, 1986).

b. Nature of students' affective orientations toward science. If most students perceived that they liked science, science was fun and interesting, and that they were curious to learn about science, what was the nature of their affective orientations toward science? Students' reports show that the nature of affective orientations did not differ significantly across different patterns of task engagement. In fact, almost all the students reported positive attitudes and high interest because it was "fun to do experiments and stuff" and "fun to learn science":

> Jason (Pattern 1): You know, science is interesting, to learn a bunch of things about science. I think it's just interesting.

> Sara (Pattern 2): Yeah, I like it. I like science, to do experiments and have fun. I think it's fun and stuff.

> Neil (Pattern 3): Because you learn more and usually it's pretty fun when you get to do experiments and stuff...Well, it's just fun to learn.

> Sean (Pattern 4): Science is one of my favorite subjects and plus you do a lot of fun things in it, like experiments and stuff. Like that, you have fun with science. Um, you learn different things in science, new things.

> Kim (Pattern 5): Because it (science) helps you learn and I like doing experiments and stuff.

The responses above suggest that students' affective orientations toward science combined their perceptions of both affective (e.g., fun, liking or interest) and cognitive components (i.e., learning). Interestingly, affective components were rather specific and concrete mainly in terms of science experiments, whereas cognitive components were vague and abstract.

Of the 12 students in this study, only one student (Thea of Pattern 5) reported negative attitudes:

> Thea: I don't like science. It's sometimes boring .... Boring in science class. Sometimes teachers just tell stuff that makes it boring and you're getting ready to fall asleep.

Nora's case (Pattern 6) was rather complicated. Although she reported positive orientations on the questionnaire (rating +4 of maximum +6), her affective orientations seemed to fluctuate depending on contexts. Although she liked some aspects of science, she did not like the science class because of her personal conflicts with the teacher:

> Nora: I don't really like the teacher that much .... I don't really like science class.
> I: Is science ever fun?
> Nora: Sometimes.
> I: Yeah? What parts of science are fun for you?
> Nora: When you do experiments with models and different kinds of things.*

Thus, in the cases of Thea and Nora their negative attitudes toward science seemed to be related to the nature of their motivation during task engagement. With Thea, her lack of interest in science and negative attitudes seemed to be related to her avoidance to engaging in classroom tasks. With Nora, her active resistance to the teacher and, for that matter, negative orientations toward science class seemed to be related to her disruptive behavior and disciplinary problems in class. In fact, Nora's attitudes seemed to explain that her disciplinary problems in class might be a means of actively expressing her negative feelings toward the teacher and science class.

<u>Summary and Discussion: Affective Orientations Toward Science</u>

The results show that almost all the students reported positive attitudes toward and high interest in science. Students' positive orientations toward science seemed to depend heavily on science experiments, in addition to some vague notion of learning. However,

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*Note: Nora's negative perceptions of the teacher do not seem to indicate any mistreatment of this student on the part of the teacher. On the contrary, according to classroom observations, the teacher tried to help this student with her learning. The two observers who visited the classroom puzzled about the origins of her negative perceptions of the teacher.

one student expressed negative attitudes, and another student reported mixed feelings.

The results suggest that students' reports of their affective orientations toward science did not distinguish different patterns of task engagement, especially between students who were motivated to learn science and those who were not. Students who had positive attitudes and high interest were not necessarily motivated to learn science during task engagement. However, negative affects seemed to be related to lack of motivation to learn science. Thus, students' reports of their affective orientations seemed to be related to their task engagement to a limited extent.

As research on student motivation suggests, students' reports of their affective orientations seem to be quite different from actual task engagement in classrooms (Brophy & Merrick, 1987). Further, as conceptual change research suggests, students' affective orientations did not seem to be related to the nature of science learning or enjoyment of scientific understanding. Instead, their affective orientations seemed to be related to insignificant aspects of science learning or science class, especially "fun" experiments.

Achievement after Unit Instruction and Changes in Students' Goal Orientations and Affective Orientations (R.Q. 3)

The question examines whether students' success or failure to achieve scientific understanding after unit instruction leads to any change in their general goal orientations in science class (i.e., cognitive aspects of student motivation) and affective orientations toward science (i.e., its affective aspects). Does success achievement lead students to internalize the goal of understanding in science class and also more positive affective orientations? Does failure achievement lead to deterioration of students' cognitive and affective aspects of motivation?

Three major issues of findings are discussed. First, is success or failure to achieve scientific understanding related to changes in students' goal orientations in science class? Have students' perceptions of the nature of science and science learning been changed? Second, is success or failure achievement related to changes in affective orientations toward science? Has the nature of their affective orientations been changed? Finally, are changes in students' goal orientations related changes in affective orientations? Is there any consistency (or inconsistency) in changes between cognitive and affective aspects of student motivation?

Changes in Students' Goal Orientations in Science Class

The assessment of scientific understanding for individual students at the completion of unit instruction has already been discussed for Research Question 2-b, student progress in scientific understanding (see Table 5.6).

The examination of changes in students' goal orientations in science class, with focus on the goal of understanding, show three major patterns. First, some students more strongly emphasized the goal of understanding after unit instruction than prior to instruction. Second, some de-emphasized the goal of understanding. Finally, others failed to recognize understanding as a major goal in science class and, thus, showed no change.

When the results from the above two sources are related, four major patterns seem to emerge. Some students successfully achieved scientific understanding, and more strongly emphasized the goal of understanding after unit instruction. Some failed to achieve scientific understanding, and de-emphasized the goal of understanding. Others failed to achieve scientific understanding, failed to recognize the goal of understanding as a major goal in science class, and showed no change in their perception of the goal of understanding. Still others were successful or moderately successful in scientific understanding, but de-emphasized the goal of understanding after instruction. The results are summarized in Table 5.9.

The question to be examined is: Did success or failure in the achievement of scientific understanding lead to changes in students' perceptions of the goal of understanding in science class? As shown in Table 5.9, the relationship between achievement and changes in students' goal of understanding is not completely systematic. For some students, there seemed to be a systematic relationship; for others, there was not a systematic relationship.

In the following, four major patterns of change will be described. For each pattern, two types of results will be described. First, according to research on student motivation, changes in students' perceptions of the goal of understanding in terms of expectancy of success and value for the goal of understanding will be described. Second, according to

Table 5.9

Achievement and Changes in Student Goal of Understanding After Unit Instruction

Achievement/ Change	Success	Moderate success	Overall Failure	Number of students
More emphasis	Jason (Pattern 1) Sara (Pattern 2) Dan (Pattern 2) Ann (Pattern 2)			4
Less emphasis	Ken (Pattern 1)	Neil (Pattern 3) Sean (Pattern 4)	Maria (Pattern 2) Lin (Pattern 5)	5
No change			Thea (Pattern 5) Kim (Pattern 5) Nora (Pattern 6)	3
Total				12

research on conceptual change, changes in students' perceptions of the nature of science and science learning will be described.

Group 1: Success achievement, and more emphasis. The first group involves students who successfully achieved scientific understanding and more strongly emphasized the goal of understanding after unit instruction (Jason of Pattern 1 engagement, and Sara, Dan, and Ann of Pattern 2). For instance, Jason emphasized that "to use science to understand the world" and "to have scientifically correct ideas" were his top two priorities in science class:

> Jason: Because that (i.e., *to use science to understand the world)* is mainly why I'm in science, just to use science to understand the world, and science stands for everything around us and everything. I think they (i.e., *to use science to understand the world, and to have scientifically correct ideas)* would almost make a tie, because you have to know science, correct science, to use science to understand the world.

On the contrary, Jason de-emphasized the goal of good performance in class that he had reported as his second priority before unit instruction:

I: What do you think about these two reasons (i.e., *get good grades, and do well in class activities*)?
Jason: To get good grades would now probably be my fourth reason. To get good grades. I would, that's a major part of it, of using science to understand the world is more like me.

Further, Jason developed a more definite conception of science and science learning as a way to understand and explain the world around him:

I: Do you have any idea why your thinking might have changed?
Jason: Well, in earlier, I might have, earlier I might have counted vocabulary and, vocabulary and facts and memorizing facts as a part of using science to understand the world. I don't know. They are very different.
I: Does that surprise you?
Jason: Sort of. That does surprise me.

Similarly, Sara emphasized the goal of understanding as her first priority in science class after unit instruction, as compared to her second priority before instruction:

I: Could you tell me why you think now that understanding is the most important reason than anything else? Why your idea has changed?
Sara: Yeah, well, because I just feel that it's more important than others .... I just think that it's more important because I'd like to learn more about science than to please my parents or to get good grades or whatever I said before. That's what science is.

Clearly, these students had successfully achieved scientific understanding. Through the experience of success achievement, they seemed to develop a better conception of the nature of science and science learning. They also internalized the goal of understanding as their first priority in science class. External factors, such as getting good grades or pleasing their parents and teachers, became only secondary reasons. The results suggest that the students developed a higher value for the goal of understanding in science class.

<u>Group 2: Failure achievement, and less emphasis</u>. This group involves students who failed to achieve scientific understanding and de-emphasized the goal of understanding after instruction, although it had been a primary goal for them before unit instruction (Maria of Type 2, and Lin of Type 5). Instead, other competing goals became far more salient to them after instruction. For example, Maria reported the goal of understanding as

her second priority before instruction; after instruction, she reported this goal as her third priority. She also de-emphasized this goal from the perspectives of a good science student and a science teacher. Explaining why she gave one of the lowest ratings to the goal, *to have scientifically correct ideas* from her own perspective, Maria expressed her learning difficulty as a cause:

> Maria: Because sometimes when we take tests, it is like one after another...We would first study about molecules, then we would take the test last. And it would be hard for me to remember all of them if I have—I know that I am taking all kinds of tests, it would be hard for me to study and everything, so I wouldn't remember all that well.

Despite her reduced emphasis on the goal of understanding and recognition of her learning difficulty, Maria seemed to have developed a better conception of the nature of science and science learning:

> Maria: He (teacher) wants me to know about the world and explain things, about what kind of gases are in the world, what kinds of molecules are in the air, what kind of—what molecules do, how molecules are, and to know more about science

On the other hand, Lin reported the goal of understanding as her third priority before instruction. After instruction, she did not identify this goal either as one of her primary goals or from the perspectives of a good science student and a science teacher. She wondered whether her science teacher would emphasize the goal, *to have scientifically correct ideas*:

> Lin: Well, he doesn't usually care about if they're scientifically correct. Well....that's—he wants us to understand what they are, what they mean, what the real meaning is. I don't know if he really wants us to know if we're scientifically correct for answers, or ideas are scientifically correct, you know.

When asked by the interviewer about such changes in her thinking after instruction, Lin was unresponsive:

> I: You said that "to use science to understand the world" is an important reason in the beginning of the year. And now you didn't even mark it. Can you tell me why you have changed your idea?
>
> Lin: I don't know. That was in the beginning of the school year. This is in the middle of the school year. I switched .... Um, maybe, I think I have a different, um, how should I put it? Different view of it .... Well, that was a long time ago. I don't remember it.

I: Why you have changed your idea?
Lin: I don't even remember it, or I wouldn't have changed it.

Yet, evidence suggests that these changes seemed to be related to her sense of learning difficulty and cognitive demands of classroom tasks:

> Lin: I don't know. Because it's hard work. Probably because it's easier to understand, and hard work is a big challenge. BIG challenge.

Before unit instruction, Lin had some understanding about the nature of science and science learning as a means to understand and explain the world. After instruction, Lin became sarcastic about science learning:

> I: What do you think is really important in science learning?
> Lin: Learning about science. Umm, you know, how the world is compared to other planets and all that crap —oh, excuse me. The earth compares—

Thus, both Maria and Lin de-emphasized the goal of understanding, which seemed to be related to their learning difficulties or cognitive demands of classroom tasks. The results suggest that after experience of learning difficulties and failure achievement, the students developed lower expectancy of success in achieving scientific understanding, which also led them to develop lower value in the goal of understanding.

However, there was a significant difference between the two students in their perceptions of the nature of science and science learning. Maria who was motivated to learn science (Pattern 2) developed a better conception of what scientific understanding involves. In contrast, Lin (Pattern 5) did not demonstrate a conception of scientific understanding. In fact, she seemed to be sarcastic about science learning and science class and was not open to talk about her thoughts and feelings.

<u>Group 3: Failure achievement, and no change</u>. This group involves students who failed to achieve scientific understanding, failed to realize understanding as a major goal in science class, and showed no chance in their perception of the goal of understanding (Thea and Kim of Pattern 5, and Nora of Pattern 6). Further, they remained unaware of what scientific understanding involves.

For example, Kim did not show any significant change in her ideas about science class after unit instruction:

> I: In general, when you think about how you feel about science class, do you think your ideas have changed since the beginning of the year, or are they pretty much the same?
> Kim: Pretty much the same.

Like Kim, Thea maintained basically the same ideas after instruction as prior to instruction. She reported memorization of factual information as one of her primary goals. Further, she perceived the nature of science and science learning as memorization of facts:

> Thea: *(to memorize facts and information)* If I have a test and if I don't know it, then I am in trouble. I guess if I memorized the facts and information, I'd know about the outside. Well, I'd know the facts and information so I could understand it.

In contrast to her emphasis on memorization of facts, Thea gave one of the lowest ratings to the goal, *to have scientifically correct ideas* after unit instruction, exactly the way she had done before instruction:

> Thea: I don't, I really don't care whether I am right or wrong scientifically.

Nora's case was more complicated. She gave identical ratings (lowest) to the goals, *to use science to understand the world* and *to make sure my ideas are scientifically correct* both before and after unit instruction:

> Nora: Because I don't like to understand the world. I don't like to know about things that go on. I don't like to correct my answers and I don't like to go back and look through things 'cause it's boring and I'd rather do other things.

Although Nora actively denied the importance of understanding, she seemed to have a better conception of the nature of science and science learning than her rating of the goal indicated:

> Nora: For me or for us to get good grades and so we could learn more about the matter, like um, learn more about science and things that happen in nature, and like, and solids and liquids and gases, what really goes on and like that.

Her denial of the goal of understanding seemed to be related to her personal conflicts with the teacher. Further, her reaction seemed to be complicated by her learning difficulty or sense of failure in science learning. Unfortunately, the data in the study did not provide evidence for any possible causal linkage between her negative feelings toward the teacher and learning difficulty in science:

Nora: I don't know. He (teacher) is just, he's just weird. It's like if you don't learn science, he don't like you, but I don't know ....
I: Do you think your reasons for doing work in science class have changed since the beginning of the year?
Nora: I hate doing work in science .... If I don't do it, I will get suspended, I'd get bad grades. So that's one reason I do it.

Thus, the results suggest that without experience of success in achieving scientific understanding, the three students showed no change in their perception of the goal of understanding in science class. In the cases of Thea and Kim, they maintained their low value for the goal of understanding in science class. Further, they remained unaware of what scientific understanding involves. Nora, for example, developed even lower value on the goal of understanding due to personal reasons. Further, she also developed lower expectancy of success, as she implied her learning difficulty and failure in science class. Yet, she seemed to develop a better conception of the nature of science and science learning.

Group 4: Success achievement, but less emphasis. This group involves students who were very successful or moderately successful in achieving scientific understanding after unit instruction. Yet, they put less emphasis on the goal of understanding after instruction than prior to instruction (Ken of Pattern 1, Neil of Pattern 3, and Sean of Pattern 4). Rather, other competing goals, including good grades and expectations of parents and teachers, became more salient to them.

In the case of Ken, prior to instruction of the unit, the goal of understanding was his first priority, fact acquisition the second, and good grades the third. After instruction, pleasing his parents became his first priority, understanding the second, and pleasing his teacher the third:

Ken: Well, I want, I just want them (parents) to be happy with my school work, happy with what I am doing.
I: Before the unit, the primary reason was understanding. After the unit, it is pleasing your parents?
Ken: I just, I don't know. I just want my parents to be happy, I guess, happy

with my science work.
I: Can you tell me why you have changed your idea?
Ken: I guess then it wasn't really important because I guess I just like started. And I wanted to get used to it or something. I don't know. . .

In Neil's case, he reported understanding as his second priority before unit instruction. After instruction, he did not report understanding as one of his primary goals at all. Instead, he emphasized getting good grades, pleasing his parents, and doing well in class activities as his three primary goals:

I: Why didn't you include *to use science to understand the world* this time?
Neil: I don't know why I put that last time. Well, it is kind of, but this (to do well in class activities) is more important.
I: Why is this more important now?
Neil: Well, it's more important to do this, and get that.
I: Get what?
Neil: Well, if you do good in this, you usually get good grades.

For all the three students, good grades seemed to serve as means for other personally important goals:

Ken: Well, they (parents) just like it because I get good grades. I don't know. They just like when I do good work in science .... I need good grades because then I could get into a good college, a real good college. Cause I want to be a marine biologist when I grow up.

I: So, you are concerned with getting good grades and pleasing your parents now?
Neil: Right. Well, if I don't, I don't get to play hockey, so—I mean, I won't be able to do anything else, like, I won't be able to do any, any extra activities after school or anything.

Sean: Because I'd rather get good grades, and if I get good grades, then my parents would be pleased .... Because my ma said that if you're going to go to college, you're going to need your science to pass something, to get something.

Despite less emphasis on the goal of understanding after unit instruction, the students seemed to have developed a better conception of the nature of science and science learning. For example, all of them emphasized the goal of understanding as the first priority from the perspective of a science teacher:

Ken: I think that (*to use science to understand the world*) is one of the most important ones, because he (teacher), that's why he's teaching you is to use science to understand the world.
I: You think that *to use science to understand the world* and *to make sure my ideas are scientifically correct* are the two most important reasons—

Neil: Yeah, to a science teacher. I wouldn't think so, but a science teacher would.
I: Would a scientist think that these two reasons are the most important?
Neil: Yeah.
I: But you wouldn't think so?
Neil: Right.

Sean: He (teacher) does want us to use science to understand the world, like the molecules. He is teaching us to understand about molecules and stuff like that.

Thus, after having experienced scientific understanding, the students developed a conception of the nature of science and science learning. Yet, they became more concerned with other competing goals than the goal of understanding in science class. The results suggest that the students developed lower value for the goal of understanding (despite, possibly, higher expectancy of success). Further, the results seem to reflect students' experiences in school environments during the transition to middle school, where there is heavy emphasis on external evaluation, primarily through the form of grading.

Summary and Discussion: Changes in Goal Orientations

The results suggest that the relationship between achievement and changes in goal orientations is not completely systematic. For some students, there seemed to a systematic relationship. Some of the students who successfully achieved scientific understanding seemed to develop higher value for the goal of understanding in science class. Others who experienced learning difficulties and failure achievement in scientific understanding developed lower value as well as lower expectancy of success in the goal of understanding in science class.

The relationship, however, was not systematic for other students. Some of the students who failed to achieve scientific understanding showed no change in their perception of the goal of understanding. Other students, despite their successful or moderately successful achievement, developed lower value for the goal of understanding in science class and became more concerned with other competing goals.

According to research on student motivation, the results seem to be explained in terms of expectancy x value theory. Success or failure to achieve scientific understanding led to changes in students' expectancy of success and value in the goal of scientific understanding (i.e., Groups 1 and 2). Some students did not show any change, since they never realized the goal of understanding in the first place (i.e., Group 3). Further, students' goal orientations were influenced by external factors (i.e., Group 4).

Research on conceptual change in science also seem to be consistent with the results of the study. Students who achieved scientific understanding developed a better conception of the nature of science (i.e., Groups 1 and 4). Some students did not show any change in their perception of the nature of science and science learning, since they never had an awareness of what it means to understand science in the first place (i.e., Kim and Thea of Group 3).

However, conceptual change research does not seem sufficient to explain the remaining three students (Lin and Maria of Group 2, and Nora of Group 4). All of them had some understanding of what scientific involves initially, experienced learning difficulties over the period of instruction, and failed to achieve scientific understanding after instruction. Yet, during post-instruction interviews, they exhibited different perceptions of the nature of science and science learning. These differences seem to be more adequately explained in terms of motivational variables of students: Maria was willing to expend effort to achieve scientific understanding; Lin exhibited a learned-helpless pattern of motivation; and Nora had personal conflicts with the teacher.

Changes in Students' Affective Orientations toward Science

This section describes the findings in relation to two issues: (a) changes in students' ratings of their attitudes toward and interest in science; and (b) changes in the nature of students' affective orientations toward science.

a. Changes in students' affective orientations. When instruction of the unit was completed, almost all the students reported positive affective orientations toward science. With regard to student attitudes toward science, 10 of the 12 students reported positive attitudes, and two reported negative attitudes (average rating +1.2 of maximum +2). With regard to these two students (Thea and Nora), Thea remained to be negative, and Nora changed from mixed to negative attitudes. Thus, there were no significant changes in students' attitudes toward science after instruction as compared to before instruction.

With regard to interest/curiosity in science, 11 students reported high interest and curiosity in science after instruction (average rating +2.8 of maximum +4). Only one student reported complete lack of interest and curiosity in science (Nora, –4). Thus, two students showed changes in their interest after instruction as compared to before instruction: Thea changed from neutral to high interest and Nora, in contrast, changed from high interest to complete lack of interest.

The results suggest two main points. First, students (despite the small number in the study) generally showed less positive orientations after instruction compared to before instruction. The average rating of students' attitudes prior to instruction was 1.5 of maximum 2, which dropped to 1.2 after instruction. In a similar manner, the average rating of students' interest/curiosity prior to instruction was 3.5 of maximum 4, which dropped to 2.8 after instruction. Not counting the drastic changes with Nora, the trend of change was still on the decline. The results suggest that consistent with previous research, students' attitudes and interest in science seemed to decline during the transition to middle school.

Second, students' reports of their affective orientations toward science showed that most of the students did not show significant changes in their affective orientations after unit instruction. Although some students failed to achieve scientific understanding, they still reported positive attitudes and high interest. Thus, success or failure achievement did not seem to be significantly related to changes in students' affective orientations.

b. Changes in the nature of students' affective orientations. If there were no significant changes in students' ratings of their affective orientations toward science after unit instruction, was there any change in students' reports of the nature of their affective orientations? If so, was the change in affective orientations related to students' learning experience or achievement?

The results suggest that success or failure achievement did not seem to be related to changes in affective orientations in a systematic manner. For some students, changes in their affective orientations seemed to be related to their learning experience or achievement. For other students, however, changes in their affective orientations, if any, seemed to be related to other aspects of science class, rather than their learning experience or achievement. These two patterns will be described in the following.

Group 1. Achievement and affective orientations related. This group involves students for whom changes in affective orientations seemed to be related to their learning experience or achievement. The students who had successfully achieved scientific understanding (those of Patterns 1 and 2 engagement, except Maria) seemed to enjoy and appreciate expanding scientific knowledge. Their successful experience of scientific understanding seemed to produce more positive attitudes and higher interest in science:

> Jason: Well, in September I wasn't in that much of science and I didn't have a lot of interest in it and now it's January and I've gained an interest in science, so of truthfully.
> I: Why do you think your interest has changed?
> Jason: Because I've learned a lot more than in September about science. I got different ideas, explanations, and I've got, I like challenging work.
> I: Do you think your reasons for doing work or feelings about science have changed since September?
> Jason: A little, a little—I gained an interest in science, learned a lot more, a lot more and I've just changed my explanations and all that kind of thing.

> Sara: It's kind of fun to learn about the world, about, you know, how it works and stuff, cause before I didn't know about molecules, I didn't understand it, and it was fun to learn.

In contrast, one student (Maria of Pattern 2) experienced frustration and confusion over the period of instruction. She knew that she was not successful in achieving scientific understanding. Yet, she maintained positive attitudes toward science after instruction:

> Maria: Because, you see, in the beginning of the year, I liked science and I like science now. It's my best subject next to math. I don't get the best grades in science, but I get good grades, and I want to know more about science to get the best grades. And I like science to know about the molecules and the gases and everything, so like when my sisters need help in that kind of situation, I would know how to do it and how to explain it. I like science.

Group 2. Achievement and affective orientations not related. This group involves students for whom there was no systematic relationship between changes in affective orientations and learning experience or achievement. Instead, their affective orientations seemed to be related to class activities, especially science experiments. Even when students were not successful in achieving scientific understanding, their affective orientations remained positive and unchanged after instruction:

Neil: Well, sometimes it's fun.
I: When is it fun?
Neil: When we get to do experiments.
I: What else?
Neil: That's about it.
I: Is there a time when science is not fun?
Neil: When we have to a lot of work?
I: Like what?
Neil: Like a lot of writing stuff—uh, listening to the teacher talk a lot.
I: Was there a lot of writing in the unit?
Neil: Yeah.

Lin: Sometimes it's fun when we do experiments, and sometimes it's boring ... When you do experiments in science, it's fun. It's a lot of fun.
I: When is it boring?
Lin: Sometimes I don't like to do the work, things I don't like.

Although two students (Thea and Nora) reported significant changes in their affective orientations after instruction, their changes were influenced by reasons other than learning experience or achievement:

Thea: It (the unit) was fun, and we get to do a lot of experiments and talked about all the things that had molecules in it .... It was boring at first, but it's not any more.

Nora: Science is boring. In science, you have to be quiet.
I: Other reasons why science is boring?
Nora: The work is boring.
I: Does that mean that you don't think the work that you are doing in science class is important?
Nora: Well, it's important, but it's boring.
I: Can you tell me at all why your feelings about science class have changed?

Nora: Because in the beginning, I thought school was fun and that science was fun, too. But now it's boring. The teacher, you know, I don't know, he's weird.

Summary and Discussion: Changes in Affective Orientations

The results suggest that success or failure to achieve scientific understanding did not seem to be related to changes in students' affective orientations in a systematic manner. Students who successfully achieved scientific understanding seemed to enjoy and appreciate expanding scientific understanding. However, many others who were not successful generally remained positive in their attitudes and maintained high interest after unit instruction. The results suggest that changes in students' affective orientation often seemed to be related to aspects of science class, especially science experiments, rather than learning experience or achievement.

Changes between Students' Goal and Affective Orientations

Is there any systematic relationship in the changes between these two aspects of student motivation? Did students change their affective orientations toward science as they developed different conceptions of the nature of science and science learning and, thus, changed their goals in science class?

As already discussed, success or failure to achieve scientific understanding did not seemed to lead to changes in either students' goal orientations or affective orientations in a systematic manner. Thus, it is quite complicated to find a relationship in changes between student goals (i.e., cognition) and attitudes and interest (i.e., affect). The following discussion covers only two major patterns, disregarding other variations.

When students successfully achieved scientific understanding and experienced meaningful learning of science, they developed a better conception of the nature of science and science learning and also more strongly emphasized the goal of understanding in science class. Further, they seemed to enjoy and appreciate a deeper and richer understanding of scientific knowledge. In this case, achievement of meaningful understanding led to the internalization of the goal of understanding and also enjoyment of scientific understanding in a consistent manner.

In contrast, some students were not successful in achieving scientific understanding after unit instruction, failed to develop a conception of the nature of science and science learning, and did not recognize understanding as a major goal in science class. Or, others de-emphasized the goal of understanding after having experienced learning difficulties or failure achievement. Nevertheless, the students reported positive affective orientations toward science mainly due to aspects of science class, especially science experiments. In this case, changes in students' goal orientations and affective orientations were not consistent.

CHAPTER SIX

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

This chapter begins with a summary of the findings. Then, implications of the study for research and curriculum development and classroom teachingwill be addressed.

Summary of Findings

The present study examines three research questions: (a) What are the patterns of students' task engagement (i. e., choice of goals and strategies) in science classrooms? (b). What are the key factors related to patterns of task engagement? and (c). What happens to student motivation when students succeed or fail to achieve scientific understanding?

The findings of the study showed six different patterns of task engagement. These patterns are related to several key factors, including (a) students' interpretations of the nature of classroom tasks, (b) students' success or failure to make progress in scientific understanding, (c) students' general goal orientations in science class, and (d) to a limited extent, students' affective orientations toward science. Finally, achievement of scientific understanding after a period of instruction seemed to lead to changes in students' goal orientations and affective orientations, although not in systematic ways. The findings of this study are summarized below; they are arranged by patterns.of task engagement

<u>Pattern 1: Intrinsically Motivated to Learn Science</u>

On their own initiative, the students actively constructed their own knowledge as they tried to integrate their personal knowledge with scientific knowledge and apply scientific knowledge to understand and explain the world around them. Thus, they seemed to be motivated to learn science as a general disposition because they found learning science intrinsically interesting and enjoyable.

While engaging in classroom tasks, these students adequately understood the content objectives and difficulty of those tasks. They recognized that the problems posed in the classroom tasks had to be solved through scientific thinking, and they monitored their learning difficulties. They made consistent progress in scientific understanding as instruction of the unit continued. They had a conception of the nature of science and science learning as a means for understanding and explaining the world around them. They emphasized the goal of understanding as their first priority in science class and reported positive attitudes and high interest in science.

When the unit was completed, these students successfully achieved scientific understanding of kinetic molecular theory. They could construct spontaneous and elaborate scientific explanations. They had developed a clear conception of the nature of science and science learning and also enjoyed a deeper and richer understanding of scientific knowledge. One student internalized the goal of understanding in science class, while the other became more concerned about other competing goals, such as getting good grades and pleasing his parents and the teacher.

Pattern 2: Motivated to Learn Science.

With the support of the curriculum unit and the teacher, the students tried to integrate their personal knowledge with scientific knowledge and apply scientific knowledge in order to understand and explain natural phenomena. Thus, they demonstrated a state of motivation to learn science in many specific task situations.

While engaging in classroom tasks, these students adequately understood the content objectives and difficulty of those tasks. Able both to recognize the nature of the problems posed in the classroom tasks and to monitor their learning difficulties, Pattern 2 students made overall progress in scientific understanding as instruction continued. They had some knowledge of the nature of science and science learning and emphasized understanding as one of their major goals, although not the first priority, in science class. They also reported positive attitudes and high interest in science.

When the unit was completed, the students successfully achieved scientific understanding, developed a conception of the nature of science and science learning, and internalized the goal of understanding in science class. They also enjoyed and appreciated expanding their scientific knowledge.

Pattern 3: Intrinsically Motivated but Inconsistent.

The quality of the task engagemnt for this one student seemed to depend on his intrinsic interest; it was inconsistent across task situations. In those task situations that he found interesting, he demonstrated initiative in cognitive engagement. In other situations, however, he was neither attentive nor involved in class activities.

While engaging in classroom tasks, he adequately understood the content objectives and difficulty of those tasks. As instruction of the unit continued, he made overall progress in scientific understanding, although he failed in those task situations in which he was not attentive in class due to his lack of interest. He had some knowledge about the nature of science and science learning and emphasized understanding as one of his major goals in science class, although this was not the first priority. He also reported positive attitudes and high interest in science.

When instruction of the unit was completed, the student was reasonably successful in achieving scientific understanding. Although he demonstrated a clear conception of science and science learning, he no longer emphasized understanding as one of his major goals in science class. He reported positive attitudes and high interest in science.

Pattern 4: Task Completion

The Pattern 4 student generally appeared to be attentive in class and involved in class activities. However, he was not cognitively engaged in classroom tasks. He seemed to be concerned with completing classroom work, not necessarily with understanding.

In specific task situations, this student often failed to understand the content objectives or difficulty of classroom tasks. Over the period of instruction, he showed mixed performance in scientific understanding. He seemed to have some knowledge of the nature of science and science learning, although he did not emphasize understanding as one of his major goals in science class. He reported positive attitudes and high interest in science.

At the completion of unit instruction, the student was moderately successful in achieving scientific understanding and seemed to develop a better conception of science and science learning. Yet, he did not emphasize understanding as one of his major goals in science class and, instead, remained more concerned with other competing goals in science class.

Pattern 5: Task Avoidance

The Pattern 5 students were not cognitively engaged in classroom tasks. They were neither attentive nor involved in class activities. Their main concern seemed to be getting the work done with a minimum of effort.

In specific task situations, these students failed to understand the content objectives of classroom tasks or monitor their learning difficulties. As instruction of the unit continued, they generally failed to achieve scientific understanding. They did not have knowledge of the nature of science and science learning and did not emphasize understanding as one of their major goals in science class. Yet, they generally reported positive attitudes and high interest in science.

When the unit was completed, the students failed to achieve scientific understanding, develop a conception of science and science learning, and recognize understanding as a major goal in science class. Yet, they reported positive attitudes and high interest in science.

Pattern 6: Disruptive Behavior

The Pattern 6 student actively avoided engaging in classroom tasks or participating in class activities. Further, she resisted engaging in classroom tasks and often displayed disruptive behavior and disciplinary problems in class.

While engaging in classroom tasks, she had some understanding of the content objectives of the tasks, but did not seem to admit when she was having learning difficulty. Over the period of unit instruction, she consistently failed to achieve scientific understanding. Despite the fact that she had some knowledge of the nature of science and science learning, she seemed to deny the goal of understanding in science class. She reported negative attitudes toward the science teacher and science class, although she liked some aspects of science and had high interest in science.

When instruction of the unit was completed, this student actively denied the goal of understanding in science class. Further, she developed completely negative attitudes and no interest in science.

Conclusions and Implications for Research

The goal of this study was to better understand the critical problem of students being unwilling to work hard in science classrooms. Even when they are willing, they expend effort to achieve less valued outcomes, such as memorizing vocabulary words or facts, rather than trying to achieve scientific understanding. While engaging in classroom tasks, many students rely on strategies that minimize their efforts in completing the work. This raises a concern among science educators about how to stimulate student motivation to learn science.

Problems of student motivation in science classrooms have been addressed by two research traditions: conceptual change in science tradition and student motivation. Conceptual change researchers stress content knowledge and propose various ways to improve curriculum materials and develop instructional strategies to help students understand the content in science. Motivation researchers, on the other hand, focus on motivational variables, proposing various strategies to stimulate aspects of student motivation. Prior to the current study, research in the two research traditions was conducted separately, focusing either on content knowledge or on motivational variables, but never addressing the two in conjunction. This study attempted to examine issues of student motivation in science classrooms according to both research traditions.

The present study was conducted in science classrooms where the curriculum materials were developed according to a conceptual change approach and instruction was implemented as intended in the curriculum. This research context provided a test case for examining the assumptions of conceptual change research about issues of student motivation. The results show that when the curriculum materials and instruction provided students with the opportunity to learn science in a meaningful way, some students accepted this opportunity and were motivated to learn science, while others still expended little effort to achieve scientific understanding.

Do the results indicate that the assumptions of conceptual change research are wrong? Unfortunately, the results allow only partial testing of the assumptions, because the research context did not approximate ideal conditions for study according to the conceptual change approach. There were aspects of teaching that were not addressed in the curriculum, and the implementation of instruction was inadequate. The teachers did not interact with individual students in ways that would have led to greater students' engagement within the social contexts of classrooms.

Since the research context was not ideal for student learning of science, the student motivation problems encountered in the study can be attributed either to features of curriculum materials and instruction or to motivational variables of students. The results of the study suggest that both of these traditions have important insights to offer to those who wish to understand and improve science teaching. Yet, there are limitations and conflicts that make it difficult to integrate knowledge generated by the two traditions.

For instance, consistent with conceptual change in science, the extent of students' background knowledge and constructed knowledge over the instructional period seemed to be important factors for the quality of students' task engagement. Further, the effects of curriculum and instruction in helping students expend high quality of task engagement seemed to be significant. (e.g., Patterns 1 and 2). However, many students did not accept the opportunity provided in the curriculum and instruction as a better alternative (Patterns 3 to 6).

Consistent with research in student motivation, on the other hand, problems of low quality of task engagement *could* be attributed to students' low expectancy of success or low value for the goal of scientific understanding. Further, negative affects could also be a barrier to task engagement.

The results of the study, however, do not permit a complete resolution about problems of student motivation during task engagement. Sine the curriculum and instruction did not approximate the ideal situation, problems of students' low quality of task engagement would be attributable to either (a) the inadequacy of curriculum and instruction, although they would be willing to expend effort if they received more support, or (b) their lack of willingness to expend effort due to inappropriately low expectancy of success or low value, even when the curriculum and instruction provided a better context for their learning.

These results rail fundamental questions about issues of student motivation in science classrooms for further research. Can we separate content knowledge from motivational variables of students? How much of students' patterns of task engagement or their success or failure to achieve scientific understanding can be attributed to content knowledge? How much is the work of motivational variables? The results here suggest that student motivation is a complex problem. To solve this problem, both content knowledge and motivational variables need to be considered.

The methodology used in the study has significant implications for the research community. The rich descriptions in this study provide a deeper understanding of the constraints as well as contributions of each tradition to explain issues of student motivation. Further, the rich descriptions show how various factors interact in individual students.

This study only begins to tackle these questions. Although the results of the study do not provide clear answers, they make significant contributions to the research community about how to integrate the two research traditions. Future research should investigate the limitations of each tradition and how to resolve conflicts between the two.

Implications for Curriculum Development and Classroom Teaching

The following discussion covers two issues related to the findings of this study. The first part of the discussion concerns the effects of curriculum materials and instruction on patterns of student task engagement in the present study. The second part of the discussion uses the study findings as a starting point, relating them to implications for future curriculum and instructional development in science education.

Effects of Curriculum and Instruction

The curriculum materials and instruction in this study were designed to help students expend high quality of task engagement and, thus, achieve scientific understanding. The results of the Science Achievement Project show that a higher proportion of students taught by the revised "Matter and Molecules" unit achieved scientific understanding (50% success rate) than those taught by a commercial curriculum unit (26% success rate). However, only half of the 12 students in this study accepted the opportunity provided by the curriculum and instruction as a better alternative and exhibited clear motivation to learn science during task engagement (Patterns 1 and 2). Five of these students successfully achieved scientific understanding of kinetic molecular theory (Patterns 1 and 2, except Maria). The results of the Science Achievement Project also showed that 50% of students who were taught by the revised "Matter and Molecules" unit failed to achieve scientific understanding of kinetic molecular theory. Thus, the effectiveness of the curriculum materials and instruction seems to be limited.

Pattern 1. These students were distinguished by their self-initiated cognitive engagement. They expanded their thinking and understanding about science beyond the scope of the content presented in the curriculum and instruction. Further, they seemed to engage in science tasks primarily because they wanted to learn science. When instruction started, they had substantial background knowledge and placed high value on the goal of understanding. In this regard, they did not seem to need extensive support from curriculum materials and instruction. Even without such support, they *could* have demonstrated high quality of cognitive engagement independently

Pattern 2. The quality of task engagement for Pattern 2 students occurred within the scope of the content that was actually presented. This suggests that their pattern of task engagement was closely related to the special features of the curriculum materials and instruction. While engaging in science tasks, these students recognized their misconceptions and the confusion between their personal knowledge and scientific knowledge. With the support of the curriculum materials and instruction, they resolved their learning difficulties and achieved scientific understanding. The curriculum materials and instruction seemed to be most effective for these students; they realized the value of scientific understanding and recognized their chances of success in achieving this valued outcome.

Patterns 3 and 4. The curriculum materials and instruction were only partially effective in helping these students expend high quality of task engagement. For Neil (Pattern 3), the meaningfulness of the curriculum materials and instruction triggered his intrinsic motivation in certain task situations. In those instances, Neil successfully connected his prior knowledge to the content being taught and applied scientific knowledge to explain his personal experiences. Sean's (Pattern 4) primary goal was to complete classroom tasks; the curriculum materials and instruction were effective for him because they set a high standard of curricular goals and forced him to exert enough effort to complete classroom tasks.

Despite some potential, however, neither student accepted scientific understanding as a preferred alternative. The results suggest that both Neil and Sean were more concerned with other competing goals than with achieving understanding in science class. Thus they seemed to have low value in the goal of understanding, although they were reasonably successful in achieving scientific understanding.

Pattern 5. The curriculum materials and instruction did not have any significant impact on helping these students expend high quality of task engagement. While engaging in science tasks, Pattern 5 students tried to avoid task engagement and relied on strategies to minimize their efforts in completing the tasks. The results suggest that the students never claimed scientific understanding as a preferred goal. Further, they had low expectancy of success in science class altogether.

Pattern 6. This student's low quality of task engagement stemmed primarily from her personal conflicts in science class and was further complicated by her sense of failure achievement. Study results suggest that her negative attitudes toward science class led her to actively resist the goal of understanding.

Strategies to Overcome Motivational Barriers

The effects of curriculum and instruction differed across patterns of task engagement. The two students of Pattern 1 might have been successful without extensive support of curriculum and instruction. Research also shows that in traditional classrooms using commercial textbooks, a small proportion of students (about 20% of the student population) can expend the high quality of task engagement needed to achieve scientific understanding. (C. Anderson, 1987; Fensham, 1985; Yager and Hofstein, 1986).

The curriculum and instruction seemed to be most effective for students who were willing to expend effort but needed extensive support from curriculum materials and instruction (Pattern 2). Without such support, they might have expended their effort for the less valued outcomes, as is often the case in traditional practice. Thus, the results indicate significant improvements of the curriculum and instruction in the present study over traditional practices.

The effects of curriculum and instruction, however, were limited for other students. (Patterns 3 to 6). They needed more support than the curriculum design and instructional method provided. This uneven distribution of task engagement was especially noticeable in the students of Patterns 3-6. What might have happened to these students if the curriculum materials and instruction had provided more support? Such methodological and content additions as slowing down the pacing of instruction for individual students, using additional tasks, more scaffolding for conceptually complicated tasks, and increasing expectations for students to be accountable for their learning outcomes instead of just finishing the work are among the possible devices for improving the supportive nature of the curriculum and classroom teaching.

The results of the study suggest implications for science educators to help students, including those who are currently failing, expend high quality of task engagement. The following discussion suggests strategies to overcome the four factors identified as barriers to student motivation to learn science, and considers the effects of constraints in the social contexts of classrooms on student motivation.

<u>1. Help students adequately interpret classroom tasks.</u> Students' interpretations of the nature of classroom tasks are a particularly serious problem in science class. Many students, like Pattern 4 student Sean, are committed to their common-sense explanations. Relying heavily on his incorrect prior knowledge, Sean often misinterpreted the content objectives of classroom tasks and, thus, failed to realize when his prior knowledge was in conflict with scientific knowledge.

Curriculum materials and instruction should clearly communicate to students what classroom tasks are intended to teach. They should make explicit how the scientific knowledge presented in the tasks is related to students' prior knowledge. Curriculum and instruction also need to emphasize places where many students are expected to have learning difficulties. For this purpose, curricular development should be based on an extensive knowledge base about common students' misconceptions in a content domain.

<u>2. Help students make progress in achieving scientific understanding.</u> Curriculum materials and instruction should provide extensive support for students to realize that they can achieve scientific understanding if they expend a reasonable effort. They should help students actually experience scientific understanding, as illustrated by the case of Lin

(Pattern 5). Although Lin accurately identified both what the classroom tasks were intended to teach and her own learning difficulties, she was easily discouraged and quickly terminated task engagement. Lin seemed to focus on low expectancy of success at the expense of the value of understanding. The case of Maria (Pattern 2) was more complicated. Although Maria tried hard to achieve scientific understanding, she failed. The results suggest that her low expectancy of success after failure achievement could be a problem in motivation.

One way to help students like Maria and Lin is to design curriculum materials to be simpler for the student to access. More importantly, teachers need to provide such students with more individual attention and scaffolding. Continuous experiences of success achievement would gradually build up their knowledge base; as a consequence, their expectations of successfully achieving scientific understanding would also increase.

3. Help students realize the value of the goal of understanding. Some students recognized understanding as a major goal in science class, but did not emphasize it as a personal goal. Instead, they were more concerned about other competing goals. A major motivational problem seemed to be their low value in the goal of understanding, considering that they were moderately successful in achieving scientific understanding. This is especially true of Neil (Pattern 3) and Sean (Pattern 4).

Well-designed curriculum materials and teaching methods can help students realize the value of the goal of scientific understanding. The teachers' initial prodding of students toward realizing the importance of the goal of understanding serves as a means toward achieving other goals, probably the ones that the students themselves are more concerned with. As students experience the value of scientific understanding, teachers can guide them to internalize the goal of scientific understanding as an end itself in science class.

The value of understanding is a far more important factor for the students of Pattern 5, who never realized the goal of understanding in science class. Curriculum materials and instruction should help students realize that the goal of understanding is relevant to their performance in science class. Recent research suggests various motivational strategies for tapping the value aspects of understanding (Brophy, 1986).

4. Help students develop positive affective orientations toward science. Curriculum materials and, particularly, teaching methods should incorporate an awareness of students' affective orientations. It is likely that negative feelings toward aspects of science class, including curriculum materials, class activities, and teachers, is detrimental to students' willingness to expend effort during task engagement (e.g., Nora of Pattern 6). For these students, sources of negative feelings or personal conflicts need to be eliminated early on in the instruction (Brophy & Rokrkemper, 1982, 1987).

Finally, in addition to effective curriculum materials and implementation of instruction as planned in the curriculum, teachers should provide well-conducted scaffolding for individual students according to their individual needs. However, the constraints of the typical social context of classrooms could be a barrier to student motivation to learn science. For example, the teacher's decisions about the pace of instruction and accountability system require substantial modifications of traditional whole-class instruction methods. To provide needed support for individual students, especially those who possess less content knowledge or are less motivated than others, teachers need to pay more individual attention to such students and hold them accountable for their learning.

Maria's (Pattern 2) case presents an example of how constraints in classroom settings can be a barrier to student motivation to learn science. Even under the best conditions, when the curriculum materials, instruction, and the student all are oriented toward the goal of scientific understanding, classrooms are structured in such a way that one teacher can not attend to the needs of every single student. Teachers have to decide how to conduct instruction within the social environments in classrooms.

APPENDICES

APPENDIX A

CLASSROOM OBSERVATION GUIDELINE

I. READING

Quality of Task Engagement (R.Q. 1)

1. Behavioral Engagement

   a. Student involvement, on-task behavior:
   What is the student's apparent target of attention? (e.g., read text, talk to others, look at neighbors, look around the room, put one's head down on desk, draw or write on paper)

   b. Is there any indication that the student pays extra attention to reading? (e.g., move one's mouth, follow reading with a finger or pencil, reread passage)

   c. When the student is off-task, what is the nature, duration, and the apparent cause of the behavior?

   d. (read aloud in class)

   How frequently does the student volunteer to read aloud?
   How frequently is the student called on to read aloud by the teacher?

2. Cognitive Engagement (during informal interview)

   a. The observer asks the student about content of reading:
   "What did you read about?"
   "Can you summarize what you read?"

   b. A couple of specific content questions will be selected in advance and used to probe the student's content understanding. (e.g., How big are molecules? How does their size compare with, for example, the size of a speck of dust? Can you see molecules with a very powerful miscroscope?)

Interpretations of Classroom Tasks (R.Q. 2-a)

1. Content Objectives (during informal interview)

   a. "Do you learn anything new in the reading?"
   "What is new in the reading?"

b. "What is the main idea of the reading?"
"What is the reading about?"
"What does the reading help you to learn about?"

c. "Why do you think you read these pages?"
"What is the purpose?"

2. Perceived Difficulty (during informal interview)

a. "How difficult is the reading to you?"
"Is there anything you don't understand?"

b. "Which parts of the reading are difficult? Why?"
"Which parts of the reading are easy? Why?"

II. WRITING IN ACTIVITY BOOK

Quality of Task Engagement (R.Q. 1)

1. Behavioral Engagement

a. Student involvement, on-task behavior
What is the student's apparent target of attention? (e.g., talk to other students, work on assignment)

b. Are there any indications of persistence or lack of persistence?

c. How does the student respond to distraction?

d. How many questions in the activity book has the student finished?

e. If the student finishes ahead of time, what does the student do next?

f. After the student finishes the activity book, does the student read over, check, or revise the answers?

2. Cognitive Engagement

a. Where does the student find information for questions in the activity book? (e.g., read textbook, discuss with others, copy someone's answers)

b. Which questions has the student finished? What is the nature of the questions finished and those not finished?

c. If the student talks to friends or the teacher, who initiates the conversation? What is the conversation about? (e.g., content-related, socialization)

d. A couple of specific content questions in the activity book will be decided in advance and used to probe the student's content understanding.

Interpretations of Classroom Tasks (R.Q. 2-a)

1. Content Objectives

   a. "What is new with these questions?"
   "Did you learn anything new from the questions?"

   b. "What are these questions about?"
   "What is the main idea in the questions?"
   "What do these qustions help you learn about?"

   c. "Why do you think these questions are here?
   "What is their purpose?"

2. Perceived Difficulty

   a. "How difficult are these questions to you?"

   b. "Which questions are difficult for you? Why?"
   "Which questions are easy for you? Why?"

III. HANDS-ON EXPERIMENT

Quality of Task Engagement (R.Q. 1)

1. Behavioral Engagement

   a. Student involvement, on-task behavior:
   What is the student's apparent target of attention? (e.g., talk to friends, walk around the room, spend most time on experiment)

   b. How does the student respond to distraction?

   c. How enthusiastic does the student appear to be?

   d. How many questions has the student finished in the activity book?

   e. After the student finishes the experiment and the questions in the activity book, what does the student do next? (e.g., talk to friends, read text, go to teacher to talk)

   f. After the student finishes the questions in the activity book, does the student read over, check, or revise the answers?

2. Cognitive Engagement

   a. What aspect of the experiment does the student appear to be most concerned about? (e.g., set up equipment, measure or observe, interpret results?)

   b. How well does the student follow the procedure of the experiment?

c. When the student seems to be confused about the experiment, how does the student react? (e.g., simply complete it, check with friends, teacher or textbook)

d. Where does the student get information for questions in the activity book?

e. Which questions has the student finished in the activity book? What is the nature of the questions finished and those not finished?

f. If the student talks to friends or the teacher, who initiates the conversation? What is the conversation about? (e.g., content-related, socialization)

g. One or two specific questions concerning the content of the experiment or questions in the activity book will be decided in advance and used to probe the student's content understanding.

Interpretations of Classroom Tasks (R.Q. 2-a)

1. Content Objectives

a. "What is new to you in this experiment?"
"Did you learn anything new in this experiment?"

b. "What is this experiment about?"
"What is the main idea of this experiment?"
"What does this experiment help you learn about?"

c. "Why do you think you do this experiment?"
"What is its purpose?"

2. Perceived Difficulty

a. "How difficult is this experiment to you?"
"How difficult are the questions in the activity book?"

b. "What parts of the experiment are difficulty? Why?"
"Which questions in the activity book are difficult?"
"Which questions are easy? Why?"

IV. CLASS DISCUSSION

Quality of Task Engagement (R.Q. 1)

1. Behavioral Engagement

a. Student involvement, on-task behavior: What is the student's apparent target of attention? (e.g., teacher, text, outside the window, look at neighbors, draw or write on paper)

b. How frequently does the student engage in class discussion?
—raise his/her hand
—ask questions
—give answers to questions
—make comments
—called on by the teacher

c. How enthusiastic or uninterested does the student appear to be? (e.g., volunteer to express ideas, wait until other students give their answers first, hesitate giving answers, tone of voice)

2. Cognitive Engagement

a. When called on by the teacher to give an answer, how does the student respond? (e.g., wait until the teacher calls on another student, give key words, do not respond)

b. Where or how do the student find the answer? (e.g., copy somebody's answer; copy from text)

c. What is the quality of the student's questions, comments, or answers? (e.g., not relevant to content being discussed, factual information; higher-order thinking)

<u>Interpretations of Classroom Tasks (R.Q. 2-a)</u>

1. Content Objectives

a. "What is new during class dicussion?"
"Did you learn anything new during discussion?"

b. "What is the dicussion about?"
"What is the main idea in the discussion?"
"What does the discussion help you learn about?"
c. "Why do you think you have class discussion today?"
"What is the purpose?"

2. Perceived Difficulty (during informal interview)

a. "How difficult was the discussion to follow?"

b. "Which parts were difficult to follow? Why?"
"Which parts were easy to follow? Why?"

APPENDIX B

Clinical Interview Protocol for Kinetic Molecular Theory

TASK 1: Describe, contrast, and classify the three states of matter.

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

Materials:
Rock or metal, Water, Plastic bag of air
Sheet with a list of things
Pencil and paper for drawings

		Questions	Commentary
Task 1-1	O:	Can you tell me how these three things are different?	
States of matter	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 liquid?	
	P6:	How do you decide whether something is a liquid or gas?	

Task 1-3	Questions	Commentary
Nature of gas (air)	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?	whether students think in terms of empty spaces and constant motion of molecules (waves, chunks, etc.), and
	P2: Suppose you are able to see air with magic eyeglasses. What is air made of? (What is in the air?)	Purposes: To determine (1) students' conceptions of air, (2) student's microscopic view of gases (air), liquids, and solids,
	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?	(4) whether students understand that
	P5: (If student mentions molecules) Is air a mixture? What does that mean? Is air made of different molecules?	the empty space and motion vary in solids, liquids, and gases (air). What we want to know:

Task 1-4		
Nature of liquid (water)	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 (waves, etc.)? Are they all the same? What is between them? Are they moving? If so, are they always moving?	

		Questions	Commentary
Task 1-5 Nature of solid	O:	Another student told me that a rock is made of very very, very smal 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 a rock still?	
	P2:	Suppose you can see rock through magic eyeglasses. Draw a picture of what you would see.	
	P3:	(If student draws dots) What are these dots? Are they all the same? Is there any space between them?	
Task 1-6 Comparison of three states of matter	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 2: Explain and contrast Compression of Gases and Liquids

Situation:

Student will cover the end of the syringe with his/her finger and push down on the plunger first with the syringe filled with air and second with the syringe filled with water.

Materials:

Syringe (2)
Water and air
Drawings of syringe in normal state and when compressed

Task 2-1	Questions		Commentary
Compression of gas	O:	What do you think will happen if you push down on the plunger?	Purposes: To determine whether students (1) know that air (gases) is compressible and water (liquids) is not in a syringe,
	P1:	What do you notice when you push on the plunger?	
	P2:	Explain why the plunger can be pushed in most of the way, (2) but not all of the way.	and (2) can relate compressibility of gases to the relative size of empty spaces between gases (air) and liquids (water).
	P3:	Draw a picture of the air before and after compressed in the syringe. (If the student cannot respond to this question, show him/her the drawings from the test.)	What we want to know: Can students (1) explain (on a microscopic level in terms of space and distribution) why air (gases) is compressible and water (liquid) is not, and (2) generalize from these examples to all gases and liquids.
	P4:	Compare the drawings when the air is compressed and not compressed.	
	P5:	Name another example of a gas.	
	P6:	What will happen if you use another gas in the syringe.	

Task 2-2		Questions	Commentary
	O:	What do you think will happen with water in the syringe?	
Compression of liquid	P1:	Why can't you compress water? (If student has difficulty, ask) You pushed on the plunger of the syringe with air in it and then with water in it. Why can you compress air but not water?	
	P2:	Name another example of liquid.	
	P3:	What will happen if you use that liquid in the syringe?	

Task 2-3			
Comparison of gas vs. liquid	O:	You pushed on the plunger in the syringe with air in it and then with water in it.	
	P1:	Why can you compress air but not water?	

Task 3: Explain Changes of States of Matter

Situations:

Melting ice: Leave ice cubes melting in the plastic cup.
Boiling water: boil water in the beaker on the plate.
Condensing water: Pop can and glass plate above boiling water
Evaporating alcohol: Place drops of alcohol on the slide.
Smell of perfume: Take top off of perfume container

Task 3-1	Questions	Commentary
Melting ice	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	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?	
	P3: (If student mentions bubbles) Is there anything inside the bubbles? What?	

Questions | **Commentary**

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 more freely?
P8: In which state do molecules move farther apart?

Task 3-3

condensing on glass plate

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?

<u>Task 3-4</u>	O:	What do you see happening here?
Evaporation	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?

<u>Task 3-5</u>	O:	Can you smell the perfume?
	P1:	What is the smell made of?
Smell	P2:	How did the smell of perfume get from the glass to your nose?
	P3:	Can you explain in terms of molecules?
	P4:	Molecules of what? Where did they come from?
	P5:	If we put a top on the perfume, would you still be able to smell it? Why or why not?

TASK 4: Explain Pure Substance vs. Mixture and Process and Rate of Dissolving

Situations:
Dissolve Epsom salts (in tea bag) in water.

Materials:
Epson salts, Tea bags, Cups, cold water

Task 4-1	Questions		Commentary
Dissolving Epsom salts (or sugar)	O:	What is happening to the Epsom salts (or 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 Epsom salts and water sitting for one day, what will happen? Will Epsom salts be all over or in one place? Will Epsom salts sink to the bottom? Why or why not? Can you explain in terms of molecules?	
	P4:	If we put a tea bag of Epsom salts 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 Epsom salts and water a mixture or a pure substance?	
	P6:	Can you explain why?	

Task 5: Explain Thermal Expansion of Gas and Solid

Situations:

Put the balloon on the rim of 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.

Materials:

Balloon, Bottle,
Ball, Ring, Hot Plate

Task 5-1	Questions	Commentary
Thermal expansion of gas	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?	Purposes: To determine how students explain thermal expansion of gases and solids. What we want to know: Macroscopic: (1) Do students think that solids and gases expand or shrink when heated, and (2) do students think in terms of hot air rising or expanding in all directions when heated? Microscopic: Can students explain ther expansion in terms of molecular motion and empty spaces?

		Questions	Commentary
Task 5-2	O:	The ball goes through the ring now (unheated). What will happen if we heat the ball?	
Thermal expansion of solid	P1:	Why can't we pull the ball through the ring after heating? Can you explain in terms of molecules?	
Task 5 (cont.)	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 C

INTERVIEW PROTOCOL: STUDENT GOAL ORIENTATIONS IN SCIENCE CLASS AND AFFECTIVE ORIENTATIONS TOWARD SCIENCE

Note: This is the instruction for the interviewer. Five short sets of questions will be presented to the student on separate sheets during the interview.

Introductory Direction to Student:

I: "Today we will talk about why you and other people do work in science class. First, we will talk about how you like science."

Opening Question:

I: "Suppose you had a choice between science class and free time. Which would you choose? Why?"

PART I: AFFECTIVE ORIENTATIONS TOWARD SCIENCE

1. Using the sample question, the interviewer explains to the student about how to answer the questions on Question Set I.

2. The student completes Question Set I by him/herself.

3. The interviewer asks the student about his/her reasons for the responses.

   I: "Would you explain to me about each of your responses?"

QUESTION SET I: HOW I LIKE SCIENCE

Sample Question

	really true for me	sort of true for me				sort of true for me	really true for me
	☐	☐	Some kids would rather play outdoor in spare time	BUT	Other kids would rather watch TV.	☐	☐
1.	☐	☐	Some kids like science.	BUT	Other kids don't like science.	☐	☐
2.	☐	☐	Some kids think science is boring	BUT	Other kids think science is fun and interesting.	☐	☐
3.	☐	☐	Some kids are curious to learn about science	BUT	Other kids don't care to learn about science	☐	☐

PART II: STUDENT GOALS IN SCIENCE CLASS

1. The interviewer asks the student to explain what he/she think about science and science learning.

   "What does science mean to you?"
   "What does learning science mean to you?"
   "Why do you study science?"
   "Is science important? Why?"

2. The interviewer asks the student to generate his/her own list of goals in science class.

   I: "What are some reasons you do work in science class?"

   I: "What might other people give as reasons for doing work in science class? (e.g., classmates, science teachers, parents, or scientists)

3. The interviewer presents the following list of goals (in a random order arranged on a sheet of paper) to the student and briefly talks about the goals on the list.

   I: "Here are some reasons that people sometimes give for doing work in science class."

   The interviewer makes sure that the student understands the conversation.

Possible Reasons for Doing Work in Science Class

a. Understanding
to use science to understand the world
to make sure my ideas are scientifically correct

b. Fact Acquisition
to learn vocabulary and definitions
to memorize facts and information

c. Performance in Class
to get work done on time
to do well in class activities
to get good grades
to do better than other students

d. Expectations of Significant Others
to please my parents
to please my teacher
to show that I am a smart person

e. Extrinsic Rewards
to receive rewards from parents (e.g., extra money)

f. Work Avoidance
to do as little work as possible

1. ABOUT MYSELF

1. The interviewer asks the student to complete Question Set II.

   I: "After reading each question, mark the number that you think applies to youself most closely."

2. The student completes Question Set II by him/herself.

3. The interviewer asks the student to report three primary reasons (goals) in order.

4. The interviewer asks the student to explain the responses.

   I: "Would you explain to me about each of your responses?"

2. VERY GOOD SCIENCE STUDENT

1. This time, the interviewer asks the same set of questions with reference to a very good science student.

   I: "Now, let's imagine a student who is really good in science. How do you think this student would respond to the following questions?"

2. The student completes Question Set III by him/herself.

3. The interviewer asks the student to report three primary reasons (goals) in order.

4. The interviewer asks the student to explain the responses.

   I: "Would you explain to me about your responses?"

3. SCIENCE TEACHER

1. The interviewer asks the student about why his/her science teacher would like him/her to do work in science class.

   I: "Think about your science teacher. Why do you think he wants you to do work in science class?"

2. The student completes Question Set IV by him/herself.

3. The interviewer asks the student to report three primary reasons (goals) in order.

4. The interviewer asks the student to explain the responses.

I: "Would you explain to me about your responses?"

4. SCIENTIST

1. The interviewer asks the student about why a scientist would like him/her to do work in science class.

I: "Think about a scientist. Why do you think he wants you to do work in science class?"

2. The student completes Question Set V by him/herself.

3. The interviewer asks the student to report three primary reasons (goals) in order.

4. The interviewer asks the student to explain the responses.

I: "Would you explain to me about your responses?"

QUESTION SET II: ABOUT MYSELF

"I do work in science class ...."

	not at all like me			a lot like me
a. to get work done on time	1	2	3	4	5
b. to memorize facts and information	1	2	3	4	5
c. to learn vocabulary and definitions	1	2	3	4	5
d. to receive rewards (e.g., extra money) from parents	1	2	3	4	5
e. to do better than other students	1	2	3	4	5
f. to use science to understand the world	1	2	3	4	5
g. to please my parents	1	2	3	4	5
h. to get good grades	1	2	3	4	5
i. to make sure my ideas are scientifically correct	1	2	3	4	5
j. to do as little work as possible	1	2	3	4	5
k. to show that I am a smart person	1	2	3	4	5
l. to do well in class activities	1	2	3	4	5
m. to please my teacher	1	2	3	4	5

QUESTION SET III: VERY GOOD SCIENCE STUDENT

"A very good science student would do work in science class ...."

	not likely			very likely
a. to get work done on time	1	2	3	4	5
b. to memorize facts and information	1	2	3	4	5
c. to learn vocabulary and definitions	1	2	3	4	5
d. to receive rewards (e.g., extra money) from parents	1	2	3	4	5
e. to do better than other students	1	2	3	4	5
f. to use science to understand the world	1	2	3	4	5
g. to please parents	1	2	3	4	5
h. to get good grades	1	2	3	4	5
i. to do as little work as possible	1	2	3	4	5
j. to make sure his/her ideas are scientifically correct	1	2	3	4	5
k. to show that he/she is a smart person	1	2	3	4	5
l. to do well in class activities	1	2	3	4	5
m. to please teacher	1	2	3	4	5

QUESTION SET IV: SCIENCE TEACHER

"My science teacher wants me to do work in science class...."

	not likely			very likely
a. to show that I am a smart person	1	2	3	4	5
b. to make sure my ideas are scientifically correct	1	2	3	4	5
c. to do well in class activities	1	2	3	4	5
d. to get work done on time	1	2	3	4	5
e. to memorize facts and information	1	2	3	4	5
f. to learn vocabulary and definitions	1	2	3	4	5
g. to do better than other students	1	2	3	4	5
h. to use science to understand the world	1	2	3	4	5
i. to get good grades	1	2	3	4	5

QUESTION SET V: SCIENTISTS

"Scientists want me to do work in science class...."

	not likely			very likely
a. to show that I am a smart person	1	2	3	4	5
b. to make sure my ideas are scientifically correct	1	2	3	4	5
c. to memorize facts and information	1	2	3	4	5
d. to learn vocabulary and definitions	1	2	3	4	5
e. to use science to understand the world	1	2	3	4	5

APPENDIX D

Student Conceptions of Matter and Molecules

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 or properties of the state attributed to individual molecules (e.g., solid molecules are hard, liquid molecules are in drops, etc.).
18.	Molecular explanation of changes of state	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 E

CLINICAL INTERVIEW ANALYSIS FORM

Student #______ Pre/Post

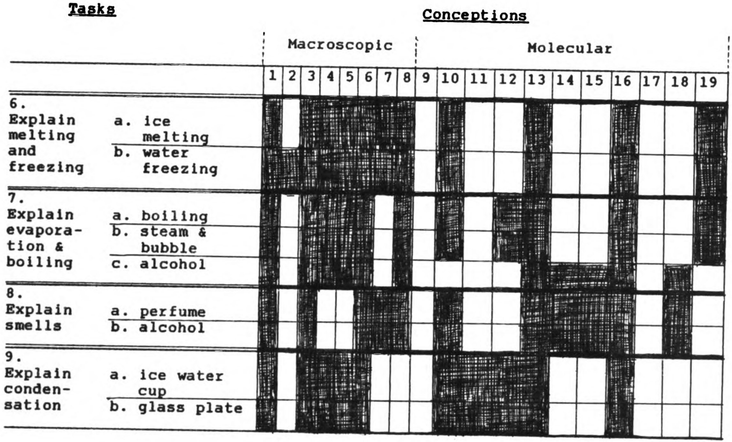
Key: G = Goal Conception
N = Naive Conception
M = Mixed (goal + naive)
A = Ambiguous/Inconclusive

Tasks by Conceptions Chart for Kinetic Molecular Theory

Tasks **Conceptions**

Assessment		Macroscopic								Molecular										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Matter vs. non-matter	a. describe & contrast																			
	b. classify examples																			
2. Compare/ contrasst states of matter	a. composition																			
	b. dif. betwn. s/l/g																			
	c. examples of s/l/g																			

Tasks		**Conceptions**																		
		Macroscopic								Molecular										
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
3. Explain expansion & compression of gases	a. syringe																			
	b. syringe: air vs. water																			
4. Explain thermal expansion	a. balloon/bottle																			
	b. ball/ring																			
5. Explain dissolving	a. sugar																			
	b. hot/cold water																			


Tasks
Conceptions
Macroscopic
Molecular
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
6. Explain melting and freezing
a. ice melting
b. water freezing
7. Explain evaporation & boiling
a. boiling
b. steam & bubble
c. alcohol
8. Explain smells
a. perfume
b. alcohol
9. Explain condensation
a. ice water cup
b. glass plate

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