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LEARNING ABOUT HEAT AND TEMPERATURE: A STUDY OF A GRADE NINE SCIENCE CLASS

by

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ABSTRACT

Many students complete science units with little or no understanding of the concepts taught. Such students frequently cope with difficult science concepts by memorizing definitions, formulas and other school science facts. Some researchers have suggested that one factor which may be related to difficulties students have is the students' prior beliefs about the topic. If a student possesses well established beliefs about scientific phenomena, and if those beliefs are contrary to the view presented in school science, the student is placed in a conflict position. If instruction does nothing to discredit a prior alternative belief, a student may reject the school science view, in favour of his/her alternative view.

Students' beliefs about heat and temperature were investigated prior to, and during a grade nine science unit. Many of the students' prior alternative beliefs persisted in spite of instruction. Instruction did not attempt to discredit the alternative beliefs. Rather, the school science view was presented and said to be correct. Many students responded by memorizing school science definitions and facts. Some students appeared to distinguish between correct answers for school science and what they believed to be true, giving one view on the school science test and another on the posttest.

School science achievement was significantly related to success on the lowest level questions of the posttest, but not to higher level questions, presumably because many students

relied on rote learning for their success in school science. Boys outperformed girls on higher level, but not lower level posttest questions. Boys contributed more to class discussion than did girls, and participation in class discussion was related to success on higher level posttest questions.

Five factors appeared to account, in part, for many of the difficulties experienced by students: many phenomena were explained in terms of the mechanical energy of the particles of matter; some phenomena were not explained, and some of the more competent students expected to have explanations; some alternative beliefs were neither identified nor addressed during instruction; many students seemed unaware of the function of a scientific model; and, some concepts were not adequately discussed in class.

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CHAPTER I

INTRODUCTION

1.0. Introduction

Assessments of science knowledge conducted in British Columbia (Taylor, 1982; and Hobbs, Boldt, Erickson, Quelch and Sieben, 1979), the United States (NAEP, 1978) and internationally (Comber and Keeves, 1973) have revealed startling misunderstandings about many of the basic science concepts. The 1978 British Columbia assessment team concluded "apparently many students leave school with limited understanding of some very fundamental concepts" (Hobbs et al., 1979, p. 94). The Science Council of Canada has also expressed concern about school science education. In 1980 a large scale investigation was launched, aimed at analysing the history of Canadian science education, its present purposes and characteristics, and promoting "active deliberation concerning future options for science education in Canada" (Orpwood, 1980). The Science Council final report (1984) provided a comprehensive description of Canadian school science and identified a number of questions which the authors felt need to be addressed. Thus we find not only are education officials and researchers urging inquiry into the teaching of science, but there is concern within the scientific community as well.

Several studies conducted at the University of British Columbia and elsewhere (Aguirre, 1981; Anamuah-Mensah, 1981;

Arnaudin and Mintzes, 1985; Deadman and Kelly, 1978; Erickson, 1975, 1979, 1980; and Novick and Nussbaum, 1981, among others) have explored children's ideas about a variety of science concepts, mostly in clinical settings. Beliefs which are at variance with the accepted scientific view are sometimes referred to as "alternative beliefs" (Driver, 1981). The term "alternative framework" may be used to describe an integrated set of ideas or beliefs which differs from the current scientific view. As Posner, Strike, Hewson and Gertzog (1982, p. 211) have indicated, "identifying 'alternative frameworks,' and understanding some reasons for their persistence, falls short of developing a reasonable view of how a student's current ideas interact with new, incompatible ideas."

The present study addressed this latter problem, investigating the interaction between students' prior knowledge and instruction. The study was conducted in a natural classroom setting, as a grade nine class studied a unit on heat and temperature. The topic of heat and temperature was selected for two reasons. First, children's ideas about heat and temperature have been previously investigated and are well known (Erickson, 1975, 1979, 1980; and Shayer and Wylam, 1981). Secondly, heat and temperature is a topic which is consistently taught at the junior secondary level across Canada (Connelly, Crocker and Kass, 1984) and which poses many difficulties for students.

1.1. Science Concepts and Learning and Development

Much of the recent research into learning of science has revolved around children's abilities, or lack thereof, to demonstrate the capacity for "formal reasoning," as defined by Piagetian theory. Formal reasoning abilities include proportionality, hypothetico-deductive reasoning, controlling variables and propositional logic, among others. These abilities are considered by many researchers to be basic to an understanding of most science concepts studied at the secondary level (e.g., Lawson, 1983, 1985; Shayer and Wylam, 1981). This research may underestimate the influence on learning of what children already know about a concept, irrespective of Piagetian stage.

Another approach to investigating learning in science has been based on the knowledge children bring to the classroom. This approach is often associated with Ausubel's concept of "prior cognitive structures." Novak (1977), in a summary of Ausubel's theory, stated that the most important idea in that theory was simply that the "most important single factor influencing learning is what the learner already knows."

The importance of children's ideas about science concepts is becoming more widely recognized as a fruitful area of research. Studies have shown that many children have informally developed beliefs about certain scientific phenomena, and that many of these beliefs are based upon a perspective different from that of the current scientific discipline. This incongruency may subsequently result, as Hawkins (1978) has suggested, in "critical barriers" which act to interfere with the child's learning. Driver and Easley (1978) refer to sets of these ideas as "alternative frameworks," while Hewson and Hewson (1983) use the term "alternative conceptions." Little is known about the effect of alternative beliefs on a child's capacity to learn the scientifically accepted view of concepts. Teachers and curriculum developers appear to assume that presenting evidence of the accepted view will result in the students' embracing that view. Recent studies (e.g., Hewson and Hewson, 1983; Osborne and Wittrock, 1983; and Pope and Gilbert, 1983) suggest that this assumption is often not warranted.

In this study, the learners' prior beliefs about heat and temperature were first identified, and then the extent to which those alternative beliefs were replaced by scientific ideas was investigated in this study. Finally, factors which may be related to the persistence of, or changes in student beliefs were explored.

1.2. The Concepts of Heat and Temperature

One of the first words learned by many children is "hot." Initially "hot" and "cold" are indistinguishable, evidenced by the toddler who exclaims "hot!" after his first taste of ice cream. Soon the young child learns to distinguish hot and cold, but an understanding of the distinction between heat and temperature may never be established. The development of the concepts of heat and temperature in school-age children has been studied by several investigators (Albert, 1974, 1978; Erickson, 1975, 1979, 1980; Hewson and Hamlyn, 1984; Shayer and Wylam, 1981; Stavy and Berkowitz, 1980; Tiberghien, 1980 and Triplett, 1973). As a result of these studies, children's alternative beliefs about heat and temperature are relatively well known. The impact of those beliefs on learning and their interaction with that learning, has not been investigated.

A study of fourth grade children in Israel (Stavy and Berkowitz, 1980) revealed that completion of a unit on temperature did not result in the children modifying the ideas they held prior to instruction. The children measured the temperature of water in two containers and found each to be 10°C. When the water from the two containers was combined, many children expected the mixture to have a temperature of 20°C (10 + 10 = 20). When the resulting temperature was found to be 10°C, many children concluded there was something wrong with the thermometer. They were unable to assimilate the unexpected result, although the same children had previously recognized that cold water combined with cold water resulted in cold water. In this case, the children's alternative belief appears to have led them to reject their experimental findings.

Although temperature is discussed daily by almost everyone, the distinction between heat and temperature is not well understood. Many adults cannot explain the difference. While temperature is readily measured, heat cannot be measured directly, and this is undoubtedly much of the problem.

In the grade nine science textbook (Schmid and Murphy, 1979) heat is defined as the total mechanical energy of all the particles added up. Temperature is said to depend on the average mechanical energy of each particle. In these school science definitions, "particles" refer to atoms and molecules.

In thermodynamics, the former definition would more accurately describe "internal energy," with the term "heat" being restricted to energy which is in motion across a temperature gradient. This distinction has not been made for students at this grade level. Thus we find terms being used differently in different contexts. In this study we will refer to concepts and definitions drawn from the field of thermodynamics as "scientists' science." The concepts and definitions presented in the grade nine science program will be referred to as "school science." An additional category, "children's science," will refer to the students' ideas and beliefs about heat and temperature concepts.

Summers (1983) has recognized the difficulties students have with the concept of heat, and has proposed that the word "heat" should not be used as a noun at all. He suggested the following terminology: "heating is the name given to the process by which internal energy transfers occur as a result of a temperature difference." In this study however, we will consider the terms "heat" and "heat energy" in the school science sense, to include the concept of internal energy.

A number of science concepts are involved in an understanding of heat and temperature. Basic to that understanding are the kinetic theory of matter (studied in the British Columbia grade eight science course) and the law of conservation of energy (studied in the grade nine course, immediately before the study of heat energy). To satisfactorily complete the heat and temperature unit, students must understand the relationship between particle motion and heat energy, and be able to explain the phenomena of thermal expansion, conduction, convection, radiation, temperature, phase changes and insulation in terms of those relationships.

None of the previous studies of children's beliefs about heat and temperature have examined the interaction of the alternative beliefs held by students and the development of heat and temperature concepts during instruction in an actual classroom setting. This study has investigated that interaction.

1.3. Sex Differences in Learning Science

Sex differences in achievement have been reported in the science assessments referred to earlier. In the British Columbia assessments, as in others, sex differences were greatest on physics questions and at higher grade levels. Physics concept and application questions were particularly difficult for girls. A closer look at items related to heat and temperature reveals some interesting variations in responses given by males and females (Hobbs et al., 1979). The number of correct responses to items whose content was kitchen-related (loosening jam jar lids by heating the lid and how a refrigerator keeps food cool) did not differ greatly between males and females. However, items related to laboratory activities did elicit different responses. For example, on the 1978 grade eight test, 54 percent of the males and only 40 percent of the females had correct responses on an item concerning the final temperature of water when two equal volumes initially at different temperatures are combined. Another item asked why the stopper popped out when a stoppered test-tube of water was heated. On this item the responses were 63 and 47 percent correct for males and females respectively. Similar differences were observed in 1982 (Taylor, 1982). On a question asking for the final temperature if one litre of water at 50°C were combined with one litre of water at 70°C, 53 percent of the males and 34 percent of the females correctly predicted 60°. The girls were even less successful than in 1978. Thirty-three percent of the students (unfortunately the report did not indicate percentages of males and females for incorrect responses) chose 120° as their answer. Reasons for such sex differences are not clear. These results would suggest that the context of a question has an effect on success rates, but this has not been documented.

Two aspects of this phenomenon were investigated. Sex of the student was considered in relation to student understanding of heat and temperature prior to and upon completion of the heat and temperature unit. In addition, classroom observations investigated differential treatment and responses of boys and girls during instruction.

1.4. Junior Secondary Science

The decision to examine junior secondary science was based on the general concern that has been expressed about science education at this level and the apparent decline in attitudes towards science that occurs during the junior secondary years.

The first British Columbia science assessment (Hobbs et al., 1979) identified the junior secondary level as the area of greatest concern at that time. Several reasons were given to support that view. The Interpretation Panel judged that performance was less than satisfactory for 70 percent of the items on the grade 12 achievement test, compared to 30 and 18 percent respectively for grades eight and four. Of 26,416 grade 12 students surveyed in 1978, 36 percent had not completed any senior secondary science courses. These data indicate a substantial portion of students take no science beyond the junior secondary level. Unfortunately, comparable data were not provided in the second assessment. The Science Council of Canada (1984) reported that only Manitoba required a grade 11 science course for high school graduation (British Columbia is about to implement a science 11 requirement) and recommended that all provinces should require science every year to grade 11 as a graduation requirement. Studies in the United States have also expressed concerns about junior secondary science. Buccino and Evans (1981) found that most students receive all of their high school science instruction at the junior high level. Recent studies in British Columbia (Duncan and Haggerty, 1985) and North Carolina (Simpson and Oliver, 1985), and the American National Assessment of Educational Progress (Yager and Yager, 1985) have all reported a steady decline in attitudes towards science as students progress through the junior secondary years. Thus, there appears to be widespread consensus on the need for a closer look at the teaching of science at this level.

1.5. Problem Statement

The general aim of the current study was to investigate ways students' prior beliefs about matter, heat and temperature influenced their understanding of the concepts of heat and temperature as presented during an instructional unit. In particular, eight questions were addressed.

The first two questions look at school science--the concepts as they are presented to the students.

1. How are the concepts of heat and temperature presented to grade nine students in school science (i.e., by the curriculum, the textbook and the teacher)?
2. Does school science differ from scientists' science? If so, in what ways?

The next two questions examine children's science prior to and upon completion of the heat and temperature unit.

3. What are students' ideas about matter, heat and temperature prior to studying a science unit on heat and temperature?
4. To what extent do student beliefs about matter, heat and temperature change after completing a unit on heat and temperature?

The next question looks at the learners as they proceeded through the unit.

5. What characteristics distinguish the more successful from the less successful learner? In particular, are there differences in learning that are related to gender?

Two questions address the instruction that was provided. The emphasis is on the interaction between the teacher and the students in the class.

6. How does the teacher provide opportunities for students to learn about heat and temperature?
7. How does the teacher respond when alternative beliefs are expressed by students?

The last question addressed the key goal of the study.

8. If some alternative beliefs persist in spite of that instruction, what are some possible explanations for that persistence?

1.6. Delimitation of the Study

As stated earlier, this study has examined alternative beliefs about heat and temperature held by junior secondary students, and has investigated the interaction of these beliefs with the learning of concepts presented during the study of heat and temperature in a grade nine science class.

The study investigated one British Columbia lower mainland grade nine science class. The findings can only be regarded as tentative, given the limited nature of the data base. Many concerns have been identified and will provide opportunities for further investigation. The reader must examine the findings, and then, based on the description of the class investigated, he/she will be able to judge the extent to which these findings are compatible with his/her own teaching experience and/or situation.

1.7. Summary

This chapter has summarized the rationale behind the study. Widespread concern about students' understanding of science concepts has been identified and it has been suggested that children's prior, alternative beliefs about science may be related to difficulties students have acquiring these concepts. There is also some evidence that boys' achievement exceeds that of girls.

The concepts of heat and temperature were selected for study as alternative beliefs have been investigated for these concepts and are well known. Eight specific questions were addressed and are presented above.

Subsequent chapters review the relevant literature, describe the methods used for the data collection and analysis and present the findings. The final chapter presents the conclusions derived from the study and identifies some areas in need of further investigation.

1.8. Definitions

Alternative belief: a belief held by a student, which differs from the school science view, but which the student accepts as correct.

Alternative framework: a coherent set of ideas or expectations students hold about the way natural phenomena occur, which differs from the currently accepted school science view and from the intended outcome of learning experiences (after

Driver, 1981).

Belief: any idea that a student accepts as being correct.

Children's science: "those views of the natural world and the meanings for scientific words held by children before formal science teaching" (Gilbert, Osborne and Fensham, 1982, p. 627).

Composite score: a score derived solely for the purpose of ranking students according to their pretest responses, and which has no value in any absolute sense.

Conception: a set of related ideas or beliefs which focusses around a scientific concept; e.g., the concept of heat has several different conceptions.

Conceptual capture: conceptual change which occurs when a student is able to reconcile new phenomena with existing beliefs.

Conceptual exchange: conceptual change which requires that a student relinquish his/her existing beliefs, in order to acquire the new concept.

Heat: the total mechanical energy of all of the particles added up (after Schmid and Murphy, 1979, p. 132).

Idea: any possible view about a scientific phenomenon; an idea has not necessarily been accepted as correct by the student.

Knowledge: facts, ideas and beliefs known to an individual as a result of experience and/or study.

Learning: the process of acquiring knowledge through experience and/or study.

Particles: atoms and/or molecules in school science.

School science: the interpretation of scientific phenomena presented by the curriculum, the textbook and the teacher (after Driver and Erickson, 1983).

Scientific perspective: the scientific interpretation of phenomena; in this case, based on the kinetic-molecular theory of matter and energy.

Scientists' science: "the consensual scientific view of the world and meaning for words" (Gilbert et al., 1982, p. 627).

Sequence: a grouping of questions and answers dealing with a single topic, usually consisting of a question, a response and a reaction to the response.

Target students: students selected for in-depth study and representing a range of beliefs about heat and temperature.

Temperature: a measure that depends on the average mechanical energy of each particle or the hotness or coldness of something (after Schmid and Murphy, 1979, pp. 132 & 110).

CHAPTER II

REVIEW OF THE LITERATURE

2.0. Introduction

Three main areas of the research literature were investigated as background to the study:

1. What is known about how children learn science concepts--what variables influence that learning?
2. What are children's ideas about heat and temperature?
3. How can we investigate the effects of children's prior beliefs on the learning of science concepts in the classroom?

This chapter will summarize recent research dealing with various aspects of these questions.

2.1. Factors Influencing How Children Learn Science

Learning may be thought of as the process of acquiring knowledge and developing skills. Hence, it may seem to follow that the teacher's role consists of presenting knowledge and providing opportunities for students to develop skills. Ausubel has distinguished between two kinds of learning--rote and meaningful learning (Novak, 1977). According to Ausubel, rote learning occurs either when the learner must recite something verbatim or when the learner has no relevant concepts available in his cognitive structure to which he can relate the learned material. For example, a student may be able to calculate the density of an object by applying the formula, D=M/V, and be able to repeat the definition that "density is the mass per unit volume," yet be unable to relate the definition to the formula and/or to explain the meaning of the definition. In meaningful learning the new knowledge can be related to relevant concepts in the learner's cognitive structure. Novak also points out that these two types of learning are not a dichotomy, but a continuum.

2.1.1. Prior Beliefs and Instruction

Griffin and Mehan (1981) have stated:

> The conventional wisdom about schooling includes the view that children enter school as tabula rasa, to be etched with the knowledge necessary not only for performance in school, but for life after school as well... knowledge is added to knowledge step by step until the requisite total amount of cognitive and technical skills is reached.
>
> Our experience with the teaching-learning process in elementary schools suggests an alternative view. It seems that students come to school with a wide variety of experience and varying interpretations of the world... Thus, instead of making entries on a blank slate, teaching in school seems to be involved in erasing entries from a too full slate. (p. 212)

Griffin and Mehan view the school child as an "active participant in the construction of knowledge, not as a passive recipient" (p. 213). This view is consistent with Piagetian theory as well as the concepts of prior cognitive structures, critical barriers, and alternative frameworks or conceptions referred to in the previous chapter. All express the view that children do informally develop beliefs about scientific phenomena, and that these beliefs are often incompatible with the scientific viewpoint.

Pope and Gilbert (1983) have stated:

> Our main premise is that significant learning is likely to occur only if the "facts" to be learned are construed by the learner as having personal relevance. We suggest that a "cultural transmission" approach to teaching and knowledge dominates science education. This approach has neglected the role of students' personal experiences in their construction of knowledge. (p. 193)

A child's established beliefs have presumably been found useful in the past and research findings do indicate that students are reluctant to reject their prior beliefs and accept a new point of view. Driver and Easley (1978) and Osborne and Wittrock (1983) have discussed examples of studies in which instruction failed to refute students' alternative beliefs. Osborne and Wittrock derived three major findings from their review:

1. Children have many firmly held ideas about many science topics, prior to studying science in school. Some of those beliefs are quite different from the scientific view, and the beliefs are not isolated ideas, but rather are "parts of conceptual structures which provide a sensible and coherent understanding of the world from the child's point of view" (p. 490).
2. Children's beliefs can be remarkably resistant to change.
3. If children's beliefs are changed by science teaching, the changes may be regressive, rather than progressive.

They provided the following summary of their review:

> While children frequently pass tests and other formal assessment hurdles, the present studies clearly suggest that children often do not really change their ideas of how and why things behave as they do as a consequence of science teaching. (p. 491)

The authors then recommend that science teaching build on students' prior knowledge and beliefs by showing them the inadequacies of their alternative beliefs and helping them recognize the validity and usefulness of the scientific view.

Children often view school science as being different than their real world. In the words of Strike:

> [students] are not exactly overburdened with a need to have what they learn in science classes be consistent either with other scientific ideas or with their own experience. Somewhere they have gotten the idea that science is allowed to be paradoxical and is not supposed to have anything to do with their everyday experience. (Strike, 1983, p. 93),

and,

> ...many students approach their science courses with a distinction between the world of ideas and the real world which easily leads them to discount contradictions between theory and experience. (Strike, 1983, p. 97)

These findings suggest that when a science concept is taught it will meet with varying degrees of acceptance from students. Students will recognize that they are expected to "learn" the new concept or point of view, and that they will be tested to determine if that learning has been achieved. Some will memorize certain aspects of the concept as presented in class and/or in the book, and successfully reproduce what they have "learned" when asked. As Doyle (1979, p. 16) has pointed out, the "performance-grade exchange is a prevailing reality in classrooms" and learning as determined by written performance does not necessarily reflect understanding. The findings described above also suggest that we should be cautious about assuming that written performance indicates that a student believes what he or she writes on tests or in written assignments.

There is an additional concern about the possible effects of students not believing that school science is relevant to their personal experiences. It may be assumed that there is little, if any, harm in this. Some would say that students will learn school science, whether or not they believe it describes the real world and someday they will recognize the validity of what they have studied in school. However, failing to see any relevance for school science may lead to negative attitudes toward studying science. Pope and Gilbert (1983) have suggested, "many students may be 'turned off' science because of [the] perceived gap between the content of science lessons and their own world views" (p. 200). In a study investigating attitudes of grade six to ten students towards science, Duncan and Haggerty (1985) found that very few students believed the science they learned in school had anything to do with real life, although they thought that science was very important in our modern society.

Triplett (1973) studied concepts of heat and temperature among nine and ten year olds. He frequently encountered what he called the "recitation syndrome" (which he contrasted to the "investigative syndrome"). Children often appeared to be reciting information that had been previously acquired, even if this information was inconsistent with their own observations. This appeared to be an attempt to elicit positive feedback from the investigator, and recitation appeared to provide security for most children. Recitation may occur with or without any real understanding of the concept as recited. Among Triplett's subjects, all but one child appeared more secure reciting than using an investigative approach. A similar situation was reported by Driver (1973) in her dissertation. In discussing that research, Driver and Easley (1978) stated:

> When an alternate theory was presented either by the teacher or other pupils, which better accounted for the data it was not necessarily understood, but was accepted and learned at a verbal level (p. 79).

It appears that Ausubel's use of the term "rote" (described earlier) is comparable to Triplett's "recitation" and Driver's "verbal" learning.

Posner et al. (1982) have proposed that learning is "best viewed as a process of conceptual change" (p. 213). Kuhn's "normal science" and "scientific revolutions" (Kuhn, 1970) are seen as analogous to the process of learning science. Normal science is similar to the situation where a student is able to incorporate new phenomena into his/her existing framework or cognitive structure. However, if a new phenomenon is incompatible with an existing framework, then there must be a change in the framework to accommodate the new phenomenon (analogous to a scientific revolution). The terms, "conceptual capture" and "conceptual exchange" respectively, have been used by Hewson and Hewson (1983) for these two processes. Posner et al. (1982) identified several conditions which must be fulfilled before conceptual exchange is likely to occur:

1. There must be dissatisfaction with existing concepts.
2. The new concept must be intelligible. That is, the new knowledge must be understood by the student who can explain what it means, but he/she may not believe it is true.

   For example, a grade eight student (female, age 13:9) was asked, "What is volume?" Her initial response was "the amount of space occupied by an object." Upon probing, this proved to be a memorized definition which she could not explain. When asked how she would measure volume, she offered three alternatives. One involved measuring an object with a ruler and calculating the volume ("length times width"). Another involved the notion of volume as the capacity of a container and the third method utilized liquid displacement to measure the volume of solid objects. She did not recognize these as alternative ways of measuring the same thing. Rather, she saw them as three different kinds of volume, and was quite comfortable with that distinction. Her understanding of measuring volume was intelligible, but she did not have an integrated conception of the term "volume."

3. The new concept must appear to be plausible. The new concept will not appear plausible unless it is seen to have the capacity to resolve anomalies generated by the existing concept.

   Continuing with the example above, if the student had been able to integrate her various interpretations of the term "volume" and to relate that to her own experiences with volume (for example, measuring quantities of liquids when cooking), the concept would have been plausible.

4. The new concept must be fruitful. In addition to being plausible, the new concept becomes preferable to the existing concept. It is more useful and efficient, and has predictive power. At this point, the existing concept has been exchanged for the new concept.

Learning which occurs without these conditions having been met is unlikely to be meaningful learning. This theory provides a basis for investigating the apparent tenacity of students' alternative beliefs in science.

The previous chapter referred to the question of the relative significance of prior cognitive structures and of cognitive development and their impact on learning science concepts. While Shayer and Wylam (1981) recognize the importance of students' prior beliefs, they emphasize the need to consider children's reasoning capacities as well. They remind the reader that only "about 15 percent of the 12 year-olds will possess Early Formal competence" (p. 433) and hence be capable of recognizing the independence of the three variables, quantity of heat, mass and temperature, when studying heat phenomena.

The relative importance of cognitive development and prior beliefs remains a controversial issue. Some would suggest that cognitive development is not of practical significance, as cognitive stages are not generalizable across content areas. If this were so, it would mean the stage of any individual student must be re-assessed for each different content area. For example, an individual student might demonstrate formal reasoning capacities when using a balance beam, but not when explaining heat and temperature phenomena. If formal reasoning is not generalizable then it is only of theoretical significance, rather than practical significance. That is, a teacher cannot assume that because Susie performs at a formal level when assessed on one particular task, that she will exhibit formal reasoning in any other situation. In discussing this issue, Driver and Easley (1978) said:

> We suggest therefore that Piaget's accounts of children's thinking in the causality studies, as in others, are important documents but should be read for the indications they give of the content of children's ideas and explanations, rather than as ways of assessing the development of underlying logical structures. On the related issue of the uses of Piagetian tasks for assessing pupils' development in science, it would seem more valuable information could be gained by both curriculum developers and the practising teacher through interviewing pupils in order to understand their ideas and ways of thinking about a topic in question, rather than as a device for classifying pupils and prescribing programmes for them. (p. 79)

Pope and Gilbert have suggested that Piaget's stage theory has been overemphasized in science education.

> Despite the fact that Piaget was critical of those who took the theory of stages to be a series of limitations, this would appear to be the 'received view' of many science educators. We would argue that this has been at the expense of the essence of Piaget's epistemology, i.e., the constructivist and relativistic view of knowledge in which the person's present construction of experiences forms the basis for the handling of new information and projections about future events. (Pope and Gilbert, 1983, p. 196)

This investigation has focussed on students' prior knowledge and its relationship to learning. It is based on the constructivist view of knowledge, espoused by Piaget and others, in the belief that that view leads to a more fruitful account of student learning in a classroom context.

2.1.2. <u>The Influence of Gender</u>

The issue of gender effects on science achievement remains largely speculative, although it is an issue which is currently attracting attention across Canada and elsewhere. As part of its study of Canadian school science , the Science Council of Canada sponsored a national workshop devoted to the the problem of low enrollments of girls in science (Science Council of Canada, 1982). The following excerpts from the British Columbia science assessment reports indicate pronounced differences are found in the achievement of males and females:

> The outstanding finding of the analysis of achievement results by gender was that there is a significant and substantial difference in knowledge of science concepts favouring boys. (Taylor, 1982, p. 244)
>
> ...clear differences were found between the results of male and female students...and [the differences] are most clearly evident in the grade twelve results (Hobbs et al., 1979, p. 95).

Following the 1978 British Columbia science assessment, the Ministry of Education commissioned a study of gender and school mathematics and science (Erickson, Erickson and Haggerty, 1980). In 1982 they sponsored a provincial workshop to make teachers more aware of the lower participation and achievement among girls in British Columbia secondary schools.

Kelly (1978) has conducted a comprehensive review of the literature on this subject. Findings indicate that on the average males outperform females on numerical, mechanical and problem solving skills. Males have also been shown to consistently achieve higher average scores in spatial ability, which in turn has been shown to be related to achievement in science. Average scores of females are higher in verbal skills and manual dexterity and appear to be more influenced by the type and content of problems and by motivation. The relative roles of culture and natural or hereditary ability in determining these differences have not been identified. However, it seems clear that society at large does not expect or encourage girls to succeed in science, or even to study science, particularly physical science. Undoubtedly one reason for the lower average achievement of grade 12 British Columbia girls on assessment questions in physics would be the lower enrollment of girls in senior secondary physics courses. For example, in 1985, 799 females and 3 146 males wrote the physics 12 provincial examination (Kozlow, Note 1).

Sadker and Sadker (1985) have reported on a study of science, mathematics and language arts classes at the grades four, six and eight levels. Findings were not reported separately by subject, but in all categories of classroom interaction, boys received more attention from teachers than did girls.

A study of grade nine and ten geometry classrooms found that boys were encouraged and challenged more than were girls (Becker, 1981). In one recent study conducted in British Columbia (Duncan and Haggerty, 1985), differential treatment was not observed in most of the 17 participating grade six to ten science classrooms (although this may have been influenced by the teachers' knowledge that the purpose of the study was to investigate sex differences in science achievement and participation). Kahle, Matyas and Cho (1985) studied biology classes taught by teachers with a record of encouraging females in science. Even in those classes, boys reported participating in class activities to a greater extent than did girls.

Cannon and Simpson (1985) have reported on a large scale study of grade six to ten science classrooms and concluded that science attitude was a good predictor of achievement. They found that boys had a more positive attitude toward science and achieved higher in science, although girls were more motivated to achieve. The attitude questionnaires of the British Columbia science assessment have not revealed significant gender differences in attitudes (Taylor, 1982). Duncan and Haggerty (1985) administered the same questionnaires to grade six to ten students, and again there were no significant gender differences. However, when the same students were interviewed in small groups and asked the same questions that had been on the questionnaire, more negative views were expressed. Girls in particular, were not interested in pursuing studies in science. The enrollments in grade 12 sciences in British Columbia also show pronounced gender bias, with females comprising 64 percent of the students writing the 1985 biology 12 examination; 41 percent of chemistry 12; 37 percent of geology 12; and 20 percent of physics 12 (Kozlow, Note 1). Clearly, boys and girls do have different views about the desirability and/or need to study senior science, although the causes of these attitudes can only be speculated upon at this time.

2.2. <u>Children's Beliefs about Heat and Temperature</u>

Erickson (1975), Albert (1974), and Triplett (1973) have completed dissertations dealing with children's understanding of heat and temperature. Albert conducted clinical interviews with children four to nine years old. Triplett, working with nine and ten year-olds, also used the clinical interview, but the interview was based on an experimental apparatus that was present. Neither of the latter two studies dealt with the kinetic framework of heat (the subjects were too young).

Erickson, in a pilot study for his dissertation, conducted clinical interviews with children aged six to thirteen years.

Most of the children interviewed expressed the following beliefs:

1. "heat was thought to be a type of substance which possessed its own unique properties"
2. "temperature is a measure of the hotness of an object and is a result of the amount of heat that is added to it" (Erickson, 1975, p. 129).

Based on ten in-depth interviews with 12 year-olds, Erickson developed the "Conceptual Profile Inventory." The Inventory was then administered to 276 students in grades five, seven and nine. Three distinct perspectives of heat phenomena, which he named "kinetic," "caloric" and "children's," emerged from the data obtained on the Inventory. Erickson also considered potential applications to the classroom situation.

Drawing on the tasks investigated in Erickson's Inventory, Shayer and Wylam (1981) developed a written test, "Heat" (Appendix A). The test investigated seven variables: composition of heat, conduction effects, expansion effects, chemical effects, temperature scales, change of temperature, and heat/temperature differentiation. Three levels of understanding of heat were identified for each variable, and these were linked to Piagetian stages of development (Table 2.1). The most sophisticated level was predominantly a fluid view. The textbook used by the class studied for this investigation (Schmid and Murphy, 1979) presents a view based on kinetic theory, which is summarized in Table 2.2.

One additional set of studies should be considered here. Novick and Nussbaum (1978; 1981; and Nussbaum and Novick, 1982)

Table 2.1

Summaries of Conceptions of Heat and Temperature
(Modified from Shayer and Wylam, 1981)

Level 1: Phenomenological Conception:

For heat, understanding is phenomenological. It is associated with burning, melting, etc. Expansion of gases may be seen in terms of 'hot air rises' and because expansion of solids is seen phenomenologically, it is not associated with the necessity of reversibility on cooling. Conduction may be different with different materials, and with mixing situations the hot gets cooler, and the cool gets warmer.

For temperature, on the other hand, the one to one mapping of temperature onto a linear scale is seen qualitatively and indeed semi-quantitatively--'the higher the hotter.' the temperature scale can even be extended with a simple additive strategy. Some but not all, grasp temperature as an intensive property; e.g., on mixing a liquid at 25°C with another at 25°C the resultant will be at 25°C. However, some add temperatures.

Level 2: Undifferentiated Conception:

Temperature is well conceptualized and quantitive, with multiplicative relations between temperature changes and changes in length of thermometric liquid. Heat is associated causally not only with the obvious effects (more heat has more effect), but also with less obvious ones such as conduction in gases. Expansion is now understood as a reversible phenomenon.

However, since heat is conceptualised causally, a model of it is not developed at this stage. Thus heat, amount of substance and temperature tend to be collapsed under the single concept of temperature. Provided that only one independent variable is involved the process will be correctly conceptualised, e.g., the more the amount of liquid/solid, the more heat will be required to heat it up, and the more heat that is added to a given object, the hotter it will get.

Level 3: Fluid Conception:

Interest in how heat causes its effects leads to the construction of models for conduction, expansion, heat transfer, etc. A more or less explicit model of heat flowing as a liquid from body to body allows quantity of heat, mass and temperature to be differentiated, with two being used as independent variables in simple calorimetric calculations, i.e., quantity of heat is a multiplicative function of both mass and temperature. Thus heat now becomes an extensive property. Theory can be used in contradiction of immediate experience. Although the steel blade of a spade left outside overnight 'feels' colder than the wooden handle, it is recognized that their temperature must be the same, and that the difference in feel is due to the greater conductivity of the steel.

Table 2.2

Summary of the Kinetic Framework

(Derived from Schmid and Murphy, 1979)

Observations can now be explained in terms of the kinetic theory of matter. It is recognized that the temperature of an object is due to the rate of motion of the 'particles.' Whereas heat energy is the total mechanical energy of the particles, temperature depends on the average mechanical energy of the particles. Heat transfer is seen in terms of particle motion. Specific heat is a characteristic property of matter, and is not synonymous with the density, or any other characteristic property. Thermal expansion is due to an increase in the mechanical energy of the particles of an object. As the energy increases, the particles move faster, spreading further apart and the object expands. When matter undergoes a change of phase, it is due to the increase or decrease in the average mechanical energy of the particles (i.e., temperature).

have investigated children's understanding of the particulate nature of matter. One aspect of their studies considered the effects of heating and cooling on the particles in a gas. Few of the 576 students questioned (grades 7 to 12 and second year university non-science majors) explained the phenomena in terms of particle motion or energy. Approximately 10 percent of the junior high students gave an energy or motion response. These findings are significant to the present study, as the textbook defines heat and temperature in terms of the mechanical energy of the particles.

2.3. <u>Investigating the Learning of Science Concepts in the Classroom</u>

Most classroom research has been aimed at either identifying characteristics of "good teaching" as determined by student achievement, or at investigating social interaction among students. Most of the studies have utilized one of the many systems for categorizing and counting various kinds of behaviour. These systems have tended to concentrate on the frequency of specific teacher behaviours and on learning as measured by mean scores obtained by the students in a class. One aspect of teacher behaviour which has received particular attention is questioning. Questioning is often seen as a key to promoting thinking and hence learning. Studies of teachers' questions have attempted to relate the kinds of questions asked to various measures of student achievement and/or attitudes. The use of class or group measures has resulted in the individual student being largely overlooked.

As Magoon (1977) has noted, over 50 years of such studies of teacher behaviour have not established links between particular instructional methods and student achievement. This line of research appears to assume that there are universal standards of teaching, irrespective of individual variation among students and the prior beliefs they bring to the classroom.

One recent study of teacher behaviour is relevant to the present study. Sadker and Sadker (1985) investigated how teachers called on students and how they responded to student comments in 100 grade four, six and eight classrooms. Teacher responses were found to be very neutral. Over half of all responses were categorized as "acceptance," and consisted of a comment that implied that an answer was acceptable, but was not explicit (e.g., "I see," "uh-huh"). There was a corresponding lack of "criticism" responses--that is, responses in which the teacher clearly indicated that an answer was inaccurate. The authors suggest that the predominance of neutral responses, coupled with the lack of frequent praise or criticism, deprives students of adequate feedback as to the quality of their responses. In approximately one-half of the classrooms observed, a few students received a proportionally large share of the interactions. In all classrooms, approximately one-quarter of the students did not participate at all. The authors concluded, "Our data suggest that classroom interactions between teachers and students are short on both quality and equality." As will be seen, Sadker and Sadker's findings were very similar to those of the current investigation.

Alternative beliefs or frameworks have been studied using the clinical interview approach (e.g., Erickson, 1975; Novick and Nussbaum, 1978; Triplett, 1973) and group tests (e.g., Erickson, 1975; Novick and Nussbaum, 1981; Shayer and Wylam, 1981) and/or what might be called "micro-teaching" situations (consisting of a small number of students and a teacher in a pseudo-classroom situation; e.g., Tiberghien, 1979). Only one study (Driver, 1973) has been found in which frameworks were studied in an actual classroom situation.

Delacote (1980) has urged that descriptive research, emphasizing student behaviour, can fill this need. One way to investigate the interaction of student beliefs and teacher strategies would be through an observational study of the ways in which students make sense of an ongoing instructional sequence. Studies by Driver (1973) and Tiberghien (1979) are cited as exemplars of this method. Both of these studies emphasized interactions within a small group setting. Driver studied four students in their own classroom. The class being studied had a large area available, consisting of a lecture room and two laboratories. This permitted the students to spread out during laboratory periods, minimizing the problem of concentrating on the students being studied. Tiberghien studied eight children as they were taught about heat in a television studio "very close" to their own school, rather than in an actual classroom. The teacher was from their school. Neither of these studies investigated the interactions between a teacher and an existing class of students, during regular instruction.

2.4. Summary

The review of the literature suggests that students' learning may be greatly influenced by their prior beliefs; in fact, prior beliefs may serve as a critical barrier to learning for some students. Because students are strongly motivated to provide correct answers, they may do so based on memory rather than on understanding. Ausubel has referred to these two kinds of learning as "rote" and "meaningful learning." Others have used different terms for a similar distinction. Compared to boys, girls appear to be at a disadvantage in learning science. Differential treatment by teachers and differential prior beliefs may be factors in observed discrepancies.

Students' concepts of heat and temperature have been classified into four levels of understanding: phenomenological, undifferentiated, fluid and kinetic. At the junior secondary level few students express either the fluid or the kinetic level.

In recent years classroom researchers have increasingly concluded that studies which have concentrated on teacher behaviour have not provided the sought after answer to the question, "how can teaching be improved?" It has been suggested that looking at the beliefs individual students bring to the classroom, and at the interaction of these beliefs with instruction as they learn may be a more productive line of research. This was the major objective of the present study. The next chapter describes the methods used to investigate this problem.

CHAPTER III

METHODOLOGY: COLLECTING THE DATA

3.0. Introduction

This study investigated the development of the concepts of heat and temperature while these topics were being studied by a grade nine science class. As this type of study has not previously been reported in the literature, the methods were primarily exploratory. It was anticipated that the findings would lead to the generation of hypotheses which could be tested in future studies, as well as addressing the questions posed earlier.

The school selected for the study was an urban, upper-middle class, lower mainland secondary school offering grades eight through twelve. The school was selected on the basis of two criteria: the absence of a large non-English speaking community, and the willingness of the staff to participate. In the former instance, it was judged that the results of the study would depend upon the students' abilities to express their ideas, both orally and in written work, and that facility with the English language was essential. The teachers in the school were informed that the researcher was conducting a study of difficulties students have in understanding the concepts of heat and temperature as presented in the grade nine science course, and that this topic had been selected as it appears to present difficulties for many students.

An accreditation review of the school had been conducted the previous year. The internal report of the accreditation committee provided the following information derived from responses to a questionnaire sent to randomly selected parents: most of the respondents lived in single family homes and 63 percent had lived in the area more than 10 years; 64 percent were single income families, but only 14 percent were single parent families; English was the language spoken in 97 percent of the homes; 97 percent of the parents expected their children to continue to post-secondary education after completing high school; 69 percent expected their children to attend university; 21 percent gave the school an overall rating of "excellent" and 64 percent rated the school as "good." The school emphasized academic programs. The committee noted that, as a result, "Unfortunately, many students whose interests and abilities lie elsewhere are forced to pursue programmes with which they cannot cope." The reviewers also noted that two of the science classrooms were very small and had only one sink. Their storage space and number of electrical outlets were judged to be inadequate. One such classroom was the setting for this study. The room had originally been a regular classroom, and was later converted to a science laboratory. Overall, the school and community were such that there was an absence of many of the disadvantages faced by some schools. It was assumed that if students attending this school experienced difficulties with the unit on heat and temperature, then we could anticipate that similar difficulties might be expected to occur in many, if not most, schools.

The data were collected in three phases. Phase I was intended to provide background information on the textbook as a source of information, on the students in the class and on the teacher's approach to teaching science. Interviews were conducted with selected target students. It also provided time for the investigator to "settle in" and become an accepted member of the class. Phase II involved recording the daily happenings of the class during its study of the chapters on heat and temperature. The target students had been selected for more in-depth study during this phase. The final phase consisted of the unit test and the posttest. A pilot study provided a preliminary view of student responses to the unit.

3.1. Phase I

Phase I of the study was conducted before the unit on heat and temperature was taught. The teacher was interviewed to discuss the researcher's plans, to ensure that the teacher was a willing participant and to discuss her approach to teaching the unit. The teacher expressed willingness to participate and interest in the questions being addressed by the study.

Before the study of heat and temperature began, the investigator sat in on the science classes, in order to accustom the teacher and the students to her presence. A two week period was originally planned. However, for a variety of reasons, the teacher did not begin the unit until much later than intended. As a result, the Phase I observation period lasted six weeks. Observations recorded during that period were used to investigate the feasibility of particular data-gathering techniques. They were not used as data for the study.

3.1.1. The Pretest

During the first week, one class period was provided to test students' concepts of heat and temperature. Two students were absent that day and were sent to the library the following period to complete the test. The test used was "Heat" (Appendix A), developed at Chelsea College, London (Shayer and Wylam, 1981). The authors administered the test to six classes of students aged nine to thirteen. The reliability (KR20) of the test was 0.894. Factor analysis identified only one significant factor, accounting for 38.8 percent of the variance. In the current study, scoring of the test items was based on the authors' criteria, provided to the investigator by Shayer (Note 3). The test consists of 60 items covering seven topics: temperature scales, change of temperature, expansion of heat, matter and heat, composition of heat, temperature and heat, and movement of heat. Each item had been categorized by the developers on the basis of two criteria--topic and level of understanding. In the latter case, each acceptable response to each item was categorized as one of three levels of understanding (see Table 2.1). For example, in one set of questions students are asked to predict what will happen when a nail which has been heated to 500°C is dropped into a glass of water at 18°C (see question set B, Appendix A). Students who correctly predict that the temperature of the nail will drop and of the water will rise (items B1 and B2) demonstrate Level 1 understanding. Students who explain this observation using a kinetic model (i.e., in terms of particles and their motion) demonstrate Level 3 understanding on item B3. Students are then asked to guess the actual temperatures 1, 5, 10, 15 and 30 minutes after the nail is dropped into the water (item B4). Three alternative patterns of response to this question were described by the authors:

Level 1: a continuous drop in the temperature of the nail and a continuous rise in the temperature of the water;

Level 2: the temperature of the nail drops, but the temperature of the water increases initially and then decreases; and

Level 3: the temperature of the nail decreases very rapidly and the temperature of the water increases at a slower rate until both are at the same temperature, and then both gradually cool to room temperature.

The levels for the item responses were determined from Piaget's reported three levels of children's responses to experiments on the transmission, conduction and equalization of heat (Piaget, 1974).

Each item was also assigned to one or more of the seven topics. With respect to topic, the nail and water items were categorized as follows:

Change of temperature: item B4

Composition of heat: item B3

Temperature and heat: items B1, 2 and 4, and

Movement of heat: items B1, 2 and 3.

The reliability (internal consistency) of the total pretest was 0.87. Subscale reliabilities for Levels 1, 2 and 3 respectively were: 0.81, 0.70 and 0.38. The reliabilities for the topic subscales ranged from 0.14 to 0.76. A low reliability indicates a lack of consistency in item responses on that subscale. On the one hand, this may be somewhat related to the small number of items per subscale. Four topic subscales had only seven items each and their reliabilities were 0.32, 0.49, 0.52, and 0.58. However, the "composition of heat" topic (11 items) had a reliability of 0.14, and "expansion of heat" (nine items) had a reliability of 0.76. These findings suggest that the most important factor influencing the reliability was the actual inconsistency in the responses. This could be caused by students either failing to answer many of the questions and/or guessing at the answers.

A system of ranking the students according to their understanding of heat and temperature concepts was required to enable the investigator to select target students with varying levels of understanding. For each topic, each student was assigned to one of the three levels described by Shayer and Wylam (1981), with the exception that the topic "temperature scales" has only two levels. Composite scores were determined by finding the sum of the levels obtained on the seven topics. For example, a student scoring at the maximum level on all topics would be classified at Level 3 on six topics and at Level 2 on the seventh, for a composite score of 20 (6 X 3 + 2). On the basis of the composite scores students were divided into three groups: the top third (Group T), middle third (M) and bottom third (B).

3.1.2. Selection of Target Students

Target students were selected for interview and for in-depth study during Phase II, as it was anticipated that it would be impossible to closely monitor more than eight students during class time. The following criteria were used in the selection of the target students:

1. There should be equal numbers of males and females.
2. Students selected should be among those who frequently contribute to class discussions to ensure maximum data.
3. The selected students should represent a cross section of the range of ideas and beliefs present in the class. In order to ensure that this criterion was met, students were divided into three groups according to composite scores. One target student of each sex was chosen from each of the top and bottom groups. The teacher's estimate of each student's ability and effort was also obtained and considered.
4. When one student was selected, his/her laboratory partner was also selected. Although it may have seemed desirable to match laboratory partners according to levels of understanding, this was not attempted as it would have disrupted the routine of the class. Barnes and Todd (1975) have reported on difficulties encountered when student groups were assigned by the researcher, rather than self-selected. Assigned groups were found to create an artificial situation and to inhibit the interaction among the students.

All students are identified by pseudonyms. The selected students were Jane (Group T) and her partner, Cathy (M); Joe (T) and partner, Alan (T); Susan (B) and partner, Carolyn (M); and Gordon (B) and partner, Brian (M). Jane had the highest science marks in the class and was described by the teacher as above average in both ability and effort. Cathy was described as an above average student in both ability and effort. Joe was considered to be of above average ability, but was described as "lazy." Alan was said to be of average ability, but to have very poor work habits. Alan was repeating grade nine science. His pretest responses indicated a particularly good understanding of the concepts of heat and temperature. Susan was judged to be below average in ability and Carolyn to be average. Both girls were classified as average with respect to effort. The teacher felt that Gordon was "bright," but indicated that his achievement was below average. She attributed this to very poor work habits. Brian was described as an average student in both respects.

3.1.3. <u>Target Student Interview</u>

Target students were interviewed to obtain additional information on pretest responses, using a clinical interview approach (Appendix B). Students were asked to explain more fully the reasons for their responses on the test, particularly those responses which represented lower level responses or revealed alternative beliefs. This was to allow the investigator to explore the reasoning of students who did not utilize the scientific view.

3.1.4. Curriculum and Textbook Analysis

A brief content analysis was conducted of the relevant sections of the curriculum guide (Curriculum Development Branch, 1979), the textbook (Schmid and Murphy, 1979) and the teachers' guide (Schmid, Murphy and Williams, 1980) to identify the following:

1. What concepts are presented in the unit?
2. What essential learning outcomes are prescribed by the curriculum?
3. What are the prerequisite concepts that students are expected to understand?
4. How do the curriculum guide and the teachers' guide assist the teacher with respect to teaching the unit?
5. How does the textbook present and discuss the concepts?
6. To what extent do the curriculum, textbook and teachers' güide take account of the possibility that students may hold alternative beliefs?

3.1.5. Summary

Phase I extended over a six-week interval, immediately preceding instruction on heat and temperature. The six weeks of observation provided ample opportunity to get to know the individual students and to determine how to most effectively record the class discussions. The pretest was administered and scored, the target students were selected and they had all been interviewed well before the unit began. By the time Phase I concluded, the investigator felt confident that her presence was largely overlooked by the students. This conclusion was supported by the frequent observation after the third week that when the teacher left the room, the students' behaviour changed immediately. When another teacher looked into the room, they immediately quietened down. The presence of the investigator appeared to have no inhibitory effect whatsoever.

3.2. <u>Phase II</u>

The major part of the data collection began when the class began chapter seven of the energy unit, "Heat Energy." Classroom data were gathered with two major questions in mind:

1. How does the student respond to instruction and instructional materials?
2. How does the teacher provide for learning?

To address the first question, the researcher examined student responses and behaviour in class, student interviews and all written work completed by the students (including tests). Particular attention was paid to the target students. Teacher interviews and class discussions provided data to address the second question.

Classroom data were collected at two levels: large group and small group. Large group data were collected when the teacher was providing information and/or interacting with the class as a whole. Observations were made of the behaviour and activities of all students and of the instruction provided. Small group data were collected when the students were working individually or in laboratory groups. At those times, the target students were the focus of attention. Two types of data were collected. Ethnographic data consisted of notes taken by the investigator during the classes. This written record of all class observations included details such as information written on the chalkboard or overhead projector, actions of students and a record of the names of students who were speaking. In addition, all classes were audio-tape recorded. The tapes and the written observations were used to prepare a rough transcript of each lesson. Student-teacher dialogue during class discussions was then coded on a data form using the transcripts, observations and the taped record. A total of 160 minutes (from eight of the nine periods) were devoted to discussion or dialogue between the teacher and the entire class. The dialogue was coded while listening to the tapes and following along .with the transcripts. The following categories for the students' responses are based on the extent to which the response was consistent with the school science view:

Correct: the answer was complete and correct.

Alternative belief: the answer was not completely consistent with the school science perspective, but was a logical idea and was a belief held by more than one student.

Partially correct: the answer was either partially incorrect or it was incomplete.

Incorrect: the response was completely incorrect.

No response: the student did not attempt to answer the question.

All student responses were coded as to the identity of the respondant as well.

Two aspects of the teacher's responses to student answers were of concern. The first was how the teacher evaluated the accuracy of the students response. Secondly, if the student answer was not complete and correct, how did the teacher go about eliciting the desired response or information. The following categories were used to code the teacher's responses to the student answers:

Acknowledge: a comment was made to indicate acceptance of the student's answer; e.g., that's right; very good; mhmm.

Wrong answer: the teacher specifically stated that the answer was not correct.

Encourage/explore: the teacher probed or questioned the respondant to draw out more information.

Redirect: the teacher asked another student to respond to the same question.

Provide information: a brief response in which the teacher provided specific facts about the topic in question.

Explanation: the teacher explained, often at length, a concept that the respondant did not understand.

Demonstration: the teacher used a physical demonstration to illustrate a phenomenon.

Repeat: the teacher repeated the student's response.

Ignore/dismiss: the teacher either ignored the response or indicated that she did not want to hear what the respondant had to say at that time.

Managerial: the teacher's response addressed the student's behaviour, rather than the content of a response.

The coding also indicated if the teacher called on a specific student by name (if a gesture was used it was not recorded as the data were derived from an audio-tape).

Sometimes a student initiated dialogue on a particular topic. This was also coded to indicate whether it was in the form of a question or a statement of information. Each coded category was tabulated by gender of student to obtain information on any differences in responses to or from male and female students. Summary tables of student-teacher dialogue were prepared from the coded data forms.

Small group data were derived from the recorded observations and transcripts of the classes. These data were essentially qualitative and anecdotal in nature, and related to the activities of the target students during laboratory investigations.

3.2.1. <u>Learning: How Does the Student Respond to Instruction and Instructional Materials?</u>

This aspect of the data collection looked primarily at the target students, although relevant data on other students were also considered. Interactions between the teacher and students, as well as student-student interactions were examined.

In large group activities the teacher was the primary "actor." However, students both responded to and raised questions, and made comments during the lessons. Observations were made to determine what students did when they appeared to be having difficulties understanding presented material or when they had questions or comments to make during the lesson.

During laboratory investigations the investigator observed the target students to determine the ways in which they approached an activity, investigation or assignment, the strategies used to complete the task, including the roles played by each student, and the results obtained. Photocopies were made of all written work submitted by the target students.

Check-lists were used to summarize the written work of other students and indicated whether answers were correct or incorrect, as well as identifying the alternative beliefs expressed by the students. The summaries made it possible, for example, to readily recognize that one assigned question which was fundamental to understanding the meaning of the calorimetry investigation (1.42), was answered incorrectly by all but one student. All of the students' written work was examined in relation to the observed activities. The data were recorded with the following kinds of questions in mind:

1. How does the student relate the investigation/activity to the concept(s) being studied?
2. How does the student explain the concept being investigated? Is an alternative belief utilized? What evidence does the student provide to support his/her alternative belief?
3. Does the student who expresses an alternative belief recognize anomalies in that view?
4. To what extent does the student see the school science view as intelligible? plausible? fruitful?

Whenever possible, student beliefs expressed in class were checked out by referring to their written work as well.

3.2.2. Instruction: How Does the Teacher Provide for Learning?

Two major types of activities occurred in the large group--lecture or explanation in which the teacher did most of the talking, and discussion or question-answer situations in which students contribued to a major portion of the conversation or dialogue.

In large group activities the teacher may have been introducing new material or concepts, conducting a "prelab." or "postlab." session, re-teaching material that was not well understood previously or taking up assignments. Data were collected with the following kinds of questions in mind:

1. How does the teacher introduce new concepts?
2. How does the teacher provide for student input and feedback? For example, does the teacher explore student's prior beliefs about relevant concepts while introducing new ideas?
3. What strategies does the teacher use to take into account student feedback? Does the teacher challenge students to modify their alternative beliefs?
4. What strategies does the teacher provide to allow students to shift from an alternative belief to the school science view?

3.3 Phase III

Upon completion of the unit, students were re-tested using a very slightly revised version of the pretest. For example, numbers and names of substances and objects were changed where feasible. The purpose of the posttest was to identify the conceptions used by each student upon completion of the unit. The reliability of the total posttest was 0.90; for Levels 1, 2 and 3 respectively, it was 0.81, 0.85 and 0.58. There was no change in the reliability of the Level 1 subscale. The other subscales showed an increase in reliability. The responses on the unit test (Appendix C), prepared by the teacher and administered the same day as the posttest, were also used as a data source.

3.4. Summary

This chapter has described the methods used to collect and analyse the data. Phase I consisted of an orientation period for the investigator. The students' prior beliefs about heat and temperature were assesssed using a pretest and interviews with eight selected target students. The unit on heat and temperature was studied during a two-week interval, comprising Phase II of the study. All lessons were audio-taped and transcribed. The investigator also recorded the activities of the students and the teacher in note form during the lessons. Student-teacher dialogue was coded and analysed as described in this chapter. The students' written work was collected and analysed. The final day of the study, Phase III, the students wrote the posttest and the teacher-made unit test.

Chapters IV through VI present and discuss the findings. Chapter IV will present three perspectives of the concepts of heat and temperature: scientists' science, school science and children's science. The ideas and beliefs expressed by the students in the class will be presented and those topics which provided the greatest difficulties will be identified. Chapter V will focus on the students and on learning. Three measures of learning will be compared in an attempt to identify factors that might be related to learning. The success or lack of success students experienced in learning the various concepts will be considered. The next chapter will examine instruction in an attempt to shed further light on the difficulties that students experienced with some of the heat and temperature concepts.

CHAPTER IV

PERSPECTIVES OF HEAT AND TEMPERATURE

4.0. Introduction

If a cup of boiling water is left sitting at room temperature for two or three hours, the temperature of the water will drop to that of the room. Two hundred years ago it would have been said that the water had lost some "caloric." Today many people would say it had lost some "heat," without giving much thought to the correct meaning of the term "heat." Our everyday language still suggests that heat and cold are substances which move from hotter matter to colder matter, or vice versa. In the winter we speak of keeping the heat in a house or keeping the cold out. We keep a refrigerator door shut to prevent cold from escaping. Few of us are inspired to ponder the real nature of heat or of cold.

As the writer worked on this dissertation, many people frequently asked about the subject of the research. When told it involved ideas about the distinction between heat and temperature, many of the questioners were puzzled. It is often assumed that temperature is a measure of heat. With the exception of those with science backgrounds, none understood the distinction until presented with the following illustration:

> Three identical saucepans are placed on three identical burners of a stove. One pan contains two litres of water, another contains two litres of cooking oil, and the third contains five litres of water. All of the liquids are at room temperature. The burners are turned on for five minutes and then the temperature of each liquid is recorded. Will all of the liquids be at the same temperature? If not, which will be hottest? Coolest? Why?

Everyone predicted that the oil would be hottest, and that the five litres of water would be coolest. They then recognized that the amount and the kind of substance, as well as the amount of heat energy, influence the temperature change. This illustration makes it meaningful to say that the temperature of matter depends not only on heat, but also on the mass of the matter or object, and on the kind of substance being heated.

The idea that temperature is a measure of heat is not the only lay view of heat that differs from the view of today's physicist. This chapter will examine this and many other alternative beliefs about matter, heat and temperature. Three views or perspectives of heat and temperature will be described. They include the perspectives of scientists', of school science, and of the students.

A glimpse at the scientists' perspective will briefly distinguish the concepts of heat, thermal (heat) energy and temperature, and compare these to the school science definitions. School science will be examined in more detail. The school science view has much in common with scientists' science, although each has its own unique features. School science attempts to make the concept of heat, as a form of energy, rather than a fluid, understandable to the average grade nine student. The goals, content and the activities provided in the curriculum and the textbook chapters dealing with heat and temperature will be presented.

The major portion of the chapter will identify and examine the various ideas and beliefs expressed by the students--that is, children's science. The section on children's science introduces the complex mix of the many and varied ideas expressed by the students in this class. Some of their beliefs were relatively sophisticated, while others were very naive. Most of the ideas characterizing school science and scientists' science were also expressed by one or more students. However, prior to instruction, even the most successful students revealed confusion about basic aspects of heat and temperature phenomena. Most of the alternative beliefs expressed by the students were addressed as the unit was taught, and some of the students did express beliefs on the posttest that were more consistent with school science, than their pretest beliefs. However, a number of alternative beliefs persisted throughout the unit and were expressed on the unit and/or posttest. Moreover, some alternative beliefs were expressed on the posttest that had not been stated on the pretest (as suggested by Osborne and Wittrock, 1983). Alternative beliefs which were still present at the end of the unit and were expressed on either the unit test or the posttest were called "persistent" alternative beliefs. That is, they persisted in spite of instruction. Chapter V will look at the success and/or lack of success students experienced in learning the heat and temperature concepts. In that context, the persistent alternative beliefs will be examined, and some possible reasons for their persistence will be explored.

4.1. Analysing the Data

An understanding of the particulate nature of matter is essential to an understanding of the concepts of heat and temperature as presented, as students were expected to explain their observations and ideas in terms of particle behaviour. For this reason, that topic was included in the study and was identified as the first of the major topics.

The science content covered during the study is presented in three chapters of the textbook (chapters seven to nine). Based on the organization of the text and the essential learning outcomes prescribed by the curriculum guide, the investigator organized that content into four major topics:

heat energy and its effects on matter,
temperature and how it is measured,
the distinction between heat and temperature, and
heat transfer.

With the inclusion of the particulate nature of matter, this resulted in a total of five major topics.

4.1.1. Scientists' Science

The primary data source for the scientific definitions of heat, thermal energy and temperature, and related concepts, was a commonly used college introductory physics textbook (Giancoli, 1980).

4.1.2. School Science

In British Columbia, the junior secondary science curriculum is prescribed by the Ministry of Education. Therefore, all schools in the province are required to use the same textbook for grade nine science. Relevant sections of the curriculum guide (Curriculum Development Branch, 1979, hereafter referred to as "the curriculum guide"), the textbook (Schmid and Murphy, 1979, hereafter referred to as "the textbook") and the teachers' guide (Schmid et al., 1980, hereafter referred to as "the teachers' guide") and interviews with the teacher provided the data for this section. The relevant sections of each source were carefully examined for several types of information. The following questions guided the examination:

1. What are the overall goals for grade nine science?
2. What is the rationale for including the unit in the program?
3. What are the specific goals and objectives for the heat and temperature unit?
4. What content is prescribed? How is it sequenced?
5. What assistance do the various sources provide to alert teachers to potential difficulties students may experience?
6. To what extent does the textbook take account of known difficulties when presenting the more complex concepts to the students?

4.1.3. Children's Science

The ideas and beliefs expressed by the students have been organized according to the major curriculum topics. As an understanding of the particulate nature of matter is a prerequisite to understanding the concepts of heat energy as presented in this unit, it has also been considered in this study, and appears as the first major topic. Each idea was examined in terms of three criteria:

1. its consistency with the school science perspective,
2. how many students expressed the idea, and
3. the persistence of the idea (this will be particularly relevant for alternative beliefs).

From this examination ten persistent alternative beliefs have been identified..

Several steps were involved in identifying the students' ideas and beliefs about heat and temperature. The first step was the preparation of the conceptual biographies. Each conceptual biography consisted of a detailed decription and analysis of the ideas and beliefs of one target student. The introduction to each biography provided general information on the student, including the teacher's view of the student's ability and work habits, and the investigator's comments on the behaviour and work habits demonstrated during the heat and temperature unit. The pretest and posttest responses of the target students were also carefully examined. All of the ideas were organized according to the five major topics identified above. The student's pretest interview, assignments and laboratory reports, and contributions to class discussions were also examined and categorized under the five topics. Based on these data, a description was prepared, presenting the student's prior beliefs, analysing the changes which occurred in those beliefs during the unit and concluding with the student's beliefs as expressed on the unit test and the posttest. These descriptions of the student's beliefs constituted the major portion of each biography and emphasized the contrast between the pretest and posttest beliefs of the student. The analysis stressed accounting for changes in beliefs wherever possible (Appendix D).

The next level of analysis consisted of a compilation of all of the ideas and beliefs expressed by all 23 students in the class. All of the pretests, posttests, unit tests, transcripts of class discussions and written laboratory reports and other assignments were examined for all students. All of the ideas were again categorized under the major topic headings. The textbook and curriculum guide were also examined to ensure that all of the ideas presented in "school science" were included. After the complete range of ideas and beliefs had been identified, a brief description was prepared for each idea. The descriptions indicated the extent to which each idea was expressed by the students and included quotations from the various data sources to illustrate the range of ideas expressed. These descriptions are presented in section 4.4.2, and constitute the major portion of this chapter.

4.2. The Scientists' Perspective: Scientists' Science

This rather brief section is included to indicate the extent to which the concept of heat has been modified for presentation to grade nine students. The term "heat energy" in the textbook (Schmid and Murphy, 1979) includes the two distinct concepts of "heat" and "internal energy" (sometimes referred to as heat energy or thermal energy) recognized in modern science. This terminology is in contrast to that in a college level physics textbook used in British Columbia (Giancoli, 1980), where the following distinction is made between temperature, heat and internal energy:

> Using the kinetic theory, we can now make a clear distinction between temperature, heat, and internal energy. Temperature is a measure of the average kinetic energy of individual molecules. Thermal or internal energy refers to the total energy of all the molecules in the object. ... Heat, finally, refers to a transfer of energy (usually thermal energy) from one object to a second which is at a lower temperature. Heat, as Count Rumford saw, can be generated indefinitely, but the thermal energy of a body is strictly limited. (Giancoli, 1980, p. 228-229).

These definitions are more consistent with scientists' science than with those provided in the grade nine textbook.

4.3. The Curriculum Perspective: School Science

A major revision of the Science 9 program was completed in 1979, and included the production of a new textbook. In July of that year a decision was made, based on the results of the 1978 Science Assessment (Hobbs et al., 1979), to completely revise the Junior Secondary Science Program (grades 8, 9 and 10) in British Columbia. Thus, the newly revised 1979 curriculum was identified as a "preliminary" guide and intended to be in effect only until the new program could be developed and implemented, expected to be in September, 1981. A revised curriculum for grades eight through ten was published in 1983. Preparation of new textbooks was underway. Because the existing grade nine textbook had been so recently revised, the grades ten and eight books were given priority. At the present time (1985/86 school year), the new grade eight and ten books are in use, but the new grade nine textbook is not yet available. In the revised program the study of heat and temperature has been moved to grade eight.

In the 1979 grade nine program, four broad fields of science are examined: physics, space science, chemistry and biology. Energy provides the theme for the entire text, and teachers are urged, both in the text itself and in the teachers' guide, to study the energy (physical science) unit first. In the curriculum guide, the following physical science topics are identified:

> ...what energy is, present and future sources of energy; kinds of energy (some potential, some kinetic); how each kind can be transformed to other kinds; how friction transforms kinetic energy to heat energy; how forces are involved in transformations of energy; how simple machines can change the force necessary to transform energy; what energy converters are used in everyday life; what we mean by the power of an energy converter; how we measure temperature; how heat energy and temperature are involved in phase changes; how temperature can be used to measure heat energy; how heat energy is transferred and how useful energy can be saved. (Curriculum Development Branch, 1979, p. 8).

The last five of these are the subject of this study.

4.3.1. Goals and Objectives of the Unit

The curriculum developers recognized that few teachers have specialized training in all branches of science, and hence have provided not only a comprehensive rationale and program goals, but also detailed learning outcomes for the program.

The teachers' guide states:

> The basic aim of [the energy] unit is to enable students to understand energy sufficiently for them to make wise decisions about the use of energy in the future and the conservation of energy in the present. (Schmid et al., 1980, p. 1)

The learning outcomes for this unit have been identified as either "essential" (Table 4.1) or "optional" (Table 4.2). It was recommended that a minimum of 100 hours be provided for the entire Science 9 course.

Table 4.1

Essential Learning Outcomes

Grade Nine Science (1979)

Describe the steps by which various forms of energy are eventually transformed into heat energy.

Recognize kinetic energy of particles as heat energy.

Describe and read a liquid-in-glass thermometer.

Distinguish between the heat energy of an object (the total energy of all its particles) and its temperature (which depends on the average kinetic energy per particle).

Recognize that when two bodies of different temperatures are in contact, heat energy is <u>conducted</u> from the hotter to the cooler until both bodies reach the same temperature.

Understand that the <u>conduction</u> of heat is in terms of particles.

Observe that metals are good <u>conductors</u> and air a good <u>insulator</u>.

Describe <u>convection</u> as a means of transferring heat energy.

Recognize from observations that objects that <u>radiate</u> infra-red rays will lose heat energy.

Infer from observations that dull, dark objects absorb infra-red radiation best, while light, shiny objects reflect it best.

Describe the insulation in a house and how it slows down the transfer of heat energy by conduction, convection and radiation.

Discuss the use of present and future energy sources, considering environmental effects, practical ways of using less energy and safety considerations.

Table 4.2

Optional Learning Outcomes

Grade Nine Science (1979)

Describe some other thermometers and their uses.

Explain how, during a phase change, the heat energy of water can change without its temperature changing.

Compare the amount of heat energy necessary to: 1) melt a given amount of water, 2) bring the same amount of water to the boiling point and 3) change this water to steam.

Recognize that the boiling temperature of water can be increased and the freezing temperature decreased by increasing the pressure on the water.

Understand and define <u>specific heat</u>.

Calculate the amount of energy necessary to raise the temperature of a given mass of material a given amount.

Calculate the final temperature when given masses of similar materials are mixed.

Recognize that heat energy is conducted from one body to another faster when the temperature difference between them is greater.

Recognize that a hot fluid will float on a colder amount of the same fluid.

Understand that higher temperature objects lose heat energy by <u>radiation</u> faster than objects of lower temperature.

The curriculum guide identifies learning outcomes from the affective and psychomotor domains, as well as the cognitive. It is pointed out that although the last two of these are more easily achieved, the affective domain must not be overlooked. Affective content is difficult to isolate and tends to be a result of successfully teaching the other two domains. It includes the following levels: receiving, responding, valuing, organization and characterization, with each of these further divided in relation to the students' awareness, willingness, acceptance and extent of implementation or action.

The curriculum guide also provides suggestions for teaching the course, including the use of the laboratory, selected science readings, suggested evaluation techniques and recommended audio-visual and print resources.

4.3.2. <u>The Content of the Unit</u>

Temperature and heat energy are the focus of the present study and a list of the topics examined in the three textbook chapters dealing with heat energy and temperature is provided in Table 4.3.

The balance of this section will briefly review the content and rationale of these three chapters as presented in the textbook and the teachers' guide. In addition, any comments in the teachers' guide that refer to common misunderstandings or to difficulties experienced by students will be identified and summarized.

The stated rationale for the chapter on heat energy is to make certain the students understand the meaning of temperature, at this point "best defined as a reading on a thermometer" (Schmid et al., 1980, p. 98) and to introduce the concept of heat energy. This use of an operational definition ignores the actual meaning of the term, "temperature."

The chapter begins by defining heat energy as follows: "The heat energy that any object has is the mechanical energy of all its particles added up." (Schmid and Murphy, 1979, p. 101). A narrative section explains that heat energy is produced in all energy transformations and students do an investigation in which a chaos machine serves as a model to distinguish the mechanical

Table 4.3

Contents of Chapters 7, 8 and 9

Chapter 7. Heat Energy

1.34 Heat energy and energy transformations

1.35 Investigation: Heat engine

1.36 The energy of particles

1.37 Investigation: Measuring temperature with a mercury thermometer

1.38 Investigation: Measuring temperature by expanding solids (demonstration)

1.39 Investigation: Absolute zero

1.40 Thermometers

1.41 Review

Chapter 8. The Difference Between Temperature and Heat Energy

1.42 Investigation: The heat energy and temperature of different objects

1.43 Heat energy and temperature

1.44 Differences in specific heat

1.45 Investigation: Heat energy and temperature in phase changes

1.46 Review

Chapter 9. The Transfer of Heat Energy

1.47 What happens to heat energy

1.48 Investigation: Conduction

1.49 Investigation: Convection

1.50 Investigation: Radiation of infra-red rays

1.51 What happens when energy is transferred

1.52 Infra-red radiation

1.53 Insulation

1.54 Review

energy of the individual particles from the collective energy (heat energy) of all of the particles. The teachers' guide points out that students tend to think of heat energy as a fluid that is added to or removed from an object, and teachers are advised to <u>stress</u> the idea that heat energy is the energy of the particles. However, the textbook does not use this approach (i.e., it does not acknowledge the possibility that students may have this alternative belief and point out how that belief is inconsistent with school science). The guide also states:

> The statement that gas particles have nothing smaller to give their energy to is a simplification of the facts. Thinking students may know that many particles are made of atoms which, in fact, are made of smaller particles still. ... However, because the number of component parts of a particle is small (compared to the number of component particles of a macroscopic object) energy can be given back by the component parts to the particle as a whole. In contrast, the chance of energy being given back to a large object by its particles is practically nil. (Schmid et al., 1980, p. 106)

Such an explanation could confuse teachers as well as students, as it is incorrect from the scientists' science perspective.

Celsius and Kelvin temperature scales are introduced. Using a mercury thermometer, students measure temperature and learn how a thermometer is calibrated. They learn that the mercury thermometer depends on the property of thermal expansion. The kinetic model of thermal expansion is given a great deal of emphasis. Students are told that when matter is heated its particles gain mechanical energy and hit each other harder and that the spaces between the particles become larger. They are asked to explain why: "a) liquids expand when the temperature goes up; b) liquids contract when the temperature goes down" (Schmid and Murphy, 1979, p. 110). The teachers' guide suggested answers are: a) that the mechanical energy of the particles increases so the particles hit each other harder and move farther apart; and b) the particles lose mechanical energy, do not hit each other as hard and "the forces of attraction between them pull them closer together" (Schmid et al., 1980, p. 109). Next, the bimetallic strip is demonstrated and its uses as a thermometer are described. Students are asked what happens when a solid object is heated: a) to the size of its particles; b) to the mechanical energy of its particles; and c) to the spaces between the particles (Schmid and Murphy, 1979, p. 112). The idea that the spaces, not the particles, are responsible for the expansion is stressed. A question at the end of the chapter asks what happens to the spaces between the particles of air when air is heated and how this affects the density of air. An optional investigation uses a gas thermometer to extrapolate the value of absolute zero. The concept of absolute zero is intended to help develop some understanding of the amount of heat energy in matter at normal temperatures.

The aim of chapter eight is to clarify the distinction between temperature and heat energy. Three controlled calorimetry experiments demonstrate that an increase in the temperature of matter depends not only on heat energy, but also on the mass and the kind of material being heated. The teachers' guide advises stressing the idea that these experiments are controlled, and recommends having students identify the constants and the variables. The three experiments include comparisons of the temperature change that occurs when the following are placed in water: equal masses of a metal at different initial temperatures; different masses of the same metal at the same initial temperature; and, equal masses of two different metals at the same initial temperature. A reading section provides an explanation of the difference in heat energy and temperature in terms of particles. Students are told that particles have mechanical energy and that matter has heat energy. They are told that the temperature of mercury "depends on how much mechanical energy each mercury particle has, on the average" (Schmid and Murphy, 1979, p. 132). Heat energy, on the other hand, depends not only on how much energy each particle has, but also on how many particles there are. That is, heat energy is "the total energy of all its particles added up" (Schmid and Murphy, 1979, p. 132). In the next investigation, students observe that when ice is heated until it melts and then boils, the rate of temperature change is not constant across phase changes. Because the water-ice mixture cannot be in a state of true equilibrium while being heated by a bunsen burner, the teachers' guide cautions that the temperature will be seen to rise slightly while the ice is melting and suggests that the students should stir the mixture constantly as long as ice remains in the beaker. In spite of this limitation, students observe that the temperature rises much more rapidly after the ice has melted and that it remains constant once boiling begins. The guide also warns that students should not think that the temperature of water vapour cannot exceed 100°C. The importance of these warnings will become evident as the findings of this study are presented in later chapters.

The third and final textbook chapter to be considered examines the transfer of heat energy. It is stressed in the teachers' guide "that differences in temperature cause the transfer of heat energy" (Schmid et al., 1980, p. 133). The chapter begins by explaining "heat transfer" and considers both desirable and undesirable examples of heat transfer. Conduction, convection and radiation are examined macroscopically and conduction is described at the particle level. The chapter concludes with a discussion of conservation of heat energy in the home. Throughout the chapter, frequent reference is made to everyday examples of heat transfer.

An investigation of conduction shows that heat energy is transferred from hotter matter to colder matter and that the rate at which heat energy is transferred varies for different materials. For example, metals conduct heat energy much faster than non-metals. Very poor conductors are called insulators. In the questions, students are required to explain conduction in terms of particle motion, and it is pointed out that metals feel colder than non-metals because they are good conductors.

Next, students observe convection currents and learn that when a fluid is heated, its density decreases and it rises. The investigation and the questions deal with convection in both gases and liquids, but do not ask for explanations in terms of particles. Infra-red radiation is observed and then students investigate factors affecting absorption, reflection and radiation of infra-red radiation.

A discussion section concludes the chapter by reviewing the ideas presented in the chapter. The effects of conduction, convection and radiation are considered, with particular emphasis on the greenhouse effect and home insulation.

The physics portion of the text concludes with chapter ten, "How our use of energy affects our world." In the introductory section, students are told that this chapter is more related to their daily lives and that the previous chapters have provided them with an understanding of energy that will allow them to "be better able to understand the very important material in this chapter" (Schmid and Murphy, 1979, p. 173). The chapter is summarized as follows:

> First you will look back in time to see how our present world came to be. Then, you will read about the many ways in which we use energy and the kinds of energy sources we are using. (Possible future sources of energy are also mentioned.) Finally, you will find out what things you can do to help make the future a good time to live in. (Schmid and Murphy, 1979, p. 173)

4.3.3. Teaching the Unit

The teachers' guide recommends that 13 class hours be provided for chapters seven to nine, with half of that time being devoted to laboratory investigations. In the class participating in the study, nine one-hour periods were provided for the three chapters. Chapter ten was omitted due to lack of time (the end of term was two weeks away and the biology unit had not yet been taught). All students performed investigations two periods, and during a third period one group of students performed a demonstration investigation. The teacher also performed demonstrations on two occasions. A tenth day was devoted to the teacher-made unit test and the investigator's posttest. The instruction provided in the unit is the subject of Chapter VI and will be examined in detail then.

4.4. The Students' Perspectives: Children's Science

Prior to instruction (i.e., on the pretest and/or during the interview), none of the students expressed an accurate understanding of the distinction between heat and temperature. Even Alan, whose pretest responses were clearly closer to the school science perspective than those of any other student, spoke of heat and temperature as if temperature were a measure of heat. Although almost all of the students gave acceptable (to the teacher) definitions of the two terms on the unit test, few revealed a clear understanding of the school science perspective on the posttest. This was to be the case for many of the concepts presented in this unit, as was evident from the many alternative beliefs which persisted at the end of the unit.

Three fundamental distinctions appear to lie at the heart of most of the difficulties experienced by students. In almost every case, the problems appeared to be related to a failure to understand one of the following distinctions:

1. Matter consists not only of particles, but also includes the space between the particles. While the distance between particles can vary, the size of the particles remains constant.
2. There is a distinction between the macroscopic behaviour of matter and the sub-microscopic behaviour of the particles which comprise the matter. For example, when matter is heated it expands. The particles do not expand.
3. The temperature of matter depends on the average mechanical energy of its particles, whereas the amount of heat energy (i.e., internal energy) in matter depends on the total

mechanical energy of the particles.

As all of the students in the class completed both the pretest and the posttest, these provided a major source of the data. Most of the many alternative beliefs identified on the pretest and/or during interviews were again expressed in the class discussions or in the written assignments completed by the students. All written work was handed in and examined by the investigator, who pointed out errors to the students by either writing in the correct answer or, in the case of more complex errors or misunderstandings, directing the student to discuss the question with the teacher or the investigator. Only one student, Alan, ever consulted the investigator on his own initiative.

This section will summarize the range of ideas and beliefs expressed by the students during the study. Particular attention will be paid to the target students to illustrate the range of perspectives.

4.4.1. Distinctions Which Led to Student Difficulties

The three distinctions described above caused difficulties in a variety of contexts. This section will introduce some of the problems which arose, and provide some specific examples of ideas which proved to be difficult for the students.

Matter: Particles and Spaces

All of the students easily spoke of matter being composed of particles. The problems appeared when they had to deal with the spaces between the particles. Some students believed that the "matter" included only the actual particles, not the spaces between the particles. This belief should not be surprising, as we do often define "space" as the absence of matter.

Students recognized that particles are in constant motion and that they are farther apart in gases than in liquids, and in liquids than in solids. Some of the students indicated they believed that when heat is transferred it moves through the spaces between the particles. For example, one student indicated that heat is transferred through glass by "air particles," apparently thinking the spaces contained air. Some of the students suggested that less dense matter is a better conductor of heat than more dense matter because it has larger spaces for the heat to move through.

The Behaviour of Particles and Matter

The students seemed to assume that because a particle is a very small piece of matter, that the characteristics or properties of the material also characterize the particles. Beliefs expressed by Cathy (Jane's partner) provide a good illustration of the difficulties that may arise if this distinction is not made. For example, Cathy said that ice melts because the particles become warmer and melt, and that warm air rises because the particles become lighter. Thus, she was attempting to explain the macroscopic properties of matter by attributing those same properties to the particles making up that matter. Cathy clearly did not understand the distinction between the behaviour of particles at the microscopic or molecular level, and the behaviour of matter at the macroscopic level. Other properties that students attributed to particles included: the ability to get hotter, expand and contract, dissolve, evaporate, and become heavier. These ideas are inconsistent with the kinetic theory of matter, and students who expressed any of these ideas revealed a lack of understanding of that theory. The theory may have been intelligible, or even plausible to them, but it was certainly not fruitful.

Heat and Temperature

The third and final fundamental distinction deals with heat and temperature. The teacher identified this distinction as the most difficult idea in the unit. The textbook definitions of the terms are complex and deal with the mechanical energy of the particles. Heat is the total mechanical energy; temperature is the average mechanical energy. For most of the students, these definitions were not even intelligible. Recognizing the difficulty, the textbook and the teacher advised that "hotness or coldness" would be an acceptable definition of temperature. This idea was easier to understand, but it may have led to some other difficulties. For example, on the posttest, some very able students indicated they believed that heat and cold were different thermal entities. Another alternative belief which may be related to this definition was expressed when the students observed that a metal faucet felt colder than a wooden table top, and concluded that they were at different temperatures. As the heat and temperature distinction is a key concept in the unit, it will be the focus of much of this study.

4.4.2. Students' Ideas and Beliefs

This section will present the range of student beliefs about the particulate nature of matter and about heat and temperature.

Topic A: The Particulate Nature of Matter

The students had already completed the chemistry unit before beginning heat and temperature. In the chemistry section, the textbook notes that students had examined the particle model in grade eight science. The chemistry unit is based on the particle model, and the following brief segment from the text reviews the important features of the model:

> In your last science course, you used the particle model of matter. According to this model, all materials are collections of very tiny particles that are always moving as shown in Fig. 3. The particles of a material stay together because they attract each other. They have spaces between them because they are always moving in all directions. The space between the particles contains nothing; it is a perfect vacuum. (Schmid and Murphy, 1979, pp. 350 and 352)

This description can be broken down into three ideas, each of which posed particular problems for the students.

Idea A.1: All matter is composed of particles.

None of the students expressed any doubt that matter is indeed composed of tiny particles. Prior to the unit some of the students used the terms "atoms" and "molecules", rather than "particles." By the end of the unit only one student persisted in referring to "molecules" rather than "particles." On the pretest nine students referred to either particles, atoms or molecules at least once. These nine, plus an additional ten, students did so on the posttest. Four students did not mention particles (or atoms or molecules) on either the pretest or the posttest.

Throughout the text, "particles" are referred to when matter is discussed. In class, the teacher referred to particles daily. Frequently when a student was asked to explain a phenomenon he or she would answer on a macroscopic level, and the teacher would say, "Talk to me about particles," or "Explain it in terms of particles." Thus, the students were continually being bombarded by particles, figuratively as well as literally.

We have already noted that in spite of the teacher's urging, some students did not distinguish between the properties or behaviour of matter and the properties or behaviour of the particles. In addition, some students believed that "matter" did not include the spaces between the particles, but only the particles themselves. For example, on the posttest Cathy wrote that when heated, "water looks as if it expands. Actually only the spaces are." Cathy clearly did not have a good understanding of the kinetic theory of matter.

SUMMARY: Prior to the unit none of the students revealed any doubt that matter is composed of particles. However, many revealed they did not have a good understanding of the kinetic theory of matter. The theory was intelligible, but not plausible for them.

Idea A.2: The particles of matter are in constant motion and therefore have mechanical energy.

None of the students mentioned mechanical energy on the pretest. Jane and six others referred to it on the posttest. There was some confusion about the distinction between mechanical energy (of the particles) and heat energy (the total mechanical energy of an object or of a defined unit of matter). For example, one boy spoke of particles "heating up" on the pretest. On the posttest three other students expressed the belief that particles have heat energy. One of these, a girl, also referred to mechanical energy in reference to particles. Another girl spoke of particles being heated, and Brian referred to the heat energy of particles. In a laboratory report, Cathy wrote that in a solid the particles stopped moving and therefore there were no spaces. These difficulties are related to two of the difficult distinctions identified earlier. Students who do not understand the school science distinction between mechanical energy and heat energy in terms of particles and their behaviour, will not understand the school science view that it is only matter, not particles, that can "heat up," or the textbook definitions which distinguish temperature and heat energy on the basis of mechanical energy.

SUMMARY: Students did not question the idea that particles are in constant motion. Only one student suggested that this is not always the case. The precise nature of mechanical energy and its relationship to heat energy were not well understood. To use the conceptual change terminology again, the concepts of heat energy and mechanical energy may have been plausible in their simplest form, but for many of the students, they were not fruitful. That is, students appeared to believe that mechanical energy and heat energy existed, but the concepts did not have explanatory and predictive power for them.

Idea A.3: The spaces between the particles are a perfect vacuum.

Several students seemed confused about the nature of the spaces between the particles. Alternative beliefs were particularly evident when students were trying to explain heat transfer and suggested that heat moved between the particles. For example, on the pretest Jane said that when an ice cube melts heat gets into any cracks the ice has. It appears that she thought that cracks would be the only spaces between the particles in ice and that heat only moves through spaces. On the pretest Carolyn predicted that glass would be a good conductor and that heat would get through a glass wall by "air particles." This suggests that Carolyn believed that the spaces between the particles contained air. Altogether, on the posttest six girls spoke of heat moving through the spaces or through air spaces between the particles.

SUMMARY: The nature of the spaces between the particles caused difficulty for some students. For most students, the existance of the spaces was an intelligible concept, but it was not plausible.

Topic B: Heat Energy and Its Effects on Matter

A great variety of responses were produced when students were asked what happens to matter when it is heated. This and other related questions were posed in several different and often ambiguous contexts and students frequently responded inappropriately. For example, during a discussion of thermal expansion, one demonstration involved heating a bimetallic strip. When asked to predict what would happen to the metal strip some students insisted it would melt. On other occasions when the topic was the behaviour of the particles of matter being heated, students repeatedly responded in terms of what would be observed visually and macroscopically. This section will examine student ideas about heat energy and its effects on matter, both at the macroscopic and the particle levels.

Idea B.1: Definitions of Heat Energy

A number of students experienced difficulty resolving the idea that heat is a form of energy, rather than matter. This should not be surprising, as our everyday language refers to heat as if it is indeed a form of matter (e.g., in winter we keep the doors and windows closed to keep the heat in the house). Three alternative beliefs about the nature of heat were expressed by students: heat is a form of matter and consists of particles; heat is something that moves between the particles of matter; heat is something that pushes the particles of matter. Each of these beliefs has a substance orientation. Four different ideas about the nature of heat were identified. An additional and related idea was the belief that cold and heat are two distinct "things." This idea is also examined in this section.

B.1.1: The heat energy of an object or of matter is the sum of the mechanical energy of the particles in the object or matter.

This textbook definition was provided by 12 students on the unit test. As the students were not required to explain the definition, it is not possible to determine how many students understood its meaning.

B.1.2: Heat is a form of matter and consists of particles.

Three students referred to heat particles or molecules. Carolyn mentioned heat particles three times during the pretest interview. First, when discussing heat being transferred from the hot nail to the water, again when explaining the transfer of heat through the metal rod ("the heat particles are moving"), and finally to explain the movement of a needle, which was actually moved due to a metal rod expanding as it was heated. In the last instance, Carolyn said, "the heat particles cause the needle and the pointer to move." Similarly, in the interview Gordon said that when the hot nail was put in the water, "the water molecules hit the heat substance and then somehow it sucks it in and changes." When asked where heat energy would go as the water cooled, Gordon replied, "...it could just go, just evaporate, yeah, I guess, it evaporates if it's steam." In a laboratory report, Susan also suggested that "heat turns to steam" when liquids are heated (Inv. 1.37). Gordon also spoke of air picking up heat molecules during the class discussion of conduction, and was corrected by the teacher who interjected, "heat energy transferred." On the posttest one other girl said that heat moves through a wall by "heat particles." All of these students used terminology which suggested they were thinking of heat as a form of matter. Gordon and Susan both spoke of heat turning to steam, and Gordon made one reference to heat molecules. The other two girls spoke of heat particles on only one occasion each. As these ideas were not consistently expressed by any of these students, it seems likely that they reflected confusion about the exact mechanism of heat transfer, rather than an explicit belief that heat is a form of matter.

B.1.3: Heat is something that moves between the particles of matter.

Attempts to explain conduction sometimes involved references to heat moving through spaces or cracks. As noted earlier, Jane suggested that ice melts because heat gets in cracks in the ice. She also suggested that heat may move between water particles on the pretest. Another girl referred to heat moving through "air holes" on the pretest and to heat moving through spaces on the posttest. Somewhat surprisingly, six girls spoke of heat moving through spaces or air spaces on the posttest, indicating that this idea was more prevalent at the end of the unit than it had been prior to the unit. For example, on the posttest Susan said that styrofoam would be a good conductor because it was full of holes and that heat travels better when particles are farther apart. Another girl said that heat moves through the air spaces in a glass rod. On one of the assigned questions, Susan wrote that heat goes through a metal pan "because the particles are farther apart." These six girls obviously did not understand the school science explanation of conduction as the transfer of energy from particle to particle.

B.1.4: Heat is something that pushes the particles of matter.

One girl spoke of heat pushing particles on the pretest. She did not repeat this idea on the posttest, where she indicated that when matter is heated the mechanical energy of the particles increases, so that the particles hit one another more and are farther apart. This posttest response reflects the explanation presented in class and may or may not have been rote learned.

B.1.5: Cold is a distinct thermal entity.

A careful reading of some of the students' responses revealed that at least three of them thought of cold as being something different from heat. Jane and Joe were among the three. For example, on the posttest, Jane said that metal feels colder than wood "because it conducts cold better."

SUMMARY: Several students spoke of heat particles or molecules, although they did not use these terms consistently. The extent to which this idea was believed is not clear. The idea that heat moves between particles of matter was expressed by more students on the posttest than on the pretest. The idea of heat pushing particles was mentioned by one student, and only on the pretest. The notion of "pushing" was expressed in other contexts, and will be discussed again. The concept of heat energy may be plausible in its simplest form, but for many of the students, it was not fruitful.

Idea B.2: When matter is heated/cooled many changes in the matter can be observed.

As indicated above, there was often ambiguity in questions that were posed for the students. For example, on the first day of the unit, the teacher asked, "What happens to substances when particles slow down?" Although the teacher was in the midst of a discussion about the relationship between temperature and the speed at which the particles were moving, Jane answered, "become solid?" The teacher looked surprised and responded, "It's kind of a hard question," (considering it had been discussed minutes before, it really was not that "hard"). Jane however, repeated her answer. The teacher then affirmed Jane's response, "Become solid," and added, "They really get cold." When students were asked what happens when matter is heated, they tended to focus on a change that could be seen macroscopically. The most commonly given response involved a change of phase or a change in position. Usually, one or more of the following responses was given:

B.2.1: The temperature goes up/down.

This statement might seem to be the most obvious answer to the question "what happens when something is heated?" The students believed this so firmly that many of them were unwilling to accept the data from the investigation of temperature change during phase changes. This idea will be discussed in detail later when the distinction between heat and temperature is examined (Topic D).

B.2.2: Matter expands/contracts.

All of the students had had experience with liquid-in-glass thermometers which utilize the property of thermal expansion. However, there was some confusion about what causes a liquid to rise in a glass tube as it is being heated. On the pretest/posttest students were asked why liquid in a glass tube rises when it is placed in boiling water, and whether the statement, "hot water rises" is a good explanation of that observation. Susan agreed on both tests that it was a good explanation, and her partner, Carolyn, agreed on the posttest.

Neither girl explained why it was a good explanation. Five other girls and one boy agreed on the pretest and explained that when water boils it rises--either it bubbles up, evaporates or is given off as steam. All of these phenomena were judged to be "rising." On the posttest one of those five girls and a different boy agreed with the statement. Both students gave explanations that were derived from convection, suggesting that hot water rises because it is less dense than cold water. Thus the explanations given on the pretest and on the posttest were quite different. The pretest explanations referred to rising due to boiling or evaporation. However, on the posttest rising was said to be due to a decrease in density. Ideas about convection appear to have led the students to an alternative belief not expressed prior to instruction. One other girl gave a very interesting explanation on the posttest. She said it was a good explanation "because it's true but it's just not scientific but it's good enough for the average person."

The students had no difficulty with assigned questions asking about thermal expansion with respect to loosening the metal lid of a jar or expansion/contraction of metal telegraph wires, bridges or railway tracks, suggesting they are comfortable with the idea that metals expand when they get hotter. However, some difficulties arose when students attempted to explain why a bimetallic strip bent when heated. Gordon said that the particles got more energy and spread apart and thus the strip became heavier, bent and stretched. The teacher acknowledged that he was correct on the first part--the metal did expand. She did not deal with Gordon's idea that the metal became heavier as it expanded. The following period when the demonstration was being discussed, the teacher said that the rod bent because it contained two different metals which expanded differently. Joe suggested that the rate of expansion for the two metals was different, but that eventually both would expand by equal amounts. Alan proposed that the two metals "expand at different heats," and another boy in the class said they would melt. Jane suggested that one metal expanded more than the other, and her response was accepted by the teacher. Alan then asked why his idea was not correct, and the teacher responded with a rather lengthy explanation. Alan looked very attentive throughout the explanation, and did not question the teacher further, but he later told the investigator that he had not understood the explanation.

B.2.3: Matter rises.

On the posttest some students confused thermal expansion and convection phenomena when considering why matter "rises" when heated. As mentioned above, one question on the test asked why the water level in a glass tube rose when the water was heated. The responses given on the pretest were diverse, and included:

1. the particles move faster and/or spread out and/or the spaces expand (3 students).
2. the particles expand (3).
3. the water wants to get out (1).
4. bubbles are pushing up the liquid; it bubbles up (2).
5. because it is evaporating (2).
6. hot water rises (3).

7. air displaces the water and forces it up the tube (1).
8. pressure created by the heat forces it up the tube (1).

Only the first of these is consistent with the school science view. On the posttest fewer alternative beliefs were expressed:

1. the particles expand (3).
2. convection (2).
3. the spaces expand and mechanical energy pushes the liquid up (1).
4. the boiling water is pushing the liquid (1).
5. the water molecules are more active and push themselves up (1).

Several students mentioned the idea of a push or force being involved. The students were not asked to elaborate on any of the responses in which they used these terms, but it would have been interesting to hear more about these ideas. Later when convection is discussed we shall encounter such forces again.

Two other pretest/posttest questions dealt with warm or hot air. One asked where in a classroom would you expect to find the warmest air. Nearly all students replied that the warmest air would be near the ceiling because warm/hot air rises. The other question presented an empty syrup can with a balloon over the opening. Students were first asked what would happen to the balloon if the can were upright and heated by a bunsen burner set below the can. Secondly, they were asked what would happen if the can were again heated from below, but inverted so that the balloon was attached to the lower surface. Students predicted that the balloon on the upright can would be blown up by the heated air. Two types of reasons were given. Most students said that warm air rises. Others said that the air expanded into the balloon, with a few students predicting that both would occur. Difficulties arose when students were explaining what would happen when the can was inverted. Most students, having said that warm air rises, said that warm air would rise to the top and hence the balloon would not inflate. Most of those who did predict that the balloon would inflate said it would do so because the air was expanding in all directions. Only one student, a boy, gave a hint of the idea of convection on the pretest, when he said the balloon would expand because as the hot air rises it pushes the cold air down. During the pretest interviews, Jane and Brian had both conceded that the balloon on the inverted can might expand a bit if the can were heated long enough and there was not enough room at the top for all of the hot air. However, neither suggested this possibility on the posttest. Carolyn, Alan, Gordon and two other students (both male) did refer to convection in their posttest explanations.

B.2.4: Matter softens, melts, liquifies, boils, evaporates/hardens, freezes, solidifies, condenses.

Understanding the process of phase change was very difficult for some of the students, and a variety of alternative beliefs were expressed. This topic will be examined in detail in connection with the heat/temperature distinction (Topic D).

B.2.5: Matter gets heavier/lighter.

These common alternative beliefs about the behaviour of matter when it is heated/cooled appear to arise from confusion about the process of thermal expansion. Some students seemed to believe than if an object gets bigger, it will also become heavier. Others appeared to think that because the object becomes less dense when it expands, it will also become lighter. The difficulty appears to derive from confusion about the concept of density and/or the law of conservation of matter. Both topics had been studied prior to this unit, and thermal expansion was being presented with the assumption that students did have scientifically appropriate understandings of both density and the conservation of matter. Responses made by some of the students suggest that they believed it was changes in the particles themselves, rather than in their energy levels and the relative distance between the particles, that was responsible for thermal expansion and contraction. Examples of such beliefs are presented in the next idea.

SUMMARY: Students understood that many different kinds of changes occur when matter is heated. The temperature increases, the volume usually increases and a change of phase may occur. In addition, when fluids are heated, they "rise." The most frequent responses involved a change of phase or rising--changes the students could see. The scientific principles behind these phenomena were not always clear. The ideas about temperature change and thermal expansion were intelligible and they were plausible to some. Once again, they were not fruitful.

Idea B.3: We make inferences about the behaviour of particles when matter is heated/cooled.

Difficulties with two of the fundamental distinctions appear to account for the alternative beliefs about the behaviour of the particles. First, both the textbook and the teacher stressed the idea that it is the spaces, and not the particles, that "expand" when matter is heated. This is presumably intended to counteract the belief held by many students, that the particles themselves expand and contract. Secondly, some students confused the macroscopic behaviour of matter with the behaviour of the particles. This difficulty is not addressed in the textbook, nor was it discussed in class.

B.3.1: When matter is heated: the mechanical energy of the particles increases; the particles move faster; the particles hit one another more frequently.

The textbook presents the idea that the heat energy of an object is the total mechanical energy of the particles in the object, and hence heating an object will result in an increase in that mechanical energy. None of the students referred to an increase in mechanical energy on the pretest. On the posttest Jane and three others did so, although one girl said, "the spaces between the particles expand and gain more mechanical energy." On the pretest, she and Jane had both said the particles moved faster. Most of the students talked about particles moving faster when heated on the posttest. Only three students (Alan and two others) made no mention of either the particles gaining mechanical energy or moving faster at that time. Altogether, ten students spoke of particles moving faster on the pretest and 17 on the posttest. A few students noted that the particles hit one another more frequently when matter is heated. Cathy and another girl said this on both tests, whereas Alan, Gordon and two other girls expressed this idea only on the posttest.

B.3.2: When matter is heated: the particles are farther apart; the spaces expand or get bigger.

As mentioned above, the textbook stresses the idea that when matter is heated the spaces between the particles get bigger. In the textbook, the review questions at the end of the chapter refer to spaces:

> What happens to the spaces between the particles of air when air is heated? How does this change the density of the air? Explain your answer. (Schmid and Murphy, 1979, p. 125)

The suggested answers provided in the teachers' guide indicate that the students should respond that the spaces between the particles become larger. It would appear that the authors felt that they could better emphasize the lack of expansion of particles by indicating that it is the spaces that become larger, rather that saying that particles spread apart. Susan's response to the question about what happens to the size of the particles was, "The particles between the air expand..." All other students (including those who were to say later that particles expand when matter is heated) responded that the spaces would become larger. Thus it appears that emphasing the expansion of spaces did not necessarily discredit expanding particles.

B.3.3: When matter is heated: particles expand, increase in mass, decrease in mass, or melt.

Students who expressed one or more of these beliefs had not disinguished between the observable behaviour of matter and the unobservable behaviour of particles, a distinction previously identified as a key source of difficulty for several students.

As mentioned above, the idea that thermal expansion occurs because the particles (atoms or molecules) have expanded is very common. Nine of the 23 students in the class expressed this idea on the pretest and/or in class. Because the question, "Do particles expand when matter is heated?" was not asked directly, we cannot be certain about the beliefs of those who did not refer to particles when explaining thermal expansion. However, there were only three students who made no mention of either particles, atoms or molecules on either the pretest and/or the pretest interview. On the posttest, five students still explicitly stated the belief that the particles expand when matter is heated.

Two students spoke of particles becoming heavier when they expanded. On the pretest Carolyn said that, "water particles expand when they're heated so they have a greater mass." Although Carolyn's response may have been correct according to scientists' science, it was incorrect from the school science perspective. When the bimetallic strip was being heated Gordon predicted that it was bending downwards because the particles were getting more energy and spreading apart, and it became heavier. The teacher responded that Gordon was right on the first part, but she did not deal with his suggestion that the strip got heavier. The next day just before the end of the period, one of the girls spoke to the teacher privately and said that she thought that the mass must change when something gets bigger. She pointed out that if we get bigger our mass changes. As the bell was ringing the teacher told her that the mass did not change. Two days later, while discussing properties which change when matter is heated, another girl gave mass as an example. The teacher responded by asking if any particles were to be thrown away, and the students said no. As the discussion continued some students said when water evaporates some particles are given off. The teacher then agreed that there could be a change in mass in this situation. She did not point out that the water has gone somewhere else, rather than its mass actually changing.

Later, when Investigation 1.42 (The heat energy and temperature of different objects) was being discussed, the teacher herself referred to mass "changing" rather than speaking of different masses (or of changing to an object of different mass), undoubtedly further confusing the issue. This investigation will be discussed in more detail in the next chapter.

Other students spoke of particles becoming lighter when matter was heated. This idea was provided by Cathy as an explanation of why matter rises when it is heated, and will be further discussed in the section dealing with convection. None of the questions on the posttest or unit test addressed the matter of mass changing, and none of the students said anything about it on either test.

A final alternative belief to be examined in this section is the idea that particles melt when matter is heated. On the pretest Cathy used the terms "melt" and "dissolve" interchangeably. She did not use the latter term on the post-test. However, when explaining why the ice cube melts she responded that the particles get warmer and melt. Again, Cathy did not distinguish between the behaviour of matter and the behaviour of the individual particles.

SUMMARY: Many students appear to have assumed that observable changes in matter also occur in particles. That is, if matter expands, the particles are expanding. An attempt to correct this particular alternative belief by concentrating on the spaces was not effective for some students. They apparently saw no conflict in the two phenomena. None of the other specific alternative beliefs discussed in this idea (e.g., particles melt) were discussed in class.

Topic C: Temperature and How It Is Measured

Most thermometers depend on the property of thermal expansion, discussed above. The students investigated temperature by finding the freezing and boiling points of water using a mercury thermometer (Inv. 1.37). When discussing the investigation the teacher asked for definitions of temperature. One student responded, "how hot it is." Another said, "the heat that's contained within the object," a response repeated by the teacher and then ignored. Brian then replied, "how hot something or how cold something is," whereupon the teacher said, "the hotness or coldness of an object." She then told the class to write that down in their notebooks.

Idea C.1: Definitions of Temperature

C.1.1: Temperature is a measure of the average mechanical energy of the particles.

This definition, provided in the textbook, was rarely expressed by either the students or the teacher. When students were asked to define temperature on the unit test, only Jane and one other boy gave this definition (Jane also gave the alternative definition). Another girl replied, "an approximation of how much mechanical energy the particles have each all together," evidently confusing the textbook definitions of heat and temperature. This definition was not intelligible to the students.

C.1.2: Temperature is the hotness or coldness of an object or of matter.

This definition is also provided in the textbook (Schmid and Murphy, 1979, p. 110) and it was emphasized by the teacher in class. Ten students used this definition on the unit test. Two of them, Brian and Joe, said temperature was a measure of how hot or cold something is. Some unacceptable responses which may have been derived from this definition include those of two students who simply said it was a measure and one girl who replied, "how hot the particles are," another instance of confusing the distinction between the properties of matter and of particles.

C.1.3: Temperature is a measure of the heat of an object or of matter.

A surprising number of students defined temperature as a measure of heat or heat energy on the unit test. Three students said it was a measure of heat or heat energy, while Gordon and two other students said temperature was the heat being given out, or in the words of one boy, "the heat you can feel on the surface." One girl gave a definition that would more appropriately define heat, the mechanical energy of the particles all together. More detailed discussions of the distinction between heat and temperature follow under Topic D and in Chapter V.

SUMMARY: Several students were still unable to provide an acceptable definition of temperature on the unit test, although both the textbook and the teacher stressed definitions. Many students still seemed to believe that temperature is really a measure of heat. Memorizing the complex definitions provided by the textbook or by the teacher did not necessarily displace that belief. In such cases, the school science definition of temperature was neither plausible nor fruitful.

Idea C.2: The characteristic property of thermal expansion allows us to use the volume of a fixed amount of matter to indicate the temperature of that matter.

Although this idea provided the rationale for the thermal expansion investigations (1.37 and 1.38) it was not made explicit to the students. The chapter review questions included the following:

> What properties of matter are affected by temperature? How are these properties used to measure temperature? (Schmid and Murphy, 1979, p. 125)

Students appeared to be unaware of the meaning of the term, "property," as only one student answered this question appropriately. Several students responded, "solid, liquid, gas," and others said volume or mass. Noting this difficulty, the teacher discussed the meaning of the term in class, but the second part of the question was overlooked in the discussion.

The topic was not raised again, nor was it addressed on either the unit test or the posttest. Another textbook question, "List five changes in matter that are caused by changes in temperature" (Schmid and Murphy, 1979, p. 123) was not assigned. If students had had to answer this question before coming to the review question cited above, they may have been more successful on the latter. On the unit test the students were asked to explain how to calibrate a thermometer. Those who understood Investigation 1.37 and this idea should have had no difficulty with the explanation. In fact, only 12 students answered the question correctly.

SUMMARY: Although the students understood that substances expand when they are heated, most of them were unable to apply that knowledge to explain how a thermometer is calibrated. Again, the phenomenon of thermal expansion was plausible, but it was not fruitful.

Topic D: The Difference Between Temperature and Heat Energy

Many students were still not clear about the distinction between heat and temperature on the posttest. The posttest included a set of questions concerning a large and a small ice cube placed in a beaker of water. Students were told the small cube would melt first and they were then asked if both cubes were the same temperature, why they thought the small ice cube would melt first, if they thought that both cubes needed the same amount of heat to melt them and why. Students who clearly understood the distinction between heat and temperature should not have had difficulty with these questions. On the other hand, students who assumed that temperature is a measure of heat could be expected to say that both cubes needed the same amount of heat to melt. On the pretest 16 students, including many of the more successful students (among them Jane and all other target students except Alan), did say the cubes needed the same amount of heat. Some students also said that the bigger cube just needed more time. On the posttest Jane, Carolyn and four other students still agreed with that view. Jane's incorrect responses on the posttest suggest that this idea was not clearly addressed during instruction (it is very unlikely that Jane would give an answer which had been identified as incorrect). On the pretest Jane said, "yes, the larger one will just take longer." During the interview she reversed her answer and said they would not need the same amount of heat. However, on the posttest Jane went back to her original position and said, "yes, but the larger one will take longer to melt."

Idea D.1: The amount of heat energy contained in matter depends on: the kind of material; the amount of matter; and the temperature of the matter.

The idea that the temperature and the mass of matter influence the amount of heat energy in matter caused no difficulties. On the unit test 13 students gave both of these factors, and only one student missed both. Two girls said mechanical energy, rather than temperature. However, the "type of material" caused problems. The textbook refers to the type of material as being one of the factors influencing heat energy. Density is never mentioned in the text. The students however, tended to assume that the relevant property was the density of the material, and then used this term in their conclusions and when answering questions. This alternative belief was common in the pilot study class as well. During class discussions the students usually referred to density, rather than type of material. When they did so, the teacher told them it was better to refer to the type of material rather than the density. However, when grading assignments and tests, she did not penalize students for using the term. On the unit test students were asked to "list three factors which affect the heat energy of an object." Most students said type of material as one of their answers. Two boys said both density and type of material. However, Gordon gave neither and all of the other boys but one said density. Only one of the girls, a very low achiever, gave density as an answer. It is interesting that most of the boys persisted in using the term, whereas most of the girls did not. It may be that the girls, being more compliant, were more willing to do as the teacher said (i.e., not use the term "density"), even if the distinction made no sense to them. The students also tended to assume that a greater density meant more heat energy for equivalent temperature changes. Joe once made a statement to this effect in class, and his error was not picked up by the teacher.

SUMMARY: The students had no difficulties understanding that temperature and mass are related to heat energy. The idea that a property of matter other than density was also a factor was apparently too abstract and nebulous for most of them. At no time was it specifically stated that if mass and type of material (or density), as well as temperature affect the amount of heat energy in the material, then temperature and heat cannot be the same, and temperature cannot be a measure of heat alone. The students were apparently expected to recognize this themselves. In fact, most of them did not.

Idea D.2: When matter is heated the rate at which the temperature increases is not constant when a phase change occurs.

As we saw in the discussion of Topic B, the students were convinced that the temperature of matter should increase as long as the matter is being heated. The second investigation in chapter 8 (Inv. 1.45) examines heat and temperature during phase changes. The introduction states, "In this Investigation you will see what difference a material's phase makes to its heat energy" (Schmid and Murphy, 1979, p. 135) The questions to be answered by the investigation are:

> 1. Which has more heat energy--ice at 0°C or the same mass of water at 0°C?
>
> 2. Which has more heat energy--ice at 100°C or the same mass of water vapor at 100°C?
>
> 3. Which takes the most heat energy--melting ice, raising the temperature of the liquid water from 0°C to 100°C, or boiling away all the water? (Schmid and Murphy, 1979, p. 135)

The investigation involved measuring the temperature of ice and water in a beaker, as it was being heated. Readings were taken every two minutes until the water boiled. Students were expected to note that although the water was heated constantly, that during a phase change the temperature remained relatively constant. However, this was not what they expected, and as we shall see, some of them did not believe the results were correct. None of the questions on the pre/posttest addressed this issue, but it was a topic which Alan and one other boy had discussed earlier. Brian also expressed concern about this matter, a concern which was not satisfactorily resolved. This investigation, its results and the confusion that arose during the discussion of the investigation, will be discussed in more detail in Chapter V.

SUMMARY: The distinction between heat and temperature was never clearly resolved for many of the students. Although students were able to recite definitions and distinctions, the posttest revealed that many did so with no understanding. The distinction was intelligible to some, but not all.

Topic E: Heat Transfer

Although the students appeared to be relatively familiar with the concept of conduction, they knew little about convection or radiation. Some used the term "conduction" on the pretest, while others referred to heat being either "absorbed" or "attracted" when explaining conduction phenomena. The teacher accepted both of these terms as being equivalent. Students frequently mentioned density as a factor influencing heat transfer, although this idea is not mentioned in the textbook, nor did the teacher introduce the idea. However, as was indicated earlier, neither did she tell them it was incorrect.

Heat transfer was dealt with very hastily. The students were given hand-outs briefly describing conduction and convection, and they were not asked to read the text on these topics, although questions from the text were assigned. Conduction, convection and radiation were all discussed in class, and simple demonstrations illustrating the first two phenomena were performed by the teacher. As shall be seen, these demonstrations did not always produce the desired results.

Idea E.1: Conduction

The students were aware that hot objects become cooler if they are placed in a cooler environment and vice versa.

E.1.1: Conduction is the "transfer of heat energy that takes place when faster particles make nearby particles speed up by hitting them." (Schmid and Murphy, 1979, p. 42)

On the unit test students were asked to explain conduction using the particle model. Thirteen students got full marks on this question. Only Carolyn, Alan and four others got less than half marks (Alan described convection, rather than conduction), indicating that most students were able to satisfactorily explain the behaviour of particles when heat is conducted.

E.1.2: Conduction occurs when heat is transferred from hotter matter to cooler matter until both are at the same temperature.

Everyday experience tells us that if something is removed from a hot oven or a cold refrigerator its temperature changes to something approximating room temperature. On both the pretest and posttest all students knew that if a hot nail were dropped into a beaker of cold water, the nail would get cooler and the water would get warmer. Most students did not however, predict that they would reach the same temperature (ten predicted they would become equal in 30 minutes or less on the pretest; the same ten plus two more made the same prediction on the posttest).

Another set of questions on the pre/posttest dealt with a shovel left outdoors on a frosty night. Students were asked why the metal felt colder than the wood and what temperature they would expect the wood and the air to be if the metal were -3°C. On the posttest, six students (including Alan and Cathy) predicted the air temperature would be -3°C. Only Alan and Susan predicted the temperature of the wood would be -3°C. Although many students recognized that the two substances conduct heat (cold) differently, only Alan said that the wood and metal "absorb [i.e., conduct] heat from your hand." Three students, Jane and Joe included, referred to cold, rather than heat. A similar question, why perspiration cools the body, was assigned from the textbook. That question was discussed in class and almost all of the students had it correct when they handed in the assigment. In addition, the teacher had discussed the phenomenon in class, asking as an example, why the metal gas faucets on the laboratory tables felt colder to the touch than did the table top. Alan responded that the tap felt cooler because "it's taking our heat." In spite of this, none of the students, except Alan, recognized that all parts of the shovel would be the same temperature as the air temperature. Students who had developed the desired understanding of conduction should have been able to answer the shovel questions correctly. Only Alan did so, and his answers did not differ on the pretest and the posttest.

E.1.3: The rate at which conduction occurs depends on the type of material.

Many students did not recognize that a metal rod would conduct heat more rapidly than a glass rod. On the pretest six students predicted the metal would conduct faster, and 12 that the glass would. On the posttest ten predicted metal and nine glass. Jane, Gordon and two other boys predicted correctly on both tests. Alan, two other boys and three girls were correct on the posttest only. Two of those who predicted correctly on the pretest did not do so on the posttest, suggesting they may have guessed on the pretest. Again density was assumed to be the relevant property of the material. On both tests, Joe and Brian said the glass would conduct faster because it is less dense. On the posttest, Cathy and two other girls agreed with Joe, while Alan and two other boys said glass conducted more slowly because it was less dense. The idea that heat is conducted through the spaces has been discussed earlier (Idea B.1.3.). Those who predicted that a less dense object would conduct more slowly may have had one of two alternative beliefs. The first possibility, mentioned earlier, is the idea that heat moves between particles of matter and hence travels faster when it has more room. This idea was expressed by Carolyn on the pretest and by Susan and three others girls on the posttest. One girl explained, "The heat has to move in between the particles spaces." Another girl spoke of heat particles moving through matter. The second alternative belief was expressed by Brian during the interview. He said that when particles of matter were farther apart they had more room to move around and thus were able to speed up more quickly. Brian's alternative belief is much closer to the school science view as it recognizes the importance of the increased rate of motion of the particles. On the pretest, Susan and three other girls said glass would not conduct at all. One other girl said glass and metal would conduct at the same rate on both the pretest and the posttest.

SUMMARY: The students understood conduction in a qualitative sense prior to the unit. At the end of the unit, when required to explain conduction using the particle model, half the class was able to do so. However, the posttest responses to items concerning conduction revealed that many students still held alternative beliefs.

Idea E.2: Convection is the "transfer of heat energy by a hotter fluid moving to a colder place" (Schmid and Murphy, 1979, p. 150).

Convection was not at all well understood. As mentioned earlier, from the beginning students believed that heat or hot air rises. On the pretest everyone but Susan said that the air in a closed room would be warmest near the ceiling. Susan said it would be warmer near the middle "because of the heater." (There was no heater mentioned in the question.) The confusion began when the students were asked to go beyond that idea. Some of the students seemed to confuse thermal expansion and convection. This is not too surprising as convection really does occur as a result of expansion and the consequent reduction in the density of the matter. Some also confused the properties of matter with those of particles. For example, on the posttest both Brian and Cathy said warmer particles are lighter and rise.

A more difficult question posed the situation in which an empty metal container had a balloon placed over the opening. Students were asked what happened in the container and to the balloon when the can was heated, first from the bottom, and secondly when it was inverted (so that the balloon would be at the bottom). On the pretest students either said the air would rise or it would expand or both. They therefore predicted that the balloon would feel warm when the can was upright and the balloon was on the top, but not when it was inverted so that the balloon was on the bottom. Most students repeated this idea on the posttest. As they did on the pretest, Jane and Joe said that when the air was heated it would expand and the hot air would rise to the top, and therefore the balloon would not expand or feel warm. To quote Carolyn, when the balloon is on top it will blow up because, "convection would force the air to rise." When the can is inverted, "the balloon would not fill up. Hot air never goes downward." Thus Carolyn viewed convection as hot fluid rising, but not circulating. On the posttest only four boys (and no girls) identified this question as an example of convection, and correctly predicted that the inverted balloon would not only expand, but also feel warm. That is, very few students appeared to understand convection as a cycle.

On the unit test students were asked to draw arrows showing "the direction of the convection current" over a land-sea interface. Seven students drew the correct cycle, among them

Jane, Brian and Alan. Most others either drew the cycle in reverse (eight students) or showed the air rising, but not cycling (five students). One student who did the latter explained, "the cool air will force the warm air upwards convection only works upwards."

The above response also provides an example of another somewhat misleading belief--the idea that either warm or cold air pushes or forces the other to move. On the handouts given to the students, diagrams show a simple air convection demonstration and a hot water heating system. The captions say that the cooler fluid (either the air or water) "forces the warm air [or water] to rise." When convection was discussed in class, the teacher asked if someone could "explain how convection would work." Jane gave the following response:

> If you have some water and you heat up part of that water, the water that you heat up, the particles will move farther apart, the water will have more heat energy, so the heated water gets lighter than the cold water, so the cold water is heavier and it pushes the hot water and so that's how it's moving around."

Jane does not appear to have recognized that the warmer water tends to rise at the same time as the cooler water is sinking, and thus she misses the idea of the circulation of the water. Even in the textbook this confusing view is presented:

> ...the colder fluid sank because it was denser than the warmer fluid. Therefore, the warmer fluid was pushed up. When the warmer fluid rose, it carried its heat energy with it. (Schmid and Murphy, 1979, p. 150)

SUMMARY: All in all, very few students seemed to view convection as a process which involves a fluid circulating because one part of it is warmer and hence less dense than the other part.

Idea E.3: Infra-red rays, like light rays, are a form of electromagnetic radiation that travel through space. They can be reflected and refracted, just as light rays can. When an object absorbs infra-red rays, its particles gain mechanical energy. When an object radiates (infra-red rays) its particles lose mechanical energy. Therefore, infra-red rays seem to carry heat energy from one object to another. (Schmid and Murphy, 1979, p. 163)

Other than the unit test, information about the students' ideas about radiation is sparse. On the final day of class, the teacher reviewed conduction and convection, and introduced the topic of radiation. The main ideas introduced were that hotter objects radiate more heat than cooler objects, the effect of colour on reflection and absorption of heat, and the greenhouse effect. At the end of the period she distributed copies of the review summary from the heat transfer chapter (Chapter 9), saying, "These sheets are a review for your test. They review the material." The review questions were neither handed in nor discussed in class, and no other reading or questions were assigned.

Three questions on the unit test dealt with radiation. One question asked how the sun's energy reaches us. Students were also asked to describe the clothing they would wear if the temperature were -60°C and how it would keep them warm. The third question asked which would radiate more--your body at 37°C, or your surroundings on a hot day of 30°C, and what kind of clothing would help you stay cool. All but five students (four boys and one girl) recognized that the sun's energy reaches the earth by radiation. Only Joe, two other boys and one girl got the full three marks on the question about clothing for -60°. They were required to refer to: warm clothing (good insulation), keeping in body heat, and dark colours. The remaining students got one and one-half or two marks. Thus, overall the students answered this question fairly well, as they did the question about dressing for a hot day. However, ten students did not recognize that the body, being warmer, radiates more heat per unit area than its surroundings. Joe, Brian, Cathy and Susan were among the ten. Joe explained that the body radiates less heat "because your body retains its heat and your surroundings don't." This question required the students to apply their knowledge of radiation to a slightly different situation than had been discussed in class. Many of them were unable to do so.

SUMMARY: Most of the students were able to identify factors influencing absorption and reflection of radiant energy, and factors that make clothing either a good or a poor insulator. The idea that all matter radiates heat energy was not well understood.

4.5. Summary

This chapter has examined many different ideas about heat and temperature. The scientific perspective was presented and contrasted with the textbook and curriculum perspective. These perspectives have been referred to as "scientists' science" by Gilbert et al. (1982) and "school science," by Driver and Erickson (1983).

The major portion of the chapter has been devoted to a detailed examination of "children's science." That is, of the students' ideas prior to instruction and to a discussion of how those ideas changed in the course of a unit of study. We have seen that many of the alternative beliefs were related to one or more of three particularly difficult distinctions identified in the section on children's science. These were:

1. the idea that matter consists not only of particles, but includes the spaces between the particles as well;
2. the idea that the behaviour of particles is not the same as the observable behaviour of matter; and
3. the distinction between heat and temperature.

The examination of children's science identified several alternative beliefs that were still expressed by some students on the unit test and/or the posttest. Moreover, some students had changed their ideas to a less scientific view than they had held before, not an unusual occurence, according to Osborne and Wittrock (1983). Students were found to have particular problems with the school science explanations of the following topics:

1. The thermal expansion of matter, at the particle level.
2. The nature and extent of the spaces between the particles of matter.
3. The nature of heat and the difference between heat and temperature.
4. The type of material as a factor related to the heat energy (i.e., internal energy) of matter.
5. When matter is heated, the rate of temperature change is not

constant when a change of phase occurs.

6. The difference between heat and cold.
7. The effect of heating on different kinds of matter.
8. How conduction occurs, at the particle level.
9. The effect of the type of material on the rate at which heat is transferred by conduction.
10. How heat is transferred by radiation.

The next chapter will take a closer look at learning and will examine in more detail the interaction between school science and children's science.

CHAPTER V

CHILDREN'S SCIENCE: LEARNING

5.0. Introduction

To some, a school is a place where teachers teach and children learn what is taught. This view of teaching and learning seems to assume that if teachers present information in a logical way, at an appropriate level of complexity (or simplicity) and if students complete the required activities and assignments, then the students will necessarily achieve the intended learning outcomes and understanding. For students who are both intellectually competent and achievement-oriented this view may be realistic. Three of the target students, Jane, Cathy and Susan, each in her own way, worked diligently to learn what was taught. There is no doubt that all of the girls did learn something about heat and temperature during this unit. However, the products of their efforts were very different--in part, the result of different sets of prior beliefs interacting with different cognitive abilities. For Jane, most of the learning appeared to be meaningful. For Cathy and Susan, much of it was meaningless memorization. However, Cathy was much more successful than Susan at utilizing what was memorized in a test situation. If we examine unit test marks for each girl, we see that Jane and Cathy did much better than Susan (Table 5.1). However, does this necessarily mean that Jane and Cathy learned more than Susan? On the pretest Jane and Cathy received approximately equal scores. However, Cathy's posttest score was somewhat <u>lower</u> than her pretest score, whereas the other two girls showed substantial gains from pretest to posttest. Jane's scores increased for all levels, whereas Susan's gains were only on Level 1 questions (see Table 2.1 for descriptions of levels). Based on pretest-posttest gains, Jane and Susan appear to have learned more than Cathy. Observations such as these raise many questions as to how we should define learning.

Table 5.1

Test Scores for Three Selected Target Students

	Jane			Cathy			Susan			Max.
	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Score
Level 1	18	21	3	18	17	(-1)	9	16	7	21
Level 2	7	12	5	8	3	(-5)	2	1	(-1)	15
Level 3	3	6	3	2	4	2	1	0	(-1)	11
Total Test	28	39	11	28	24	(-4)	12	17	5	47
Unit Test		94%			80%			59%		100%

In the previous chapter several perspectives of heat and temperature were discussed. Many of the beliefs held by the students were presented and examined. Some of those beliefs are compatible with current scientists' science and/or with school science. However, without exception, on the posttest every student still held at least some of the alternate beliefs that had previously been expressed on the pretest. The great majority of these beliefs had been addressed in the textbook and/or during instruction. Why did the students fail to revise some of their prior alternate beliefs, even when these ideas were repeatedly refuted in the textbook and by the teacher? The overriding aim of this study has been to try to shed some light on this key question.

In this chapter, we will examine what the students "learned" during the unit. Before this can be done, we must carefully define what we mean by "learning." Although many would define learning as a change in behaviour, the most commonly used measures of learning in our secondary schools assess the extent of knowledge and/or skills demonstrated by the student at various intervals throughout the school year. In this study we will consider three operational definitions of learning:

1. learning as demonstrated by success in school science,
2. learning as demonstrated by success on the posttest, and
3. learning as demonstrated by gains from the pretest to the posttest.

The extent to which individual students and the class as a whole have been successful according to each of these criteria will first be examined. Class data will be examined to identify student characteristics which were related to the various criteria for success. Particularly successful and particularly unsuccessful students will be identified to determine the extent to which those characteristics of success typify individuals. The chapter will conclude with an examination of those content areas where learning was not successful for many students--the persistent alternative beliefs.

5.1. Analysis of the Data

All of the data collected were utilized to investigate what the children had learned about heat and temperature. Both qualitative and quantitative analyses were conducted.

5.1.1. Qualitative Analysis

The previous chapter has already described the qualitative analysis of student beliefs about heat and temperature. A further examination of all of the transcripts, tests and assignments was conducted to consider possible explanations as to why some alternative beliefs were so persistent.

5.1.2. Quantitative Analysis

The investigator scored all responses on the pretest and posttest as either correct or incorrect, according to the criteria provided by the test developers (Shayer, Note 3). As described earlier, each item had been categorized according to topic(s) and difficulty level. The LERTAP (Nelson, 1974) program was used to score and analyse the test responses. LERTAP provided total scores and subscale scores for each of the three difficulty levels and each of the seven topics. For each subscale, the following were provided: subscale scores for each student, range of scores (including histograms), mean scores and subscale reliability (Hoyt's estimate of internal consistency). These data are summarized in Table 5.2. The program also provided correlation coefficients for the relationship between the responses on each test item and the subscale and total test scores, and gender. Correlations between subscale scores and total test scores were provided as well.

Table 5.2

Range of Scores: Pretest and Posttest

	Pretest				Posttest			
	Min	Max	Mean	r	Min	Max	Mean	r
Level 1	7	21	16.5	0.81	8	21	17.7	0.81
Level 2	1	11	6.0	.70	1	15	7.7	.85
Level 3	0	4	2.1	.38	0	7	3.7	.58
Topics:								
Temp. Scales	1	6	4.4	.58	1	7	5.2	.83
Temp. Changes	1	6	4.7	.52	3	6	4.7	.40
Expansion	0	8	4.3	.76	1	9	5.3	.80
Matter & Heat	0	6	3.0	.32	1	5	3.4	.41
Composition of Heat	1	6	4.7	.14	3	10	6.3	.51
Temp. & Heat	0	7	3.8	.49	1	7	4.3	.56
Movement of Heat	2	11	7.7	.87	5	14	9.5	.64
Total Test	8	36	24.6	0.87	13	43	29.1	0.90

Three sets of school science marks were recorded. A mid-term mark had been provided to each student shortly before the observation period began. On the final day of the study the students wrote a unit test on heat and temperature which had been composed by the teacher. At the end of the term the teacher provided the final science mark assigned to each student. The teacher-made unit test and the posttest provided two different measures of student knowledge at the end of the unit. The difference between the pretest and posttest scores provided a measure of the learning which occurred during the unit (i.e., unit learning).

The coded class dialogue was summarized by tabulating and determining the relative frequencies of each of the various categories of dialogue, as described in Chapter III. The frequencies for males and females were compared to determine if there were any gender differences in class participation and/or student-teacher interactions. The number of times each individual student spoke during class dialogue was determined.

Pretest and posttest scores were correlated with school science marks and with two other characteristics which have been reported to be related to science learning (i.e., gender of student and the extent to which each student contributed to class discussions). To allow additional comparisons of the pretest and posttest responses, a correlation matrix of the subscale scores of both tests and pretest-posttest gain scores was prepared using SPSS:X (SPSS, Inc., 1983). Other measures included in the matrix were school science marks and two student characteristics: gender and the measure of how many times the student spoke during class discussions (talk).

Analysis of variance and covariance were performed to further investigate significant relationships identified by the correlational analysis, again using SPSS:X. The relationship between gender and talk suggested there might be a significant interaction between these two factors. A two-way analysis of variance showed this was not the case. Analysis of variance also showed that the status of being a target student was not a significant factor for any of the measures of learning. The relationship of gender and of talk on posttest scores was investigated using analysis of covariance, using the pretest as a covariate.

The findings of the quantitive analysis must be interpreted very cautiously. There were only 23 students in the class--nine boys and 14 girls. It is impossible to make any strong claims on the basis of this small sample. However, the findings may be useful to the extent that they:

1. support or oppose any tentative conclusions derived from the tabulated data or the qualitative data, and/or
2. suggest some alternative and/or additional findings which should be investigated by further studies.

5.2. Learning: Measures of Success

The terms "learning" and "knowledge" can mean many things. Ausubel's distinction between rote and meaningful learning provides a basis for examining different kinds of learning and knowledge. Rote learning, for example, results in knowledge that would allow a student to provide, verbatim, the textbook definition of a term (i.e., a rote response), but not necessarily to explain the term in his/her own words, identify an example which would illustrate the key features of the term, or solve a problem which required an understanding of the term. Many of the student responses in this study appeared to be rote responses. In such cases, it was impossible to determine whether the response was meaningful to the student (i.e., whether it was intelligible, plausible or fruitful).

A crucial distinction throughout this investigation has been the distinction between "learning" and "knowledge." Student knowledge can be considered to be the result of learning. For this study, it is also essential to separate a student's prior knowledge from the knowledge that was learned during the unit. Prior knowledge will be assumed to be the result of prior learning. Knowledge at the end of the unit was not always the same as prior knowledge. Changes in knowledge will be assumed to be the result of learning which occurred during the unit (i.e., unit learning).

As mentioned above, teachers are typically in a position only to measure knowledge as assessed through tests such as the unit test. Measures such as this do not separate prior knowledge from knowledge gained as a result of instruction. Nor do such measures always distinguish knowledge which has been learned by rote and is not intelligible to the students from knowledge which is intelligible and possibly plausible and fruitful. To contrast prior knowledge with knowledge following instruction for individual students, this analysis uses the difference between pretest and posttest scores. As these tests required students to apply their knowledge of heat and temperature concepts, they would have been unable to answer the questions using rote-learned definitions or facts which were not intelligible. Therefore, it will be assumed that responses on the posttest represent meaningful knowledge; that is, knowledge which was not only intelligible and plausible, but probably fruitful as well.

Responses on the posttest were also contrasted with responses on the unit test and on written assignments to identify differences between rote and meaningful knowledge that would not be identifiable from the unit test or the assignments alone. As is shown in Table 5.3, students who were successful learners according to one of the definitions of learning were not necessarily successful according to the others. Correlations between the various measures (Table 5.4) revealed that marks obtained on the unit test were more closely related to Level 1 posttest subscale scores ($r=0.590$, $p=0.003$), than to Level 2 or 3 subscale scores ($r=0.472$ and 0.505, respectively; $p=0.023$ and 0.014, respectively). Moreover, unit test marks were not significantly related to pretest/posttest gains ($r=0.230$, $p=0.291$).

5.2.1. Learning: Success in School Science

In school, the marks attained by students on tests and assignments, and ultimately the final mark in the course provide a measure of success in learning. As was stated above, these marks more accurately reflect knowledge, rather than learning. They can not distinguish prior knowledge from knowledge which has been learned as a result of instruction. They may not distinguish knowledge which is intelligible from knowledge which is not.

Seven students received marks of 80 percent or better on the unit test. These students would thus be the top third of the class. Jane had the highest mark on all measures of school science achievement. Only three of the seven students were also in the top third on the posttest.

Table 5.3

Student Posttest Scores and School Science Marks

Name	Level 1	2	3	Total Score	Unit Test	Final Mark
Alan*	21	15	7	43	70%	52%
Jane*	21	12	6	39	96	94
David	21	13	5	39	88	79
Joe*	20	14	4	38	78	77
Fred	21	13	3	37	75	76
Walter	20	9	6	35	86	75
Brian*	20	10	5	35	76	64
Mona	21	9	4	34	86	88
Melanie	20	8	4	32	88	73
Gordon*	16	9	6	31	60	38
Cindy	19	8	4	31	73	77
Laura	18	7	4	29	74	63
Lynne	19	7	3	29	71	72
Jack	13	11	3	27	68	60
Carolyn*	19	3	4	26	71	74
Marlene	16	8	1	25	59	70
Mary	18	5	2	25	46	66
Cathy*	17	3	4	24	80	62
Ellen	17	6	1	24	84	65
George	13	3	4	20	76	70
Susan*	16	2	0	18	59	55
Donna	13	3	1	17	22	24

*Target Students

Alan, the student who scored highest on both the pretest (35) and posttest (43), got only 70 percent on the unit test (and only 52 percent as a final mark in the course). The reasons for Alan's lack of success in school science are undoubtedly complex. The teacher considered Alan to be a student of average ability and with poor work habits. During class discussions she did not encourage him to question matters he did not understand. On two occasions he expressed an interest in pursuing a question, but the teacher did not follow up on his ideas. On those occasions, Alan was not heard from

Table 5.4

Correlation Matrix

	Gender[1]	Talk	Pre1	Pre2	Pre3	Total	Post1	Post2	Post3	Total	Gains	Gain23	Unit	Midt
Talk	-.510*													
PreLev1	-.295	.394												
PreLev2	-.305	.334	.204											
PreLev3	-.259	.297	.121	.992**										
Pretest	-.240	.331	.934**	.157	.063									
PostLev1	-.155	.307	.704**	.250	.196	.762**								
PostLev2	-.617**	.642**	.773**	.232	.153	.772**	.664**							
PostLev3	-.494*	.467*	.471*	.218	.187	.480*	.382	.544**						
Posttest	-.499*	.570**	.809**	.277	.206	.835**	.859**	.926**	.672**					
Gain P/P	-.506*	.486*	-.072	.241	.268	-.131	.300	.405	.426*	.435				
Gain 2/3	-.710**	.654**	.280	.249	.244	.102	.154	.623**	.597**	.525**	.781**			
Unit Test	-.195	.215	.526**	.137	.086	.534**	.590**	.472*	.505*	.612**	.230	.255		
Midterm	-.014	.169	.411	.018	-.019	.498*	.594**	.412	.292	.534**	.147	.050	.708**	
Final Mk	-.036	.127	.416*	.029	-.000	.469*	.606**	.365	.232	.501*	.135	.032	.790**	.952**

[1]Negative correlation favours males

*p<.05

**p<.01

again that day. Alan was frequently late for class, and often needed a personal reminder to hand in an assignment. His assignments were often incomplete. His attendance was not good, and he made no evident effort to make up any work he missed, including two unit tests that were missed. Although Alan appeared to have the best understanding (i.e., the most meaningful knowledge or the most plausible knowledge) of the concepts of heat and temperature, he was not particularly successful in school science (which measured both rote and meaningful knowledge, with the emphasis on the former). It seems unlikely that Alan would have gone out of his way to memorize terms, definitions, etc. On the heat and temperature unit test he lost marks for simple mistakes. He gave an inappropriate definition of temperature, did not draw a diagram that was required for one question, described conduction instead of convection, and only named two of the three types of heat transfer. Although he appeared to understand the concepts, he did not seem to remember specific details. Even so, his heat and temperature unit test mark was considerably higher than his final mark in science. Alan's failure to complete assignments, to make up tests he missed and the lack of attention to details undoubtedly accounted for much of his lack of success in school science.

5.2.2. Learning: Success on the Posttest

Another measure of learning or knowledge was indicated by the scores obtained on the posttest. Students who had the highest scores on the posttest were those who were best able to apply their knowledge of heat and temperature concepts to explain the problem situations posed on that test. For purposes of this analysis, it will be assumed that meaningful knowledge of heat and temperature concepts was related to success on the posttest. Knowledge which was rote learned, but not intelligible, could not have been used to answer questions on the posttest. It was assumed that students would only use concepts which were plausible to them to answer the questions. Therefore, posttest scores provided a measure of knowledge which was plausible. On the posttest seven students (Jane and six boys) had scores of 35 or more, of a possible 47. As already indicated, Alan had the highest score on the posttest, but his school science marks were far from high.

5.2.3. Learning: Gains in Scores from the Pretest to the Posttest

To examine unit learning, a means of comparing prior knowledge with knowledge at the end of the unit must be used. In this study, unit learning was examined by comparing the pretest and posttest responses. A comparison of the means of subscale scores on the pretest and posttest (Table 5.2) reveals that overall, students did do better on the posttest than they had done on the pretest. However, when individual scores were examined, three students (all female) received lower scores on the posttest than they had on the pretest. For example, Cathy received a total of 28 on the pretest, and 24 on the posttest. One boy, Jack, received a lower score on the Level 1 subscale, but more than compensated for that loss by making substantial gains on the Level 2 and 3 subscales. One of two possible explanations for a decrease in subscale and/or total scores may be pertinent. The pretest-posttest questions were scored on the basis of explanations provided for the various events. A student may have understood the phenomenon, but not given a full explanation, either because (a) it seemed so obvious to him/her that it did not seem necessary to explain fully, or (b) the student just did not take the time to write out a complete answer. In Jack's case, it seems likely that one of these explanations was the cause for Jack's lower score on the Level 1 posttest questions. Another possible explanation for a decline in scores is that, prior to instruction, the student had an intuitive understanding of the phenomenon, and provided that on the pretest. However, the student then became confused as a result of instruction. He/she did not understand the school science explanation of the phenomenon, and was unable to provide a correct response on the posttest.

Eleven students (all nine of the boys, Jane and one other girl) gained five or more points from pretest to posttest. Only two of the 11 (Jane and one boy who was not a target student) were also among the top six students on both the posttest and the unit test. This is not surprising, as the highest achieving students had little or no room for improvement on Level 1 questions. When the pretest scores were examined according to levels, the results indicated that the students did quite well on Level 1 items (mean score 16.5 of a possible 21), but not on Level 2 or 3 items (mean scores of 6.0 of a possible 15 and 2.1 of a possible 11, respectively). The very low reliability of the Level 3 subscale (.38) indicates relatively inconsistent responses and suggests the students may not have understood these items and were guessing or not responding much of the time. Further support for this conclusion was obtained from two sources. The correlation matrix (Table 5.4) revealed that none of the other variables tested was significantly related to either the Level 2 or Level 3 pretest subscale scores. Level 1 pretest scores, to the contrary, were significantly related to almost all of the other variables. Furthermore, the analysis of covariance showed that for Level 1, but not Levels 2 or 3, the pretest accounted for a significant amount of the variance in the respective posttest subscales.

Compared to the pretest, Level 2 and 3 scores did improve on the posttest. More students received higher scores and the subscale reliabilities increased somewhat (from .70 to .85, and from .38 to .58, respectively), suggesting that the Level 2 posttest questions were answered more consistently than on the pretest, and therefore indicating improved understanding. However, although Level 3 responses were more consistent than on the pretest, the consistency was still rather low, suggesting that most students did not understand the higher level questions.

5.2.4. Summary

Traditional and commonly used measures of school "learning" do not in fact measure unit learning or gains in knowledge, but rather the extent of certain kinds of knowledge. A comparison of school science marks and pretest and posttest scores revealed that it was not necessarily the students with the highest marks who showed the greatest gains in scores, or even the highest scores on the posttest. An examination of the teacher-made unit test (Appendix D) reveals an emphasis on knowledge which could be rote learned, whereas the pretest and posttest required that students apply their knowledge to new situations. When the class was divided into thirds, first by posttest scores and then by science marks, some interesting contrasts appeared. When grouped according to the unit test: three of the seven highest achieving students were also in the top posttest group and two of the seven were in the lowest posttest group; five of the eight lowest achieving students were also in the lowest posttest group. When grouped according to their final science marks: five of the seven top students were in the highest posttest group, but one was in the lowest posttest group; four of the eight lowest achieving students were also in the low posttest group. That is, some of those who did poorly on the posttest did very well in school science, whereas one student who did very well on the posttest (Alan) barely passed the course. These findings suggest that some of those who were successful in school science must have relied on rote knowledge, and they were unable to apply that knowledge to the unknown situations presented on the posttest. Others, who may have understood the concepts, appeared unwilling to memorize school science facts and definitions which were meaningless to them.

5.3. Characteristics of Successful Learners

The preceding section has examined the relationship between achievement in school science and scores on the pretest and posttest. In this section, the relationship of those measures of learning and two other factors, participation in class dialogue and gender of student, will be considered. Both of these factors have been reported in the literature to be related to achievement in science (they have also been reported to be related to one another).

Talk, the measure of class participation, consisted of a count of how many times the student talked during the class discussions. The duration of each instance of talking was not measured. However, it was noted that those who spoke most often (i.e., the "talkers") also tended to speak at greater length than the less frequent speakers. Participation and gender will each be examined in terms of the three definitions of successful learning.

5.3.1. Learning and Participation in Class Dialogue

The data from the class discussions suggested that the most talkative students also tended to be the most successful students. A very interesting pattern emerged when talk was correlated with the learning measures (Table 5.4). Pretest scores and school science achievement were not significantly related to talk. However, a different picture emerged for the posttest scores. Total posttest scores and Level 2 and 3 subscale scores were significantly related to amount of talking (r=0.570, p=0.004; r=0.642, p=0.001; and r=0.467, p=0.025, respectively). The Level 1 subscale score was not related to amount of talk. Similarly, pretest/posttest gains were significantly related to amount of talking (r=0.486, p=0.018). As before, gains in the higher level subscales were most closely related (r=0.654, p=0.001 for Levels 2 and 3 combined). The analysis of covariance indicated significant differences only for Level 3 by talk (Table 5.5: F=5.766, df=15, p=0.020). That is, there was a significant relationship between participation in class discussions and success on higher level questions on the posttest, as well as for gains in higher level questions from pretest to posttest. However, Level 1 and 2 posttest scores and school science achievement were not significantly different for talk (F=1.404, df=15, p=0.355, and F=2.825, df=15, p=0.103, respectively). The relationship between participation in class dialogue and gains in posttest higher level questions is interesting, and may warrant further study. If the significant relationship between participation in class discussion and achievement on questions requiring higher level thinking can be replicated in other studies, it could have important implications for instruction. One possibility, of course, is that students who are already capable of higher level thinking also tend to participate more in class discussion. If so, it could be that merely involving students in discussions will not have any effect in increasing their higher level thinking abilities.

Two other significant relationships were found--talkers were more likely to be male (r=-0.510, p=0.013) and they were more likely to be target students (r=0.572, p=0.004). These factors will be examined in the next two sections.

5.3.2. <u>Learning and Gender</u>

Research has shown that boys participate in class activities and discussions to a greater extent than do girls (Sadker and Sadker, 1985; Whyte, 1984). In mathematics classes, Becker (1981) found that boys were questioned more frequently

Table 5.5

Analysis of Covariance:

Posttest by Talk with Pretest

Source	Sum of Squares	df	Mean Square	F	Signif. of F
Total Test:					
Pretest	957.370	1	957.370	47.722	0.000
Talk	294.089	15	19.606	0.977	0.552
Residual	120.367	6	20.061		
Total	1371.826	22	62.356		
Level 1:					
Pretest	124.198	1	124.198	26.536	0.002
Talk	98.589	15	6.573	1.404	0.355
Residual	28.082	6	4.680		
Total	250.870	22	11.403		
Level 2:					
Pretest	19 761	1	19.761	2.738	0.149
Talk	305.809	15	20.387	2.825	0.103
Residual	43.300	6	7.217		
Total	368.870	22	16.767		
Level 3:					
Pretest	2.465	1	2.465	3.333	0.118
Talk	63.967	15	4.264	5.766	0.020
Residual	4.437	6	0.740		
Total	70.870	22	3.221		

than girls, and that they were asked more higher order questions. With respect to achievement, it has been reported that boys outperform girls on standardized tests of knowledge in the physical sciences (Erickson and Erickson, 1984; Kelly, 1978).

Recent assessments of science in British Columbia have revealed that boys clearly outperform girls on physical science questions and on higher level questions (Hobbs et al., 1979 and Taylor, 1982). Girls do as well as, or better than, boys on questions in the biological sciences and on lower level questions. Similar differences have been found world-wide (Kelly, 1978). However, gender differences are generally not found in school science achievement. For example, average marks obtained by male and female students writing the 1985 British Columbia provincial science examinations were almost the same (Table 5.6, adapted from Kozlow, Note 1).

Table 5.6

Results of the British Columbia Ministry

Grade 12 Science Examinations, June 1985

	Number of Students		Final Mean Score	
	Male	Female	Male	Female
Biology	2353	4228	66.1	66.1
Chemistry	3098	2156	69.8	68.3
Geology	331	191	64.6	62.7
Physics	2710	669	69.1	70.4

Two sources of data have been utilized to examine the relationship between gender and learning about heat and temperature. The results of the dialogue analysis show the relative participation in class discussion by males and females. School science achievement and pretest/posttest scores provide information about knowledge and learning.

Although girls made up 61 percent of the class, they only provided 42 percent of the student responses and one-third of the student-initiated dialogue (Table 5.7). This is particularly striking as 30 percent of the female responses were from Jane. Only Joe talked more often than Jane. If Jane had not been in the class, the male-female differences would have been much greater. Moreover, only 39 percent of the teacher responses were directed to female students. Additional, but small, differences were revealed when the type of response was examined. A greater proportion of the girls' responses were correct, suggesting that girls may be more reluctant to respond if they are not certain they have a correct answer. Differences in teacher responses to males and females were less striking. Proportionally more of the teacher responses to girls consisted of encouraging responses and explanations. The teacher was more likely to repeat a girl's response than a boy's (possibly because the girls tend to be more soft-spoken?). Proportionally more of the teacher responses to boys consisted of telling them their answer was wrong and providing information. The teacher was more likely to ignore a boy's response or redirect a question to another student when a boy responded. In addition, four of the five managerial responses were directed to boys.

Table 5.7

Tabulation of Student-Teacher Dialogue, by Gender, During 160 Minutes of Class Discussion

	Male		Female		Total
	N	%	N	%	N
Number of Students	9	39.1%	14	60.9%	23
Students Called on by Teacher	43	58.1	31	41.9	74
Student Responses to Questions					
Correct Answer	100	63.7	86	75.4	186
Incorrect Answer	14	8.9	13	11.4	27
Partially Correct	13	8.3	10	8.8	23
Alternative Belief	21	13.4	6	5.3	27
No Response	6	3.8	2	1.8	8
TOTAL	157	100.0%	114	100.0%	271
Student Initiated Dialogue					
Question	37	55.2	12	36.4	49
Information	30	44.8	20	60.6	50
TOTAL	67	100.0%	32	100.0%	99
Teacher Responses to Students					
Encourage, Explore	100	33.9	71	38.2	171
Acknowledge Answer	65	22.0	44	23.7	109
Wrong Answer	11	3.7	2	1.1	13
Provide Information	38	12.9	19	10.2	57
Explanation	28	9.5	27	14.5	55
Demonstration	2	0.7	0		2
Redirect Question	7	2.4	1	0.5	8
Repeat	24	8.1	19	10.2	43
Ignore or Dismiss	16	5.4	2	1.1	18
Managerial	4	1.4	1	0.5	5
TOTAL	295	100.0%	186	100.0%	481

None of these differences is great, except for the overall finding that far more responses came from and were directed to male students than from or to females.

In addition to gender and class dialogue, the relationship between gender and the three definitions of learning was examined. School science achievement was not significantly different for males and females (Unit test: F=0.831, df=1, p=0.372; Midterm mark: F=0.004, df=1, p=0.951; Final mark: F=0.028, df=1, p=0.869). Therefore, according to the first definition of successful learning, there were no significant gender differences in learning. However, this was not the case for the other definitions. Boys clearly outperformed girls, particularly on the posttest. The analysis of covariance showed that boys' and girls' scores on the total posttest, and on the Level 2 and 3 subscales (but not Level 1 alone) were significantly different, with the pretest as a covariate (Table 5.8). As was mentioned earlier, three girls had lower scores on the posttest than on the pretest.

A striking pattern between gender, talking and pretest/postest gains was identified. It has been noted that there was a significant relationship between gender and success on Levels 2 and 3 of the posttest. Eleven students gained four or more points in the Levels 2 and 3 combined subscale scores. Nine of those 11 were male; that is, all of the males in the class were among the top half with respect to gains on Level 2 and 3 questions. The two females who showed the greatest gains were Jane and Cindy. Jane and Cindy were the two most talkative girls in the class. Together they accounted for 43.1 percent of

Table 5.8

Analysis of Covariance:

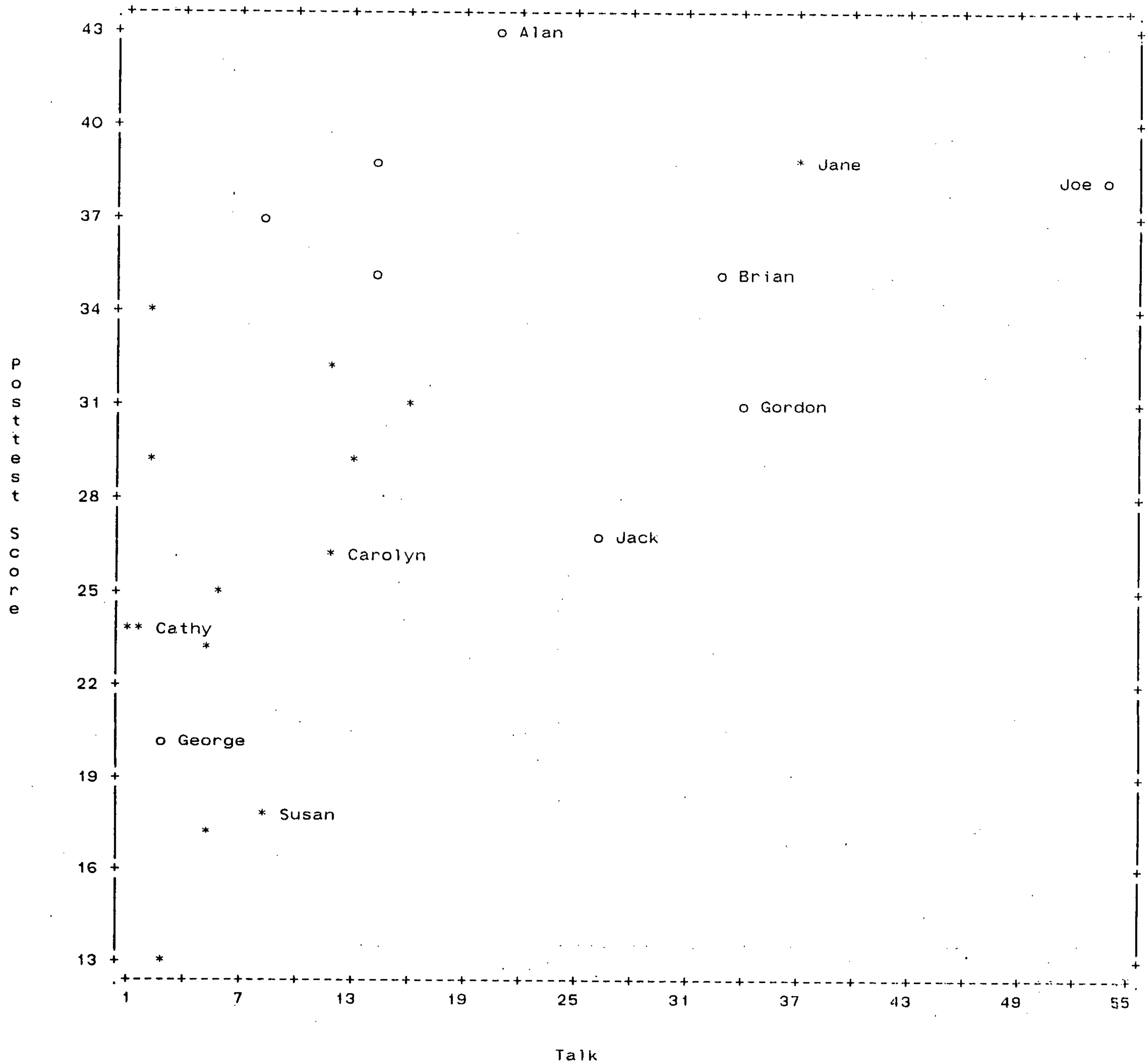
Posttest by Gender with Pretest

Source	Sum of Squares	df	Mean Square	F	Signif. of F
Total Test:					
Pretest	957.370	1	957.370	67.114	0.000
Gender	129.162	1	129.162	9.055	0.007
Residual	285.295	20	14.265		
Total	1371.826	22	62.356		
Level 1:					
Pretest	124.198	1	124.198	19.728	0.000
Gender	0.763	1	0.763	0.121	0.731
Residual	125.908	20	6.295		
Total	250.870	22	11.403		
Level 2:					
Pretest	19 761	1	19.761	1.736	0.203
Gender	121.456	1	121.456	10.670	0.004
Residual	227.653	20	11.383		
Total	368.870	22	16.767		
Level 3:					
Pretest	2.465	1	2.465	0.925	0.348
Gender	15.110	1	15.110	5.670	0.027
Residual	53.295	20	2.665		
Total	70.870	22	3.221		

the talking by girls (leaving 12 girls responsible for the remaining 56.9 percent). However, as results in Table 5.9 reveal, there was a significant main effect for gender ($F=14.956$, $df=1$, $p=0.012$), but no effect for talk ($F=5.536$, $df=15$, $p=0.034$), and no significant interaction between gender and talk ($F=3.186$, $df=1$, $p=0.134$). The explanation for the lack of a significant interaction may be the small numbers involved and the occurrence of two students who did not fit the pattern. Jane was a frequent talker and a high achiever, and one boy, George, was neither. George was an ESL (English was his second language) student, and he only spoke when called upon by the teacher. His overall achievement was low (Table 5.3). These two students were exceptions. With those two exceptions, the boys talked more than did the girls, and six of the nine boys had higher posttest scores than all of the girls except Jane (Figure 5.1). Boys and girls did equally well in school science and on lower level questions, but boys outperformed girls on higher level questions. Boys participated in class discussions more than did girls. Gains in scores from pretest to posttest were greater for boys. Declines in scores occurred for three girls (none of the boys had lower scores on the posttest than on the pretest). Findings such as these underline the importance of looking beyond statistical tests of significance, to examine the performance and characteristics of individual students.

5.3.3. Learning and the Target Students

There was concern that the fact of having been selected as a target student may have influenced learning. Two potential influences were identified. First, the target students were



Key: *Female
°Male

Figure 5.1. Posttest Scores as a Function of Talk, by Gender

Table 5.9

Analysis of Variance:

Posttest by Gender and Talk

Source	Sum of Squares	df	Mean Square	F	Signif. of F
Main Effects	1279.326	16	79.958	7.076	0.020
Gender	169.000	1	169.000	14.956	0.012
Talk	938.389	15	62.559	5.536	0.034
2-Way Interaction:					
Gender X Talk	36.000	1	36.000	3.186	0.134
Residual	56.500	5	11.300		
Total	1371.826	22	62.356		

interviewed about the pretest after it was administered, and this may have had some "treatment" effect. That is, the students who discussed the pretest with the investigator may have remembered the topics and questions better than they would have without the interview. If so, their posttest scores might have been somewhat inflated. The second cause for concern derived from two of the criteria used to select the target students. Four of the target students were chosen partially because they were frequent talkers, and talkers were found to do better on the posttest. In addition, there were equal numbers of males and females among the target students, whereas only 40 percent of the total class was male. Again, males did better on the posttest. Analysis of variance revealed no significant differences between the posttest scores of the target students and the other students (F=1.422, df=1, p=0.246).

5.3.4. Summary

This section has examined the relationship between success in learning and two learner characteristics: class participation and gender. The effect of being a target student was also examined to ensure that this had not unduly influenced learning. It was found that students who showed the greatest participation in class dialogue were more likely to be successful on higher level posttest questions and to increase their scores from the pretest to the posttest. They were not more successful in school science. Male students performed significantly better than females on higher level posttest questions, but not on lower level posttest questions or in school science. Males participated in class discussions more frequently than females (except for Jane and George!).

The next section will focus on lack of success in learning. In Chapter IV, ten topics for which unit learning was not always successful, were identified. Each of these topics will be examined in an attempt to identify some possible reasons for the persistance of alternative beliefs.

5.4. Lack of Success in Learning: Persistant Alternative Beliefs

Several topics which caused particular difficulties for the students were identified in the previous chapter. Alternative beliefs about these topics persisted throughout and in spite of instruction, and they were expressed on the unit test and/or the posttest.

5.4.1. The Thermal Expansion of Matter at the Particle Level

The authors of the textbook (Schmid and Murphy, 1979) apparently recognized that many students believe that particles expand, as they have stressed the idea that it is the spaces, not the particles, that expand. The teacher also emphasized the idea that the spaces, not the particles, expand. The students however, did not appear to see the two ideas as mutually exclusive. The expansion of particles was discussed in class on two different days. On the first occasion, an investigation to measure temperature using a mercury thermometer was being discussed. Jane was asked what had happened to the mercury when the thermometer was put in boiling water. The discussion continued as follows:

Jane: Umm, it gets heated up and the particles move faster and farther apart and so it has to expand.

Teacher: [writing on overhead projector] O.K. We'll put that down. When mercury is warmed or heated up, I'm finding it hard to hear [pause while teacher closes door to hallway]. Now, what did you say happens to the particles, Jane?

Jane: The particles speed up and moved farther apart.

Teacher: Are the particles themselves getting bigger?

Several students: No.

Teacher: What's getting bigger?

Students: The spaces.

Jane: The spaces between the particles.

Teacher: O.K. So the spaces are getting bigger. What's happening to the quantity of mercury? The volume of it?

Male student: Stays the same.

Teacher: Lynne?

Lynne: The volume's increasing.

Teacher: The spaces are getting bigger. The particles stay the same size, but the spaces get bigger. The whole quantity has an increase in volume.

Female student: The volume increases.

Teacher: And what do we call that? When we say the volume increases, the mercury?

Student: Expands.

Teacher: So it sounds like the particles are getting bigger. They're not really, of course. Just the whole blob of mercury in the bulb of your thermometer expands. Where does it go?

Jane: Rises up the tube.

[Teacher points to Susan]

Susan: Goes up the tube.

Fifteen minutes later the teacher performed the ball and ring demonstration for the class, and asked:

Teacher: What's happening to the particles inside the ball as I heat it?

Several students: Expands

Teacher: Careful now. Listen to the question. What happens to the particles? Susan?

Susan: The particles are expanding.

[Several hands raised]

Teacher: Are they?

Students: Nooo

Teacher: Jane?

Jane: They're speeding up and moving apart.

Teacher: How do they speed up? What kind of energy are they gaining?

Students: Heat/Mechanical

Teacher: They're moving farther apart and what's expanding?

Students: The spaces

Teacher: The spaces and therefore the whole ball...

In the first segment, while discussing a mercury thermometer, the students who contributed to the discussion seemed quite clear that the particles do not expand. Jane provided her opinion on two occasions--when the teacher asked Susan to respond, Susan gave the answer Jane had just called out. Although the students seemed to agree that liquid mercury particles did not expand, a few minutes later many of them said that the particles of metal in the ball-ring apparatus would expand. For example, although Susan had been paying attention during the earlier discussion, she replied that the metal particles were expanding. The teacher then redirected the question to Jane who gave the desired response. Susan's alternative belief was not dealt with directly. This was one of several times that a question was redirected to Jane after another student had responded with an alternative belief.

In class three days later, Brian, a student who had talked about particles expanding during the pretest interview, was asked if particles get bigger when a metal strip is heated. Brian said he wasn't sure. The discussion continued:

Teacher: You're not sure. If the particles got bigger, how would they get bigger?

Brian: They would expand.

Teacher: The particles would expand. Now if something expands, there has to be something pushing it to make it get bigger--something pushing harder to make it get bigger, right? What is there inside a particle to make it get bigger?

Brian: There is things--smaller things.

Teacher: O. K., but according to the particle model, the particle's the smallest thing. Now, if you want to call particles atoms, there are things inside atoms called

> neutrons, protons and electrons, that we saw in chemistry. But then we wouldn't use it as a particle model. So if you're going to call atoms particles, then you would have to be looking at the properties or characteristics of these, and it might be quite complex if you start looking at the inside of particles as the smallest part of matter. REMEMBER, THIS IS NOT REALITY, IT'S A MODEL--a model we use to explaing how things happen--like building a model airplane--you're not going to fly that airplane. So it's a model that approximates the real thing, but it's never going to be real.

After this rather lengthy, complicated explanation, the teacher turned to another student to answer a question on an entirely different topic. Brian's uncertainty was not explored and dealt with.

In the assigned questions for the chapter and on the posttest, both Brian and Susan said that particles expand. For example, one assigned question asked how adding more heat energy to the air in a balloon would change the force of air on the inside of the balloon. Brian responded, "It expands the particles making more room." When assignments were returned to students, it was indicated on their papers that such statements were not correct. Yet, on the posttest Brian said that heat causes pipes to expand because "it expands their particles." On another assigned question, Susan said that when liquid in a tube is heated and rises up the tube, it is "because of expanding particles."

Thus, although all of the students apparently accepted the idea that the particles move farther apart (and/or alternatively, that the spaces expand) when matter is heated, five students were so convinced that particles expand that they stated this on the posttest. We have no idea how many other students may have retained the same belief, but did not mention it. We can only speculate as to why the students persisted in this belief. Three of the five had been identified by the teacher as weak students who had difficulty in science. Susan and two other girls may have simply been so confused that they were not aware of any contradictions. A fourth girl was identified as a student of average ability. She was not one of the target students and did not participate in class discussions, so it was impossible to even speculate as to why she may have had difficulty with this idea. Brian's beliefs are somewhat better known. Brian was one of two boys who challenged the particle model used in the text. The model is summarized as follows:

> In your last science course, you used the particle model of matter. According to this model, all materials are collections of very tiny particles that are always moving as shown in Fig. 3. The particles of a material stay together because they are always moving in all directions. The spaces between the particles contain nothing; it is a perfect vacuum. (Schmid and Murphy, 1979, pp. 350 and 352)

Brian and Joe persistently argued that atoms and molecules are not single particles and are not the smallest particles of matter. This issue particularly surfaced during a discussion of the idea that heat energy is the energy of particles (one of the key points made in the textbook). Students were told that, unlike other energy transformations, there was no heat loss due to collisions among particles. As was pointed out in the previous chapter, the teachers' guide warns the teacher that problems may occur with this model. The following quotation from the teachers' guide bears repeating, as the teacher tried to present this idea to Brian and Joe during this discussion.

> The statement that gas particles have nothing smaller to give their energy to is a simplification of the facts. Thinking students may know that many particles are made of atoms which, in fact, are made of smaller particles still. ...However, because the number of component parts of a particle is small (compared to the number of component particles of a macroscopic object) energy can be given back by the component parts to the particle as a whole. In contrast, the chance of energy being given back to a large object by its particles is practically nil. (Schmid et al., 1980, p. 106)

When the teacher tried to present this view it simply was not accepted by either Brian or Joe. Both "knew" that neither an atom nor a molecule consists of a single particle. In the dialogue between Brian and the teacher quoted earlier, Brian said there were smaller things within particles. It is possible that Brian believed that sub-atomic particles must also be able to move apart, thereby causing the atom to expand. Although there was no opportunity to verify this possibility, it would account for Brian's persistence in the idea that particles expand.

When learning and knowledge were discussed earlier in this chapter, it was pointed out that one student might hold a belief that was different than his/her knowledge of school science. If a student were to give a "correct" answer on the unit test which was different from an answer given on the posttest, it may indicate that the student did not really believe the "correct" answer. For example, on the unit test both Susan and Brian drew diagrams to show the difference between a bar of iron at room temperature and one at 100°C. Both drew the particles the same size at both temperatures, and showed the particles farther apart in the bar at the hotter temperature. However, on the posttest (written during the same science period), both Susan and Brian said that particles expand when matter is heated.

5.4.2. <u>The Nature and Extent of the Spaces Between the Particles of Matter</u>

Some students did not distinguish between matter and particles. Beliefs expressed by Cathy illustrate the difficulties that may arise if this distinction is not made. For example, she wrote that when heated, "water looks as if it expands. Actually only the spaces are." The posttest revealed that Cathy still believed that "matter" did not include the spaces between the particles, but only the particles themselves. Carolyn's belief that heat could be transferred through a glass wall by air particles also reveals a lack of understanding of the nature of the spaces between the particles. These ideas were not discussed in class, presumably because it was assumed that the students had an accurate understanding of the particulate nature of matter.

5.4.3. <u>The Nature of Heat and the Difference Between Heat and Temperature</u>

An entire chapter is devoted to distinguishing between heat and temperature based on the findings of two major investigations. Unfortunately, the questions identified for the investigations do not make the aim of distinguishing heat and temperature clear to the student. In the textbook, "Questions to be investigated" are identified for each investigation. The students had been told that those questions indicated the <u>purpose/s</u> of the investigations.

The investigation entitled, "The heat energy and temperature of different objects" (1.42), introduces the chapter. The major aim of this investigation is to demonstrate that temperature is not a direct measure of heat energy. This experiment uses calorimetry to show that when heat is transferred from one substance to another, the temperature change varies for different substances. Students learn that the type of material and the amount of material both affect the size of the temperature change. In the teachers' guide, the following overview is given for the investigation: "A series of controlled experiments show that the heat energy of an object (as measured by its effect on a fixed mass of water) depends on its mass and its material as well as its temperature" (Schmid et al., 1980, p. 121). Similarly, in the student text (Schmid and Murphy, 1979, p. 126) the introduction tells the students that the investigation will show that heat and temperature are different, but that an object's temperature can tell us something about its heat energy. In spite of this overall aim, the identified questions to be investigated are:

1) If two objects with the same mass are made of the same material, which has more heat energy--the one with the higher temperature or the one with the lower temperature?

2) If two objects made of the same material have the same temperature, which has more heat energy--the one with more mass or the one with less mass?

3) If two objects with the same mass have the same temperature do they have the same amount of heat energy if they are made of different materials? (Schmid and Murphy, 1979, p. 126)

At no time are the students asked to explain how these observations show that heat and temperature differ. It is apparently assumed that they will recognize the difference if they are able to answer the three questions. As we have seen, this was not so. Because the questions were used to indicate the purpose of the investigation, there is no doubt that they, not the introductory statement, would be given primary emphasis. Thus, it should not be surprising that the heat-temperature distinction did not surface during class discussion. Indeed, we may conclude that this was not the teacher's view of the importance of the investigation either. On the unit test, one question dealt with this investigation. That question was, "List three factors which affect the heat energy of an object." Therefore, it appears that neither teacher nor students viewed the heat-temperature distinction as the purpose of the investigation.

The investigation is followed by a reading section in the textbook, "Heat Energy and Temperature," which provides an explanation of the distinction in terms of particles. This reading and its questions were assigned but they were never discussed in class. The questions <u>did not</u> ask students to explain the distinction between heat and temperature.

The second investigation, "Heat and temperature in phase changes," caused the most difficulty. This investigation will be discussed in more detail in a later section. However, one of the assigned questions is important for the heat and temperature distinction. The question asked:

> During this Investigation, you added heat energy steadily, but the temperature did not go up steadily. How does this Investigation show that heat energy and temperature are not the same thing? (Schmid and Murphy, 1979, p. 138)

Eleven of the 17 students who handed in this assignment had the correct answer for this question in their notebooks. Yet, few, if any, appeared to understand the implications of the answer.

The answer was not intelligible to many. When the questions were taken up in class, the following dialogue occurred:

Teacher: [reading] "During this Investigation, you added heat energy steadily, but the temperature did not go up steadily." At the beginning and at the end it levelled off. "How does this Investigation show that heat energy and temperature are not the same thing?" That's a difficult question! "How does this Investigation show?" This is the question Lynne had earlier. How does it show that the two are not the same thing?

Jane: This investigation shows that heat energy and temperature are different, because if they were the same, the temperature would have increased at the same rate as heat energy.

Teacher: Mhmm. If they were applying heat energy and the heat energy was increasing, the temperature'd have gone straight up. The heat energy, if we could've read it, would have gone straight up. The temperature went like this--it levelled off. That's a good answer.

Less than one minute was spent on this question. Jane was asked to give her answer. The teacher acknowledged that it was a difficult question, but she did not ask the students if there were any questions, not did she ask anyone to explain the answer in his/her own words. She proceeded directly to the next question.

5.4.4. <u>The Type of Material as a Factor Related to the Heat Energy (i.e., Internal Energy) of Matter</u>

Many students believed that the specific heat capacity of more dense matter exceeded that of less dense matter (although the term "specific heat capacity" was not used). This idea would have been addressed if the final part of investigation 1.42 (described in the preceding section) had not been omitted.

The experiment consists of three parts and would need at least two periods to complete in full. Each of the questions identified previously refers to one part of the experiment. The first part determines the temperature change in 100 ml of room temperature water when two equal masses of metal are added. Initially, one piece of metal is at 50°C and the other at 100°C. Part 2 compares the temperature change that results when 50g and 100g masses at 100°C are each added to 100 ml of room temperature water. Part 3 compares equal masses of two different metals and of water, all at 100°C, added to 100 ml of room temperature water. The teacher reduced the time required by having different groups of students work with different types of metal for part 2, and omitting part 3. This omission meant that the students did not have an opportunity to compare the change caused by the metals with that caused by an equal mass of hot water. Had they done so, they would have seen that the specific heat capacity of water is much greater than that of metal. The observed temperature changes for the two metals, zinc and nickel, were very small. In fact, when discussing the temperature change for the two metals, the teacher asked, "All right. Read me the statements you made please, for different matter at the same temperature." Joe responded, "Different matter at the same temperature if it's denser has more heat energy," whereupon the teacher replied, "Good." In fact, there is a tendancy for a relationship between density and specific heat capacity, but the relationship is inverse, rather than direct. The students were then directed to do the assigned questions, the first of which asked:

> Which has more heat energy--
> a) 1 kilogram of water at 30°C or 1 kilogram of water at 70°C?
> b) 1 kilogram of water at 30°C or 1 gram of water at 30°C?
> c) 1 kilogram of water at 30°C or 1 kilogram of iron at 30°C? (Schmid and Murphy, 1979, p. 129)

Everyone answered "a)" correctly; all but one student answered "b)" correctly; and only one student answered "c)" correctly. That is, all but one student believed that iron, which is more dense than water has more heat energy than water. This answer is consistent with Joe's statement given above, and approved by the teacher. Either the teacher did not listen carefully to Joe's answer, or she did not recognize that less dense materials tend to have a greater specific heat capacity than more dense materials. Perhaps the confusion about this relationship would have been avoided altogether had the students not omitted the third part of the investigation. The teachers' guide notes that it is important for students to add the hot water to the cold to demonstrate that it takes far more heat energy to raise the temperature of water than it does to raise the temperature of metal. The students did not do the one experiment that would have shown them that one kilogram of water at 30°C does have more heat energy than one kilogram of iron at 30°C.

Density was again dealt with when the chapter review questions were being taken up. The following question was discussed:

> If two objects have the same mass and the same temperature, but one is made of water and the other is made of lead, then the one made of .... has more heat energy.

Melanie: Lead.

Several students: Nooo.

Male student: That's denser, so it should be.

Teacher: What's the problem using density?

Jane: You have the same mass of each of them, so 50g of lead and 50g of water, and the water is going to have more heat energy because the particles are moving faster and so they have more mechanical energy.

In spite of Jane's explanation, many students continued to believe that denser matter has more heat energy than less dense matter. It is interesting to note that if specific heat were defined in terms of volume, rather than mass, the students' intuitions about the effect of density would be more accurate. As many students did appear to think of quantity in terms of volume (a quantity which can be seen), rather than mass, their intuitions may have been more logical than they seem. The implications of this way of thinking of quantity may warrant further investigation. Another factor may also be relevant in this particular instance. Jane was frequently called upon to explain difficult concepts or answer difficult questions. Some of the students may not have understood Jane's explanation and therefore not remembered what she said. Some students may have become accustomed to Jane giving complex answers and made no attempt to follow her explanation.

5.4.5. <u>When Matter is Heated, the Rate of Temperature Change is Not Constant When a Change of Phase Occurs</u>

Many difficulties arose with the phase change investigation (1.45). The investigation involved heating ice until the water reached the boiling point. The temperature of the water was recorded every two minutes. First of all, neither the text nor the teacher told the students that the horizontal scale (time) represented the increase in the amount of heat supplied to the water. The students' responses to the questions reveal that they assumed it was the temperature scale that represented the amount of heat. For example, in her conclusion Jane wrote that raising the temperature of the liquid water from 0° to 100°C took more heat energy than boiling away the water. This idea was probably reinforced by the teacher, who said at the beginning of the discussion,

> ...we're not measuring heat energy directly. We can't measure those little particles moving around and sum up the mechanical energy to give us heat energy directly. What we do is measure it indirectly by measuring the temperature, hotness or coldness.

This misunderstanding was not detected during the discussion.

Some of the students were asked to read their conclusions (i.e., their answers to the questions to be investigated). One boy gave an incorrect answer to one question (he said that raising the temperature of water from 0°C to 100°C takes more heat energy than boiling away the water). The teacher did not notice the error (the boy was one of the students she considered to be very bright). Alan then asked if the temperature of water vapour could exceed 100°C, and the teacher said no. This was a question Alan and another boy had raised while doing an earlier investigation (the mercury thermometer) and it had not been resolved at that time. Brian also joined the discussion. Alan next asked if ice could not get colder than 0°, arguing that lowering the temperature would lower the heat energy. The teacher responded that theoretically it should be possible, but in fact it was not. The teacher was mistaken on this as well, but she was unwilling to reconsider her position. At this point

Jane interjected, challenging the incorrect answer given earlier and Alan's concern was forgotten. The teacher accepted the correction by Jane.

Additional problems arose with respect to the temperature plateau which occurred as the ice was melting. The investigation had been performed as a demonstration by Alan and Joe, with Jane recording the data on an overhead projector. All students copied the data and completed a laboratory report. Jane obviously expected the temperature to increase at a constant rate. When the ice had melted and the rate increased sharply, Jane would not accept the results. She was more willing to believe that the boys had made an error than to abandon her alternative belief. In the end she inserted additional readings to the data to make the changes in the slope less conspicuous (for more details on the discussion which took place among Jane, Joe and Alan, see Appendix E). In this situation, like the grade four children studied by Stavy and Berkowitz (1980), Jane was unwilling to accept results which were contrary to her prior beliefs.

During the discussion of this investigation the teacher apparently assumed there was a distinct plateau on the graphs. As we have already noted, the teachers' guide indicates that the temperature would not be constant during the change from solid to liquid phase because the rapid heating prevents the system from reaching an equilibrium. The teacher had not examined either the data or the graphs and insisted that the temperature did not increase before the ice had melted. Brian tried to argue about this, but the teacher was not willing to discuss it further. The discussion left the students with two dilemmas. First, the teacher insisted there was no increase in temperature while the ice was melting, yet the data indicated that there had been an increase. Secondly, some of the students were confident that the teacher was wrong about the temperature of ice and of water vapour being constant.

5.4.6. The Nature of Cold and the Difference Between Heat and Cold

When the pre/posttest was being pilot-tested, one student came to a question which referred to cold, and said to the investigator, "I thought you said this test was about heat." I replied, "It is." The student then said, "But this question is about cold."

Daily conversation about heat and cold not only refers to heat as if it were a fluid substance, but in addition, refers to cold as if it were another fluid substance. "Hot" is the sensation of something that feels hot, relative to our body surface. "Cold" is the sensation of something that feels cold, relative to our body surface. Historically, we find that early investigators of heat and temperature phenomena also considered "cold" to be something distinct from "heat" (Wiser and Carey, 1983). Posttest explanations of why the metal blade of a shovel felt cooler than the wooden handle revealed that many of the students in the class assumed that cold is a different thermal entity than heat. Neither the textbook nor the teacher appear to have recognized this idea as a possible alternative belief, and consequently, the idea was never discussed. Moreover, the definition of temperature as "hotness or coldness" may have been perceived as a confirmation of the existance of the two thermal entities.

On three occasions, the idea of cooling (as opposed to heating) was discussed in class. The first instance was when the teacher was taking up the assigned questions from the phase change investigation. One question asked why you feel cool when perspiration evaporates. One girl replied, "You feel cool because your perspiration evaporates and you're losing heat energy." The teacher responded, "In order for evaporation to occur, we have to use heat energy. Heat energy is supplied by your body and you feel cooler." The second occasion was when conduction was being discussed. The teacher asked why a metal faucet felt colder than the table top. Alan responded, "It's taking our heat." The teacher accepted this response and went on to a different topic. Apparently many of the students did not recognize the implications of perspiration or the faucet "taking our heat." They did not relate cooling to a loss of heat. In another instance, the teacher performed a demonstration of conduction. She set a bunsen burner under a paper cup filled with water and the cup did not catch fire. When she put the burner under an empty paper cup, the cup did catch fire. The teacher asked why the cup with the water did not burn. This discussion went as follows:

Jane: The water is cooling it off.

Teacher: Heat energy is coming through the bottom, isn't it?

Jane: Yeah, but the water is cooling it from the top, too, so all the coolness from the water reaches through the paper, so it's still not gonna burn, 'cause it can't reach its kindling temperature.

Teacher: What's happening to the heat that is being applied to the bottom?

Male student: It's making the water warmer.

Later, during the discussion of conduction, the teacher said:

> ...the bottom of [the class handout on conduction] tells you something very important. Usually we think of conduction as transferring heat to warm something up. What sort of [examples] do you know of where you cool something down by conduction?

Jack: Fridge.

Joe: Umm, where you pour cold water, things like that.

Teacher: That's true, because once you pour cold water over you, you reduce the heat energy from your body.

Alan: Radiator. [This response was ignored]

Jane: Ice in a drink.

It can be seen that if a student believed that heat and cold were different, these discussions would not necessarily refute that belief. As was noted in the previous chapter, both Jane and Joe, two very capable students, expressed the belief that cold was distinct from heat on the posttest. In the preceding section, a situation was described wherein Jane rejected very strong evidence that another of her alternative beliefs was incorrect. In this instance, nothing was said during the class discussion that would have suggested to Jane that her belief about cold was inconsistent with school science.

5.4.7. <u>The Effects of Heating on Different Kinds of Matter</u>

It has already been noted that when an open question of the sort, "What happens when X is heated?" was asked, the students often responded inappropriately. For example, students replied that a paper clip would melt, although the topic being discussed was conduction. Earlier that day, the teacher had demonstrated the bimetallic strip and had asked what would happen if she were to continue heating the strip. Joe replied, "It should melt." The teacher responded, "Oho! Before it melts. We're not going to let it melt." Joe then suggested the strip would straighten out because some metals expand more rapidly than others and the metal which expanded more slowly would eventually catch up. At that point, another boy (one considered to be a good student), raised his hand and then predicted, "The brass would melt before the steel would melt." Although the teacher had indicated that melting was not relevant, the students persisted in coming back to it. After reviewing all such inappropriate responses, it appeared that the students tended to respond with an observation that could be seen. In particular, a change of phase was often predicted. That is, if the object were solid, such as ice or metal, they tended to say it would melt. A liquid in an open container usually boiled. Expansion and rising were also common responses. If a liquid in a closed container were being heated, the students usually said either it expanded or it rose. Gases, such as air, rise when they are heated. Each of these responses was an isolated incident, at no time were all of these phenomena presented together. Neither the book, nor the teacher pointed out that when matter is heated (for example, during the phase change experiment or when heat transfer was being investigated) and when the mechanical energy of the particles increases, several things happen. The temperature of a solid increases until it reaches the melting point, and the matter expands as its particles gain mechanical energy (unless it is ice!). As the solid melts, its temperature remains relatively constant. When all of the substance has melted, the temperature increases more rapidly as heat energy is no longer being used to change the substance from a solid to a liquid. At the same time as the liquid is getting hotter, it continues to expand, until it reaches the boiling point, etc., etc. Perhaps if the class discussion had pulled all of these ideas together it would have helped some students. Instead, each was treated in isolation, and the students were left to put the ideas together themselves.

5.4.8. How Conduction Occurs at the Particle Level

Many students were able to provide reasonable explanations of conduction, based on the particle model, on the unit test. However, beliefs expressed on the posttest revealed that many of the students did not understand the implications of the transfer of mechanical energy by collisions among particles. For example, students for whom this idea was fruitful would have known that a shovel left outdoors overnight would have been the same temperature as the air temperature. Only Alan answered that question correctly. Some alternative beliefs were revealed by the definitions provided on the posttest. For example, Carolyn replied:

> The particles of two objects touching attract each other and the heat of the hotter object is attracted. In this way the heat energy is transferred. The particles never move out of their places in conduction. Metals conduct better than non-metals.

The teacher had stressed two features which distinguish conduction from other types of heat transfer: heat moves from matter with more mechanical energy to matter with less mechanical energy and the particles stay in one place. The teacher concentrated on the mechanical energy of the particles, rather than emphasizing that it was a difference in the temperature of the objects that was important. In the textbook, conduction is introduced as follows:

> Hot objects cool down because they give heat energy to the cooler objects around them. Cold objects warm up because they gain heat energy from the hotter objects around them. When a hotter object gives heat energy to a colder object, we say that heat energy is being transferred from the hotter object to the colder one. (Schmid and Murphy, 1979, p. 140)

This description is in terms of concrete objects and would probably be more meaningful to most students than was the teacher's explanation, expressed in terms of the mechanical energy.

5.4.9. The Effect of the Type of Material on the Rate at Which Heat is Transferred by Conduction

An earlier section (5.4.4) discussed the belief that density is the property of matter which affects the amount of heat energy in an object. This section will focus on the rate of heat transfer by conduction in different types of material.

Some students believed that less dense solids conduct heat more rapidly than more dense solids, while others believed the opposite. Those who predicted that a less dense object would conduct more rapidly may have had one of two alternative beliefs. The first is the idea that heat moves between particles of matter and hence travels faster when it has more room. This idea was expressed by Carolyn on the pretest and by Susan and three others girls on the posttest. (A sixth girl spoke of heat particles moving through matter.) The other alternative belief was expressed by Brian during the interview.

He said that when particles were farther apart they had more room to move around and thus they were able to speed up more quickly in less dense matter.

During the class discussion, Gordon's explanation of conduction also dealt with why different materials conduct heat energy at different rates:

> ...heat conducts through different particles [pauses--teacher says, "Uhuh"] and also at different speeds, and penetrates these levels by, ummm, one molecule passes the heat, that's based on the model, and then it hits that one and it gets the heat and then it hits that one and it gets the heat and they carry on. That's why the air, since there's not enough, as many particles as solid, heat passes through slower.

The students all recognized that conduction does occur at different rates in different materials and they answered assigned questions which dealt with everyday applications of this principle. For example, the students recognized that cooking pans usually do not have metal handles because metal is a good conductor. Although the students all answered such questions correctly, many of them were unable to explain these phenomena in terms of the mechanical energy of the particles.

5.4.10. <u>How Heat is Transferred by Radiation</u>

Radiation was dealt with very superficially. No reading or questions were assigned. The class discussion concentrated on factors which influence absorption and reflection of radiant energy. The greenhouse effect and the idea that hotter objects radiate more heat energy than cooler objects were discussed briefly. The unit test included a question addressing the latter idea and which was answered correctly by 13 of the 23 students. The mechanism whereby radiant heat energy is transferred was not addressed at any time.

5.5. Summary

This chapter has focussed on "learning." It began by examining three alternative measures of learning: school science marks, posttest scores and pretest/posttest gains. It was shown that individual students demonstrated varying degrees of success in learning according to the different definitions.

Quantitative analysis showed that gender of student and class participation were both related to some, but not all, measures of learning. Students who were most successful on the higher level items of the posttest tended to participate more in class discussions, and were more likely to be male. However, boys and girls school science marks were not significantly different. Tabulations of the different categories of dialogue showed more frequent student-teacher interactions for boys than for girls.

Finally, some examples of lack of success in learning were examined. Ten topics were identified as posing particular problems for students. Alternative beliefs about these topics were identified and factors which may have been related to these difficulties were explored. In some cases, notably the belief that "cold" is an entity distinct from and equivalent to "heat," the alternative belief was apparently not identified by the teacher or by the textbook authors. Some alternative beliefs were addressed in class, but the discussion did not adequately clarify the concepts for some students. On one particular occasion (the discussion of the phase change investigation), the teacher was not at her best, and many students never did resolve the difficult ideas developed in that investigation.

The role of the teacher was critical in resolving alternative beliefs. While this chapter has concentrated on the students and on learning, the next chapter will examine the instruction provided during the unit. The focus will be on the teacher and how she planned and implemented instruction in this unit of the grade nine science program.

CHAPTER VI

SCHOOL SCIENCE: INSTRUCTION

6.0. Introduction

The overall aim of this study has been to investigate the interaction between students' prior beliefs and instruction. The previous chapter showed that although many students learned much about heat and temperature, there were still several alternative beliefs held by students at the end of the unit. This chapter will focus on the instruction provided by the teacher as she guided her students through the unit and suggest some tentative explanations as to why instruction did not always successfully resolve those alternative beliefs.

A variety of instructional activities are used in science classes. In this class, as in most junior secondary classes, the students were actively involved in learning. This active learning emphasized the acquisition of knowledge through the use of student investigations and class discussion, in contrast to lectures presented by the teacher. The various instructional activities that occurred will be examined in terms of the roles played by the teacher in that particular activity or instance.

One critical role fulfilled by a teacher is that of managing, planning and implementing instruction. The teacher must select daily activities for the students. That selection is influenced by the constraints of the curriculum, the textbook, the teacher's own values, interests and expertise, the background and ability of the students, and the available time and equipment. The teacher may choose to supplement or replace portions of the prescribed textbook, either to enrich, simplify or abbreviate instruction. The pressure of time is always a limiting factor, and frequently influences how a teacher chooses to present a particular topic or idea to the class. Time, as was evident in the present study, may become especially critical as the end of term approaches.

One of the major instructional formats in many science classes is class discussion. Ideally, discussion should involve the students and teacher exchanging ideas in such a way that the students' thinking is steered logically and systematically toward a scientifically acceptable understanding of the phenomenon being considered. All students should be equally involved in the dialogue. In practice, this latter ideal is all but impossible to attain. Some students are anxious to answer every question, while others are very reluctant to say anything and when required to respond, do so as briefly as possible. For less complex science topics, the ideal of all students understanding the topic of discussion may be achieved quite readily. For example, the students in this class were all able to read a thermometer and to define temperature as "hotness or coldness" with confidence at the end of the unit. For the more complex topics, however, understanding was achieved by only a few students. Although the teacher did provide opportunities for students to do investigations and the results of those investigations were discussed in class, many students did not achieve the desired understanding of heat and temperature concepts.

This chapter will first examine how the teacher organized the unit and her approach to instruction. Class discussion will be particulary emphasized. Instructional and school science factors which may have been related to the persistance of alternative beliefs will then be identified and examined.

6.1. Analysis of the Data

Instruction will be examined in terms of the "role" played by the teacher at any particular time. Two aspects of instruction were explored--how instruction was organized and, in particular, how the teacher and students interacted in class discussion. First, the teacher's role as "instructional manager" will be considered. This role involved the planning and implementation of the daily activities.

Two types of large group teaching situations were also identified: discussion and information. The major large group activity consisted of discussion or "dialogue" between the teacher and the students about the topics being studied. Discussion was used to introduce new topics, take up assigned questions, discuss various aspects of the investigations (purposes, results and/or conclusions), and review various concepts students were expected to understand. Three different instructional roles were identified during class discussions. These were: the teacher as "evaluator" of student responses; the teacher as "provider" or interpreter of scientific knowledge; and the teacher as "mediator" of discrepancies in student knowledge, ideas and beliefs. The second type of large group activity might be described as "directions." This consisted of the teacher providing information or instructions about various activities or procedures to be followed. Examples included assigning homework, informing students as to when and where to hand in laboratory reports and other assignments, elaborating on or supplementing instructions for conducting investigations, other management instructions, etc. This teacher was not observed to give formal, structured lectures to the class. However, she did occasionally spend several uninterrupted minutes elaborating on some of the more difficult concepts for students who were having difficulties. For purposes of this study, directions were not considered to be important in terms of the overall learning climate provided by the teacher, and hence were not subjected to further scrutiny.

The methods of collecting and categorizing the data on class dialogue have been described earlier. The analysis in this chapter will examine the teacher's responses to student answers and will investigate the roles of the teacher during that dialogue.

When a student responded to a question, typically the teacher first evaluated the response, then either continued discussing the question, or went on to another question. Four teacher response categories represented evaluation responses: acknowledge answer, wrong answer, redirect, and ignore/dismiss. If the teacher was not satisfied with a student's response, she either attempted to elicit more information from the student (encourage/explore), redirected the question to another student (redirect), or provided the desired response herself. The latter included the stating of factual knowledge or information (provide information), providing an explanation aimed at facilitating understanding of more complex ideas (explanation), or conducting a demonstration of a phenomenon (demonstration). When trying to elicit more information from the students, the teacher used probes and further questioning aimed at helping the student work out the desired answer her/himself. In this chapter, the teacher's responses will be examined in terms of the instructional roles described above.

6.2. The Teacher as Instructional Manager

A teacher is responsible for organizing units and lessons so as to facilitate student learning. She or he must decide how the prescribed curriculum will be implemented. That decision may be influenced by the teacher's background and preferences, as well as by the interests and abilities of the students. Some of the prescribed topics, such as heat and temperature, are very difficult for many students. For such topics, it is inevitable that there will be conflicts between the needs of the lower ability students and those of the more able students. The teacher must strike a fine balance, so as to avoid losing the weaker students who do not understand the principles involved, yet at the same time maintaining interest and challenging the more able students. A teacher may spend proportionally more than the recommended time on topics studied early in the school year, then find the end of term approaching with little time to complete the remaining topics. This was the case for this class. The heat and temperature unit was not started until the end of May and another unit remained to be taught. Thus, the intellectual demands of the content and the pressure of time served as major constraints influencing the instruction that was provided.

The remainder of this section will present some of the teacher's views as to the more important aspects of the heat and temperature unit and on the difficulty of the topic. A description of the first lesson will be provided to illustrate her approach to organizing and teaching the unit. The activities and assignments of the remaining lessons will be summarized.

The teacher had taught for several years, but had only taught the heat unit once before. Her field of specialization was biology. When asked what she considered the most important parts of chapters seven to ten, she replied:

> That's a good question. When you apply it to their everyday lives, which is basically what I consider most important, temperature's important, umm, expansion's important, and so are conduction, radiation, conduction [sic], because they're all a part of their lives. And the part I didn't cover [chapter 10] is also really, really important because of the energy crisis.

The less important concepts were identified as:

> I don't think the greenhouse effect is all that important. It's interesting. They do have it as part of their lives--in cars and stuff.

The teacher felt that the heat and temperature unit was among the more difficult units in the grade nine course. Within the unit, differentiating between heat and temperature was the most difficult concept to teach. She felt that by the end of the unit the student should be able to define temperature as "the hotness or coldness of something," and heat as "the addition of mechanical energy to the particles." The teacher was then asked how she would explain the difference between heat and temperature to an adult who knew little about science. She replied:

> It would have to be non-scientific, umm, I guess I would say that temperature would be the gradient they can feel with their senses, particularly the sense of touch. Uhh, and it can be measured by a thermometer, which they're all accustomed to. When you get down to measuring heat energy, that's more theoretical. Uhh, [5 sec. pause] it would have to be compared with some motion--I'm just trying to think of something--the motion which accumulated gives you an end product. Uhh, perhaps the motion of several engines pulling together--the difference between a four power and a six power engine. So that there's the idea of several things added together to give a work--an energy--a total energy and, it'd have to be something along that line--something in their everyday lives.

The teacher followed the textbook rather closely, omitting the optional sections. Most of the required sections were assigned as reading and were discussed in class. Investigations were either performed by all students or as demonstrations by the teacher or by a small group of students. The topics presented in chapter nine (Heat Transfer) were discussed in class, but the students were not asked to read any sections of that chapter.

In the first lesson, the topics covered by the first and third sections of chapter seven, "Heat energy and energy transformations" (Sec. 1.34) and "The energy of particles" (Sec. 1.36) were discussed. It was pointed out that heat energy is involved in all energy transformations and the students were asked to give examples of energy transformations involving a variety of different forms of energy. Time was provided for the students to answer the question on energy transformations from the text, and the answers were then discussed. The teacher then set some lead shot rolling on the overhead projector to simulate the motion of the particles of matter, while introducing the discussion on the energy of particles. The discussion dealt with the idea that no mechanical energy is lost because of collisions among the particles of matter. Some of the students were dissatisfied with this idea, but the teacher finally cut off the discussion by referring the class to diagrams in the textbook and by involving some different students in the discussion. The students were then asked to read orally the section on the energy of particles and questions were assigned. The teacher also told the students to "read and prepare" the next two sections, both of which were investigations, ("Measuring temperature with a mercury thermometer" and "Measuring temperature by expanding solids"). The teacher reminded the students of what she meant by "prepare" as follows:

Teacher: ...when I say prepare, what I mean, it might be a good idea to jot this down somewhere. It's a long time since you've done this. I want you to read over the lab. [pause] Then, write the title, write down purpose. How do you know what the purpose is? Carolyn?

Carolyn: The question to be identified.

Teacher: Good. And, then in a few, and I mean like two or three (keep this really, really short) sentences state the method. So, for instance, the method could be something like, we heated some bimetallic strips and watched what happened.

Male student: What experiment is this?

Teacher: Something really short, and then four, draw any charts that you're going to need so you're all ready to start the lab.

As she was speaking, the teacher wrote the following on the overhead projector:

1. write the title
2. write the purpose
3. in a few (2 or 3) sentences state the method
4. draw any charts needed for observations.

The students were given the last few minutes of the period to begin working on the assignments.

Thus, on Day 1 the students were introduced to the topics heat and temperature and necessary background information on energy and particles was reviewed, drawing on the students' previous knowledge and experience where possible. The teacher did not attempt to elicit the students' prior beliefs about any of the topics discussed. The assignment included questions on the ideas discussed that day, as well as preparation for the two investigations to be performed the next period.

A summary of the daily class activities and of the assignments was recorded by the investigator (Table 6.1). Ten class periods were devoted to chapters seven to nine. As noted in the teacher's comments above, chapter ten was omitted due to lack of time (the end of term was two weeks away and the biology unit had not yet been taught). As time became more pressing, the teacher provided alternative readings to the textbook sections on conduction and convection. The alternate readings were more concise and factual than the equivalent textbook sections. No readings were assigned on radiation. All students performed brief investigations two periods, and during a third period one group of students performed a demonstration investigation. The teacher performed demonstrations two periods. The teacher and selected students also performed demonstrations to illustrate conduction and convection. The

Table 6.1

Class Activities and Assignments

Day 1: Discuss energy transformations involving heat energy.
Sec. 1.34 (Heat Energy and Energy Transformations); do question 1.
Read 1.36 (The Energy of Particles); do questions 1, 2.
Assignment: Read and prepare 1.37 and 1.38 for next day.

Day 2: Do Inv. 1.37 (Measuring Temperature with a Mercury Thermometer); discuss conclusion.
Assignment: questions 1-4, Inv. 1.37.
Inv. 1.38 (Measuring Temperature by Expanding Solids) demonstration and discussion.
Assignment: questions 1-5.

Day 3: Inv. 1.38: discuss conclusion.
Read 1.40 (Thermometers).
Assignment: Sec. 1.41 (Review): do questions 1-6.

Day 4: Read and do Inv. 1.42 (The Heat Energy and Temperature of Different Objects, Parts I and II).

Day 5: Discuss questions, Sec. 1.41.
Discuss distinction between mechanical and heat energy and the particle model.
Discuss Inv. 1.42.
Assignment: Inv. 1.42: questions 1-5, 7, 10;
Read 1.43 (Heat Energy and Temperature), do questions 1-4.

Day 6: Inv. 1.45 (Heat Energy and Temperature in Phase Changes) demonstration by 3 students; begin discussion.
Assignment: do graph, questions 1-5, 7, 9, 10, conclusion.

Day 7: Discuss conclusion and questions, Inv. 1.45.
Conduction demonstration and discussion.
Read hand-out on conduction; do questions 1-4 from Sec. 1.48 (Conduction).

Day 8: Discuss conduction, insulation, questions 1-4.
Convection demonstration and discussion.
Complete review sheet, Chapter 8.
Assignment: Read hand-out on convection; do questions 1-4, 7, 8 from Sec. 1.49 (Convection).
Complete review sheet, Chapter 9.

Day 9: Review and discussion--conduction, convection and radiation.

Day 10: Unit test (prepared by teacher) and Posttest.

last day was devoted to the teacher-made unit test and the investigator's posttest. Overall, the teacher reduced the time allotted to the unit from the 13 hours recommended in the teachers' guide to nine hours (plus one hour of testing).

6.3. The Roles of the Teacher During Class Discussion

Most of the large group instruction consisted of class discussion or dialogue. The teacher posed questions, the students answered the questions and the teacher responded to the students' answers. The teacher had to evaluate the accuracy of the student answer and decide whether to go on to another question or to seek additional responses. If the student response was incorrect or incomplete, she either encouraged the responding student to continue, redirected the question to another student or provided the desired information herself. The discussion format was used to introduce new topics, discuss the results of investigations, take up assignments and for review. Discussions which introduced new topics were often accompanied by demonstrations of the phenomena.

This section will examine class dialogue to identify how the teacher dealt with a variety of situations in which beliefs were expressed that were inconsistent with school science. This will be done by examining the roles played by the teacher during the discussions. The following roles were identified:

1. the teacher as an evaluator of the correctness of student knowledge, ideas and beliefs,
2. the teacher as a provider or interpreter of science knowledge, and

3. the teacher as a mediator of discrepancies between students' knowledge, ideas and beliefs (i.e., children's science) and school science or scientists' science.

Within the latter role, the responses of the teacher were examined to determine the extent to which any of the following may have influenced her response:

1. the approach taken by the student who was questioning the teacher's statements,
2. the confidence the teacher had in her knowledge,
3. the identity of the student involved.

Each of these three roles will be discussed in some detail in the sections that follow.

6.3.1. <u>The Teacher as Evaluator of Student Knowledge, Ideas and Beliefs</u>

Each response from the teacher was based on an evaluation of the student's answer, whether or not an explicit evaluative statement was made. Occasionally the teacher was uncertain as to what the student was thinking and would ask for a further explanation of the answer. The following excerpt provides an illustration of this type of response. (Underlined segments were categorized as evaluative responses.)

Teacher: Can you think of another property of matter that can change?

Alan: The form.

Teacher: <u>The form.</u> <u>That's important.</u> It's not one we've really looked at yet. We're going to look at it more today. The form or shape of matter might change. Can you explain what you mean by that, Alan?

Alan: If it's a gas or a solid.

Teacher: <u>Or?</u>

Alan: That's all. That's about it.

Teacher: If you have an ice cube, what form is that?

Alan: Solid.

Teacher: Yes - and if you warm it up?

Alan: Liquid.

Teacher: Yes. We call it a change of? [pause] Does anyone remember the word for that?

Melanie: Phase.

Teacher: A phase change. An ice cube melts. That's good. That's one [property] I hadn't thought of. Any other ones?

Here the teacher's initial response to Alan was based on an incorrect assumption that he meant "shape" when he said "form." However, she was sufficiently uncertain to probe and determined that in fact he was thinking of the phases of matter. The teacher was then able to elicit the correct term from another student. Four of the six teacher responses began with an accepting evaluative statement. One response ("Or?") indicated to Alan that his answer was incomplete, without specifically calling it such. Throughout the unit, there were only 13 occasions when the teacher specifically told a student that an answer was not correct (only two such responses were to girls). The investigator judged 85 student responses to be either an alternative belief or an answer which was either incorrect or partially correct (Table 6.2). This finding is of interest in view of Sadker and Sadker's (1985) findings. In two-thirds of the 100 classrooms investigated, teachers were never observed to indicate to a student that his/her answer was incorrect. In the remaining classrooms, such responses accounted for five percent of the teacher/student interactions. The authors expressed concern that students were not given adequate feedback when their answers were incorrect.

Table 6.2

Student-Teacher Dialogue

	Number	Percent
Student responses to teacher questions:		
Correct	186	68.6%
Other (alternative beliefs, partially correct, incorrect, no response)	85	31.4
Total	271	100.0%
Teacher responses to students (excluding managerial and repeats):		
Providing/interpreting knowledge (information, explanation, demonstration)	114	26.3
Evaluating: acknowledge/accept answer (109) negatively [wrong answer (13), redirect (81), ignore/dismiss (18)]	148	34.2
Mediating discrepancies (encourage/explore)	171	39.5
Total	433	100.0%

In the previous chapter, it was noted that during the discussion of the phase change investigation the students were left with two dilemmas. During the discussion the teacher was incorrect about two important ideas. (Before class that day the teacher had told the investigator she was not feeling well and had not slept well the night before. This undoubtedly affected her teaching that day.) One of her mistakes concerned the temperature plateau. Theoretically, the temperature of ice water remains at 0°C until the ice completely melts. It has been seen that the temperature did slowly increase while the ice was melting, and that the teachers' guide indicated that this would occur as heating was too rapid for a state of equilibrium to be established while the ice was melting. The teacher expected there would be no increase in the temperature during melting, and without looking at the data, assumed this had indeed been the finding. During the discussion the teacher would not listen to Brian, who tried to tell her that the temperature did increase during melting. The teacher was confident of her knowledge, and she was unwilling to abandon her position. Other examples of the teacher erring in her evaluation of a student response have also been presented in the previous chapter. For example, she occasionally missed an incorrect response given by a student she considered to be very bright. At such times, it appeared that she was not paying close attention to the response and assumed that that student would give the correct answer. When such errors were not identified and corrected, they did lead to problems for many students.

6.3.2. The Teacher as Provider or Interpreter of Science Knowledge

The teacher, the textbook and the results of investigations provided the sources of scientific knowledge for the students. The results of the dialogue analysis revealed that during class discussions approximately 25 percent of the teacher responses were categorized as information, explanation or demonstration. Approximately 40 percent of her responses were categorized as encouraging students to work out answers or ideas for themselves (Table 6.2).

The teacher tended to provide or interpret knowledge only when there was a specific reason for not probing or encouraging further responses from the students. Three different kinds of situations were observed:

1. Assignments were being taken up and the emphasis was on identifying the correct or appropriate answers.

For example, Gordon was at the chalkboard drawing a diagram to show how air circulates in a hot air home heating system.

Gordon: Now, when you have your heat here and you're passing through the air in this direction, it [the air] comes in and right there it will pick up the heat molecules

Teacher: [interrupting] Heat energy's being transferred.

Gordon: transferred right there, and it keeps carrying on the heat, and it's forced up here and out into the air, where we feel it.

The teacher interrupted Gordon to provide the correct terminology, but she did not explore his underlying belief. In situations such as this, where the teacher seemed to merely correct a term, the student may have interpreted her simple correction as an implied acceptance of the belief behind the term used by the student. If she had questioned Gordon about what he meant by "heat molecules," it may have been more obvious to Gordon and others that there is no such thing as a "heat molecule." On this occasion, the teacher seemed to be primarily concerned with providing the correct answer to the question, and she did not appear to recognize the implications of Gordon's belief.

2. Discussion of a topic had continued for some time and the teacher was unable to elicit the desired response from the students.

For example, while discussing the phase change experiment some students still did not understand that the greater temperature change in the liquid phase did not necessarily mean a greater increase in heat energy (although this was the rationale for the investigation). It appeared that the confusion was due, at least partially, to the labelling of the two axes on the graph. The horizontal axis was labelled "time," and the vertical axis "temperature." Neither the text nor the teacher clearly pointed out that it was the time measure which was directly related to the amount of heat energy, in contrast to the temperature axis. The following exchange occurred when a student was asked to respond to a question in the textbook. The question asked which required more heat energy--melting, raising the temperature to the boiling point, or evaporating the water?

Lynne: Raising the temperature.

Teacher: O. K. Would that take more heat energy than evaporating the water?

Lynne: Well, we don't know...

The teacher than asked Lynne a series of questions developing the ideas that as ice melts and as water gets hotter and finally evaporates, the mechanical energy of the particles increases and therefore the heat energy increases. Lynne readily accepted these propositions. Then, Teacher: The more mechanical energy, the more heat energy. So which one is going to have the most heat energy?

Lynne: The evaporated.

Teacher: Yes.

Another student: When it's [the temperature?] on the chart [i.e., the graph] there, it's higher.

Teacher: Mhm. That's what we would have seen. Once you get pure water to a 100°, it's going to become boiling.

Lynne: Then wouldn't it be more heat energy to get it to 100°?

Teacher: No. The particles have more heat energy [sic] when they reach evaporation stage.

Although Lynne understood the idea that as water is heated, its particles gain mechanical energy and that the water gains heat energy, she did not relate that idea to the actual data and graph. Lynne still did not understand why there was more heat energy when the water was boiling, than when it was being heated to the boiling point. That is, in terms of the conceptual change model, the idea was intelligible to her, but it was not plausible. At that point, the teacher provided the information that there is more heat energy when the water is evaporating, and thereby closed the discussion. She then went on to a different question.

3. A student asked a specific question and it was answered by the teacher.

For example, during discussion of another phase change question it was determined that 50g of steam at 100°C has more heat energy than 50g of liquid water at 100°C. One of the boys asked:

Walter: Would that be because there's less particles [i.e., in the steam] and there's the same amount of heat energy applied?

Teacher: As?

Walter: As water.

Teacher: No. There's more heat energy in water vapour than there is in just water.

Walter: The reason why it has more is because there's less particles, but there's more heat energy.

Teacher: You're contradicting yourself.

Walter: Each particle is getting more...

Teacher: [interrupting] You're contradicting yourself. If you have 50g you have exactly the same amount of particles, you should have, because...

Walter: [interrupting] 50g of water vapour.

Teacher: 50g [of water vapour] would have a bigger space is all, and 50g of water would be smaller, but you'd still have the same number of particles.

In this example, the teacher responded to Walter (a student she considered to be very bright) with a factual response. She did not attempt to encourage him to work out the idea himself (as she had done with Lynne in the previous example) or check to see if he understood her response. He did not, but he persisted with his questioning. The teacher continued to answer his questions. In this instance, Walter's alternative belief was resolved due to his persistence in questioning the teacher.

6.3.3. <u>The Teacher as Mediator of Discrepancies Between School Science and Children's Science</u>

We have seen that the most frequent response category for teacher responses to student answers was encourage/explore. In a limited number of situations the teacher responded by providing a statement of facts, but this did not occur frequently. Most often the teacher tried to encourage the student to rethink or to elaborate on her or his answer--that is, the teacher acted as a mediator, striving to help the student reconcile the differences between his or her belief (children's science) and the desired view (school science). Again, these findings were remarkably similar to those reported by Sadker and Sadker (1985). Their equivalent category, "remediation," was observed in 99 percent of the the classrooms, and accounted for one-third of all classroom interactions. By comparison, in this study "encourage/explore" accounted for 35.6 percent of teacher responses.

As mentioned earlier, a teacher is truly faced with a number of dilemmas with respect to guiding students who do not understand the ideas being presented. The first dilemma is to identify the students who are having difficulties. It is usually the more able students who will risk asking for help when they do not understand something. These are the students who expect science to make sense and who believe they are capable of achieving understanding. As illustrated by the example of Walter above, brighter students frequently asked for explanations when they did not understand something. They expect to experience meaningful learning. On the other hand, students who have difficulties with science may not expect it to make sense. Presumably, their past experience with school science has led them to believe that it is not comprehensible. Their approach to learning science is to memorize definitions and other facts, so they can be repeated on the test. They are satisfied with rote learning. Cathy and Susan provide examples of such students. During the pretest interview when Cathy was asked to give reasons for her answers, she almost always replied either that she did not know or she had guessed. Most of Cathy's written assignments were, word-for-word, identical to Jane's. When Susan was interviewed, she was somewhat more responsive than Cathy had been. Rather than a simple, "I dunno," Susan would reply, "I don't know. (laugh) I don't really know much about science," or "I don't know. I can't think of anything." Susan's written work was occasionally identical to that of her more able partner, Carolyn, but not always. Her answers to questions were often placed in quotation marks and were identical to passages in the textbook. Like most of the students in the class, neither Cathy nor Susan was ever observed to ask the teacher to <u>explain</u> something she did not understand. However, Susan did occasionally approach the teacher to ask for the <u>correct answer</u> to a particular question (a fine, but important distinction). Cathy always consulted Jane, not the teacher, when she had questions. In so doing, she did not risk being encouraged to find the answer for herself, thereby exposing her lack of understanding. When students are unwilling to ask the teacher for assistance, their lack of understanding is difficult to identify. It will not likely be detected unless the student is called upon in class and is not able to respond appropriately. This undoubtedly results in many difficulties not being identified by the teacher, except when assignments are handed in or tests are graded. In the case of assignments, as we have noted, students frequently worked together and the answers were often provided by those most able.

By testing time, instruction has been completed, and many students are no longer interested in the correct answers.

In most cases, the students gave acceptable answers to questions posed by the teacher. Approximately one-third of the student responses were judged by the investigator to be other than correct. It has been noted that the most frequent category of teacher response to student answers was encourage or explore. Three possible types of teacher response to incorrect or incomplete answers have also been identified. Each of these types of response has both advantages and disadvantages. The stated goals of school science do not include memorizing unintelligible definitions or facts. Rather, it is desirable to encourage students to develop an understanding of the concept (i.e., for the student to experience meaningful learning). An example to illustrate the teacher providing an encouraging response is presented below:

Teacher: Those are the three things you needed to consider in your conclusion [to the phase change investigation]. First of all, let's go back and review what we mean by heat energy. What _is_ heat energy?

Jane: The total sum of all the mechanical energy of the particles.

Teacher: How could we go about measuring heat energy? Do we measure it directly? Joe?

Joe: Umm, use a thermometer and dump it in the water.

Teacher: O.K. So what are we measuring when we use a thermometer?

Joe: Umm, the temperature.

Teacher: Which is?

Joe: Which is, umm, how hot it is.

Teacher: Hotness and coldness is measured by temperature, so we're not measuring heat energy directly. We can't measure those little particles moving around and sum up the mechanical energy to give us heat energy directly in the classroom. So, we measure it indirectly by measuring the temperature, hotness or coldness. Now, turn to your graphs. [20 second pause while students take out their graphs] O.K. What is the first thing, or one of the things you can say when you look at your graph? What do you notice about the heat energy? [2 second pause] Can you tell anything about heat energy from the graph?

Alan: It's absorbed by the water.

Teacher: O.K. [turning to another student] Do you want to share that with us? [brief, unintelligible exchange between the teacher and a student who was talking to another student and not attending to the class discussion] O.K. Alan said, would you say it loudly so the whole class can hear it?

Alan: Water absorbs heat energy.

Teacher: Where is the heat energy coming from?

Alan: The burner.

Teacher: So one of the things that Alan said is that there's usually a transfer. He called it "absorbing." Is there anything else you can tell us looking at the graph? [4 second pause]

Melanie: After the ice melted the temperature increased very steadily.

Teacher: There are two very important things there. She said <u>after</u> the ice melted, is one very important thing and we'll come back to that. The temperature increased very steadily, which is the second thing she said. What can we say about the heat energy of the particles [sic] in the water? After the ice melted?

Cindy: Umm, they're getting more and more heat energy.

Teacher: Mhm. And the mechanical energy of the particles is increasing, too. O.K. Now, let's go back to the first thing she said. It's very important. "After the ice melted." What happened before the ice melted? Was heat energy being transferred?

Brian and another student: Yes.

Teacher: How do you know?

Brian: It started to melt. [And the discussion continued]

In this introductory segment of the phase change discussion, Jane first provided the textbook definition of heat energy. The teacher then turned to Joe to ask how heat energy could be measured. Initially Joe said that the thermometer measured heat energy. The teacher used probing questions to clarify that it was temperature, not heat energy, that was measured by the thermometer. She then told the class that they could not measure heat energy directly and had them look at their graphs to determine what the graphs showed about heat energy. Alan's response that heat energy is absorbed by the water was addressed and the teacher provided the term "transferred" as being equivalent to "absorbed." The teacher did not probe to ensure that the concept which Alan called "absorbing" was indeed equivalent to "transfer." The teacher then asked for further ideas from the students. Melanie's response allowed the teacher to address the idea that the teacher had wanted to deal with, that the rate of temperature increase changed after the ice had melted. The teacher emphasized what Melanie had said and then probed further to determine what was happening to the particles as the temperature increased.

If the teacher encourages a student to think out a problem in class, other students may benefit by the discussion. The disadvantages of this approach include the time required, during which some students in the class may become bored and restless, and the possibility that the student may be embarassed if she or he is unable to give the desired response. Consequently, this type of probing exchange with a student is sometimes more appropriate in a one-to-one situation, rather than in the large group.

Alternatively, the teacher or another student may provide the "correct" answer for all students, making more efficient use of class time for the large group. Sometimes when an initial response was inappropriate the teacher simply redirected the question to another student. For example:

Teacher: Now, first of all, as you measure the temperature it would be wise to write down what you mean by temperature. What does temperature mean to you? When you call it measuring temperature, what are you measuring?

Male student: How hot it is.

Another male student: The heat that's contained in the object.

Teacher: All right. The heat that's contained within the object. Brian? Do you have another way of putting it?

Brian: How hot something or how cold something is.

Teacher: Yes. That's probably the easiest way to write it down.

Female student: How hot or cold something is.

Teacher: So temperature, and you should copy this down as I write [on the overhead], is the hotness or coldness of an object.

On other occasions the teacher provided the desired answer herself. Examples of this have already been presented (Sec. 6.3.2).

Another example occurred during the discussion of an assigned question. The teacher first directed a probe to another student, and then provided additional information herself.

Melanie: [reading her answer] If two objects have the same mass and the same temperature, but one is made of water and the other is made of lead, then the one made of lead has more heat energy.

[3 second pause]

Male student: Mhm.

Teacher: Actually, no.

Several students: Nooo?

[Several speaking all at once--one male voice heard clearly]: That's denser, so it should be.

Teacher: What's the problem with using density?

[Several students speaking all at once--unintelligible]

Teacher: Who can explain that?

Jane: You have the same mass of each of them, so 50g of lead and 50g of water, and the water is going to have more heat energy because the particles are moving faster and so they have more mechanical energy.

Teacher: Mhm. Remember you can't change the mass of the thing but you can change the way the particles are moving in the water. The water is going to be moving faster. The whole thing is going to have more heat energy. The particles themselves will have more mechanical energy.

Female student: Does that mean they take up the same area?

Teacher: No. It just means they have the same--you have 50g of each.

Female student: But 50g

Teacher: [interrupting] The volume might be different.

In this segment (which has been quoted earlier) Jane was asked to explain a difficult concept. The teacher briefly elaborated on Jane's response. One girl asked a question which revealed that she did not understand the explanation, but rather than explore the student's difficulty the teacher provided a minimal response to the question and was unwilling to discuss it further. Unfortunately, when the correct answer is merely provided and not explained, those students who did not understand the concept are not helped to come to any understanding of the ideas involved. The posttest revealed that many students continued to believe that denser matter had more heat energy than less dense matter.

Sometimes if a student gave an answer which was either incorrect or incomplete, or if the student/s seemed unsure of the correctness of a response, the teacher referred the question to the entire class to vote on the correct answer. An example of this occurred when expanding particles were being discussed. The teacher asked, "Do the particles get bigger themselves?" A few students said, "Nooo." The teacher then asked, "How many say no?" [Several hands were raised.] "How many say yes?" [This time fewer hands were raised.] In this situation the students were asked to commit themselves to a decision. The teacher then continued by addressing one particular student who had voted yes, and discussed his reasons for making that choice.

6.4. <u>Instruction and Alternative Beliefs</u>

The previous sections have looked at the various types of resposes the teacher provided during clas discussion. In this section, the interactions which occurred when alternative beliefs were expressed by students will be examined.

The conceptual change model of Posner et al. (1982) has been presented in Chapter II. According to that model, when new phenomena are presented which are incompatible with the student's existing framework, the new idea will not likely replace the alternative belief unless several conditions are met. These conditions are: 1) the student must be dissatisfied with his/her existing concepts; 2) the student must be able to understand the concept well enough to explain it (i.e., it must be intelligible); 3) the new concept must resolve anomalies in the existing concept (i.e., it must be plausible); and, 4) the new concept must have predictive power and be preferable to the old concept (i.e., it must be fruitful). Only when a student comes to believe an idea and then finds it preferable to his/her prior belief, has it become plausible and then fruitful. If students' alternative beliefs are to be displaced, then they must be persuaded that the school science concept is preferable to, and more useful than, the alternative belief. This did not appear to happen for many of the concepts being dealt with in this unit.

The idea of basing instruction on students' prior beliefs is a relatively new approach to science teaching. Only in very recent years have researchers been investigating this approach, and with few exceptions, it is not in use in science classrooms. Some alternative beliefs do become known to teachers as they provide instruction. A student may be told that his/her idea is incorrect for certain reasons, and that another idea is correct for certain other reasons. Some teachers may use experiments or demonstrations, or refer a student to an authority, such as an encyclopedia, in an attempt to discredit students' alternative beliefs. Some common alternative beliefs have been identified by curriculum developers, and/or textbook and teachers' guide authors, and teachers are then alerted that a particular concept presents difficulties for students. In such cases, alternative beliefs may be identified, although the term itself is not used. Moreover, few, if any, teachers would choose to systematically elicit students' beliefs prior to instruction, in order to first identify their alternative beliefs, and then actively discuss those alternative beliefs during instruction. This approach to instruction is not yet a common feature in university programs which train students to become science teachers.

There is little motivation for most students to try to understand difficult concepts. Under the existing reward structure in most science classrooms, it is correct answers, not understanding, that are rewarded. The target students described in this study are typical of those found in many science classrooms. Students like Jane are rewarded for providing correct answers. Students like Alan are less likely to be rewarded, as they are seldom provided with the opportunity to demonstrate their understanding of science concepts. Students such as Brian present the school science view on tests, while retaining their alternative beliefs. Many students rely on memorizing correct answers to achieve a satisfactory level of performance in school science.

At best, school science measures of learning and/or knowledge determine which concepts are intelligible to the student. Even rote-learned responses may serve as acceptable answers on assignments or tests. In such cases, the concept need not even have been intelligible to the student.

Persistent alternative beliefs have been identified from ten topic areas. This study has examined the persistent alternative beliefs to identify possible factors which may account for that persistence. The goal of the study has been to suggest some possible reasons for why students did not reject their alternative beliefs in favour of the ideas presented in school science. When the instruction provided for the ten topics was examined, one or more of five types of situations appeared to be involved in most cases. In this section, those situations will be described and examples of each will be presented.

6.4.1. School Science Attempts to Explain Heat Phenomena in Terms of Mechanical Energy

Heat phenomena can be investigated at two levels: the macroscopic and the microscopic (i.e., particle) levels. When thermodynamics is studied in introductory physics courses, it is presented at the macroscopic level. Particles, atoms and molecules are not discussed. At the microscopic level, quantum theory is required to account for phenomena. Clearly, such explanations are inappropriate for grade nine science, yet this school science program attempts to use microscopic explanations in terms that could be understood by grade nine students. A number of problems occurred as students attempted to make sense of those explanations. One notable example was the attempt to explain why there is no loss of mechanical energy due to the collisions among particles. The explanation provided in the teachers' guide (quoted earlier, in sec. 5.4.1) and presented by the teacher in class, was challenged by Brian and Joe, and has been termed "absolute nonsense" by one physicist (Matthews, Note 2).

All of the phenomena that were explained or defined on the basis of mechanical energy and/or the transfer of mechanical energy among particles were largely unintelligible to the students. Some students relied on memorizing and were able to reproduce the appropriate definitions and statements. Those who sought meaning in school science, notably Joe and Brian, were disturbed by such explanations. Alan was interested in finding explanations, but rather than seeming disturbed when an explanation was unsatisfactory, he laughed and appeared to forget about it.

Some school science ideas did not present particular problems for students, but were incorrect, according to scientists' science. These included the idea that mechanical energy is solely dependent upon the speed of the particles, and the idea that in conduction, heat energy (internal energy) is transferred solely by collisions among particles.

6.4.2. <u>The Scientists' Science Explanation of a Phenomenon Was Omitted</u>

There were instances where students made observations which were contrary to their expectations. As has been shown, different students responded differently to such situations. For example, Jane tended to reject observations which were contrary to her expectations. She appeared to be disturbed by such discrepancies, and wanted experimental results which would support her beliefs. To the contrary, Alan and Joe seemed intrigued by such findings. They tried to find an explanation for their observations and were stimulated to explore further. When there was no opportunity to find an explanation to account for their observations, Joe, in particular, was left feeling frustrated. In such cases, school science told the student that a particular alternative belief was not correct, yet did not provide an alternative explanation. Students who had made a commitment to an alternative belief were therefore left without any concrete reason for rejecting that alternative belief. One example where this appeared to be a factor was the persistence of the idea that the density of an object is directly related to the amount of heat energy in the object. The students were not introduced to the concept of specific heat capacity (although there is an optional section in the textbook dealing with specific heat). In their prior experiences in school science, the students had learned that density is an important characteristic property of matter. No other property had previously been studied in such detail. In this instance, not only did school science not provide the students with an alternative property which could account for the observed differences in heat energy, but the teacher told the students she would not consider "density" to be a wrong answer. (She then added that it was better to say type or kind of material.) It was also noted that the girls tended to comply with this request (i.e., to not use the term "density"), whereas the boys did not.

Latent heat is another complex concept which was not specifically mentioned. Latent heat accounts for the temperature plateaus which occur during a change of phase, an observation which was not expected by the students, and which caused difficulty for many. In both the specific heat capacity and latent heat examples, students were asked to explain observations without having the "whole story" available to them. School science appears to assume that the student will accept the word of the teacher and the textbook on such matters, and indeed, many students do so. However, to expect students to provide explanations without evidence is inconsistent with the spirit of the junior secondary science program, as described in the curriculum guide.

The observations of phenomena which scientists call "specific heat capacity" and "latent heat" were not questioned by weaker students, who appeared to consider science to be incomprehensible, somewhat like magic. The more competent students, who did try to make sense of their observations, became frustrated as they attempted to understand the reasons for these unexpected findings.

6.4.3. Alternative Beliefs Were Not Identified

There were two instances where it appeared that not only was an alternative belief that caused difficulties for some students not identified by the teacher, but the teachers' guide had not mentioned the possibility of that difficulty. At the end of the unit, Jane and others had not abandoned the belief that cold is equivalent to, but different from heat. Neither the teachers' guide nor the curriculum guide had identified this as a potential difficulty for students. The idea had never been discussed in class. It has already been suggested that the school science definition of temperature as "the hotness or coldness of matter" may have served to validate this alternative belief that hot and cold are equivalent and different entities. The use of this definition appears to be an attempt to provide students with an intelligible alternative to defining temperature as the average mechanical energy of the particles.

Another difficulty which was not identified was the labelling of the axes on the graph of the water temperature as it was being heated in the phase change investigation (Inv. 1.45). Students were to label the axes "temperature" and "time," and the students assumed that the temperature axis represented heat. Again, this alternative belief was not identified by the teacher, nor was it anticipated in the teachers' guide. Students who held this belief were unable to understand the true relationship between heat and temperature in that investigation.

These two alternative beliefs could probably have been corrected relatively easily, <u>if</u> they had been recognized by the teacher. Unless a teacher has implemented specific strategies for identifying students' prior beliefs, alternative beliefs such as these are not likely to be recognized. In the midst of a class discussion, a teacher must balance a number of priorities. Quite understandably, priority is often given to management and finding correct answers.

6.4.4. <u>Confusion About the Use of Scientific Models</u>

School science often utilizes models and analogies to help students understand scientific phenomena. Students' prior experience with models outside of school science is often limited to concrete scale models of objects, such as cars, airplanes, etc. Such models are identical in form with the object being modelled, but they differ in size. Many students appeared to believe that scientific models are necessarily identical in form, but differ in size from the object they represent. That is, the students seemed to think of a "model" in a more restricted sense than is used by scientists. For example, the atom may be thought to be very much smaller, but otherwise identical to the classical Bohr model, with a solid nucleus of protons and neutrons, and with electrons travelling in orbits, similar to the planets circling the sun. The use of the particle model, as we have seen, caused difficulties for many students. Some did not question the model, but neither did they understand its implications for the heat phenomena being investigated. Joe and Brian tried to make sense of the particle model, and found it inconsistent with their prior knowledge about the structure of the atom. Rejecting this model appeared to account for Brian not abandoning his belief that particles could expand. Brian was certain that the "particle," be it atom or molecule, is not the smallest known particle of matter, and hence he may have concluded that there was no reason why a particle should not be able to expand.

The textbook had several diagrams which illustrated particle motion. In those diagrams, the particles were circular in shape. The scale of the distance between the particles was approximately three times the diameter of the particles. The students did not appear to have any understanding of the extent to which those diagrams reflected the actual nature of molecules or the scale of a molecule in comparison to the spaces between the molecules. In another example, the teacher used the analogy of lead shot rolling on the overhead projector to illustrate particle or molecular motion. This model was not helpful for many of the students in this class.

6.4.5. The Teacher's Explanation Was Not Understood by the Students

There were instances where the teachers' guide had identified potential difficulties, and where the teacher herself recognized that the concept was difficult for students. On some such occasions, the teacher tried to explain an idea and the students either did not understand or they did not accept the explanation. Some examples of this, such as the expansion of particles and the conservation of mechanical energy among particles, have already been discussed. On rare occasions, the teacher was actually mistaken about something. The most obvious instance of this situation was the discussion of the phase change investigation. The topic of discussion was difficult, and it was a topic beyond the teacher's area of expertise. Moreover, she was neither feeling well nor adequately prepared for the discussion that day. The result was that the students were given incorrect information. When that occurred, some of the more able students were certain the teacher was wrong, and they were very confused and frustrated. Such situations do sometimes occur, particularly in junior secondary science, where the breadth of the program often results in teachers being required to teach topics in which they have little expertise.

6.5. Summary

This chapter has looked at the instruction provided during the heat and temperature unit. Instruction was examined in terms of a variety of teacher "roles." The first role to be considered was that of "instructional manager." The role of instructional manager included the planning and organization of the activities and content of the unit.

The teacher indicated that she considered heat and temperature a difficult unit for the students to understand. She felt that knowledge of the practical applications of the topics was important. The teacher considered class discussion or dialogue an important strategy and did not "lecture" to the class. A description of the class activities on the first day of the unit provided a sample of the teacher's approach to instruction. She did not draw out the students' prior beliefs about the topics to be studied. However, she did deliberately relate the topics being studied to the students' previous knowledge and experiences, both in school science and outside of school, as she perceived them. She used concrete demonstrations to illustrate abstract phenomena, such as the lead shot to illustrate particle motion. A brief summary of the activities and assignments of the remaining lessons was also presented.

The implementation of the teacher's plans, that is, the actual presentation of the lessons to the students, was investigated by studying the "dialogue" which took place between the teacher and the students during class discussion. Dialogue included any discussion which followed a question-answer format. Ten different categories of teacher response to students were described. These categories were grouped into three broad categories, each of which represented a different role. When responding to student's answers, the teacher's initial response was generally evaluative. The teacher role of "evaluator" included: acknowledging or accepting a student response, telling the student the answer was incorrect, redirecting the question to another student, and dismissing or ignoring the student's response. The teacher used positive and supportive feedback, and rarely told a student he or she was wrong. Evaluative responses were usually accompanied by at least one of the other types of response as well. The other roles consisted of the teacher either providing or interpreting science knowledge herself (the role of "provider"), or encouraging the student to rethink his/her answer (the role of "mediator"). The greatest proportion of her responses to students served to draw out and encourage them to think out their ideas about school science. That is, "mediating" responses occurred more frequently than "providing" responses. The occasions when she redirected questions to other students or provided answers herself usually occurred when time was seen as a constraint. At such times, the teacher appeared to be primarily concerned with eliciting the "right answers" to assigned questions. Most of the students appeared to see this as the major goal of the lessons. Their approach to school science suggested they did not expect it to make sense. Very few students seemed to be concerned about understanding the phenomena preseted in the investigations, readings and discussions. Those who most often challenged ideas that seemed to them to be incorrect or illogical were invariably boys. That is not to say that some girls may not have had the same concerns. However, if they did, they did not express those concerns in class. Jane was a unique student in this class (although there are undoubtedly other "Janes" in many other classes). She wanted school science to be consistent with her beliefs, but she adopted school science definitions and terminology very readily. She appeared to be willing to accept the authority of school science, but not to accept experimental findings that were contrary to her expectations.

In this chapter we have seen that the teacher did encourage students to think out their ideas about school science. Most of her responses to students were categorized as encouraging students to think for themselves. In spite of this, many alternative beliefs persisted at the end of the unit.

In the preceding section of this chapter, five factors were identified which may be related to the persistence of alternative beliefs. They included:

1) the complexity of the textbook explanations of some concepts,
2) the omission of explanations of some concepts which would have accounted for phenomena observed in the investigations,
3) failure to recognize some of the students' alternative beliefs,
4) the lack of understanding of the role of a scientific model, and
5) one situation in which the teacher was mistaken herself.

Chapters IV to VI have presented and discussed the findings of this study. In Chapter IV, scientists' science, school science and children's science were presented. Chapter V reviewed measures of student learning, identified characteristics of the more successful learners and identified topics which posed particular problems for the students. Chapter VI has looked at instruction in terms of teacher roles and the persistent alternative beliefs. The concluding chapter of this dissertation will provide a brief overview of the study and offer some tentative conclusions and recommendations, based on the findings.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.0. Overview of the Study

Before presenting the conclusions and recommendations derived from the study, this section will briefly review the rationale and summarize the study.

7.0.1. Rationale

Children's beliefs about the particulate nature of matter and about heat and temperature have been investigated in previous studies. This study has built on and extended the scope of those studies by moving into the classroom. Two months were spent (as a non-participant observer) in a grade nine science class, investigating the interaction between the students' prior beliefs and learning. The major aim of the study has been to investigate the extent to which alternative beliefs were still present at the end of the heat and temperature unit, and to attempt to offer some possible explanations for why the students did not revise their alternative beliefs during instruction.

7.0.2. Summary

This study has investigated students' ideas about heat and temperature as they studied these topics in school science. A pretest identified students' prior beliefs about the particulate nature of matter, heat and temperature, and revealed that many of their prior beliefs were inconsistent with the school science perspective (i.e., they were alternative beliefs). The same test was also given as a posttest.

Eight target students (four males and four females) were selected to represent a range of prior beliefs. In-depth studies were made of these students' ideas and beliefs, with less detailed data being collected on the remaining 15 students in the class.

The investigator observed the nine lessons on heat and temperature, took notes which focussed on the students' activities during classes, and taped and transcribed all of the lessons. All written work completed by the students was examined, and photocopies were made of all of the target students' work. Copies were also made of all of the unit test answer sheets. Class dialogue was analysed by categorizing and tabulating all discussion and question-answer portions of each lesson. The students wrote the posttest and the teacher-made unit test on the last day of the study.

As has been noted by others (e.g., Driver and Easley, 1978; and Osborne and Wittrock, 1983), many of the prior alternative beliefs did persist in spite of instruction. This was the case even when students were clearly and repeatedly told those ideas were not correct. For example, five students referred to particles expanding on the posttest. The idea that particles expand had been discussed several times in class, and students were clearly told that particles do not expand when matter is heated. It was also noted that some students provided a "correct" answer about a particular phenomenon on the teacher-made unit test (which counted for marks!), yet expressed an alternative belief about the same principle on the posttest.

Three alternative measures of learning were compared. It was seen that the students who achieved the highest marks in science were not necessarily those whose posttest responses revealed that their understanding of the concepts was closest to the school science perspective.

Success on the lowest level questions of the posttest was most closely related to school science marks. Scores on higher level questions were related to the extent to which students participated in class discussions.

School science marks for males and females were not significantly different. However, boys did participate in class discussions significantly more than girls, showed greater pretest-posttest gains and performed better on the posttest, compared to girls.

7.1. Conclusions

A number of tentative conclusions can be offered in response to the questions identified in the problem statement. Many of these conclusions can best be viewed as tentative hypotheses which may be tested by further studies.

7.1.1. School Science

Two major constraints were seen to be influencing school science and the instruction that was provided. One was the complexity of the concepts being presented, and the other was time.

Four broad topics were addressed during the heat and temperature unit:

1. heat energy and its effects on matter,
2. temperature and how it is measured,
3. the difference between temperature and heat energy, and
4. heat transfer.

The concepts that were presented varied in difficulty. Overall, the teacher had identified the heat and temperature unit as the most difficult part of the grade nine science program.

Many of the concepts presented could have been directly related to everyday experience. For example, all of the students had had experience with a liquid-in-glass thermometer, had boiled water and seen steam produced, and would probably have had the experience of picking up an object that was very hot to the touch (such as a metal spoon left in a pan of soup heating on the stove). There are many other common experiences that we tend to take for granted, and that could be related to the concepts presented in this unit. In the curriculum guide, teachers are advised to avoid presenting ideas that are beyond the experiences of the students. The suggestions for teaching science include the following comment:

> It is important that students avoid discussion of theories which describe observations that are <u>clearly beyond their experiences</u>. ... To guide students to [such theories] is to falsify the whole scientific process. Indeed, students cannot be guided towards such theories: they must be told they are true. In this case, the authority for the theories is the teacher not their own observations. The theories then assume the qualities of revelation with the scientist as high priest or chief magician. (Curriculum Development Branch, 1979, p. 69)

The textbook does provide investigations which are intended to ensure that the students do have the necessary laboratory experiences to serve as a basis for the "theories" presented in the unit. For example, two major investigations are provided to demonstrate the difference between heat and temperature. However, the two investigations are themselves very complex and would require careful planning and discussion to ensure that students understand their significance. The constraint of time resulted in one of the investigations being abbreviated and the other being performed as a demonstration by only one group of students. In the latter case, the other students in the class were required to do seat work during the investigation, and did not have the opportunity to observe the investigation as it was being performed. This approach to these complex investigations simply did not provide an adequate opportunity for the students to understand the phenomena being presented.

One aspect of the recently completed Science Council of Canada study of school science education consisted of case studies conducted in eight Canadian schools. The final report made the following comment about the junior secondary classrooms studied:

> In the junior high school years, science teachers are constrained by the limited time available for covering the subject matter and also by the energy they spend on discipline and on encouraging good work habits in their students. Thus, content is given priority over all the other science eduction objectives. Science at this level is often presented as a catalogue of facts for the students to assimilate as quickly as possible. (Science Council of Canada, 1984, pp. 30-31)

Although the teacher did make extensive use of discussion, the limited time did have a major impact on the approach taken for that discussion. It has been noted earlier that the investigations designed to illustrate the difference between heat and temperature were not adequately discussed in class. In addition, it was noted that when the teacher was taking up assignments (laboratory reports and other assigned questions), providing the "correct" answer tended to take precedence over exploring students' beliefs.

Although this emphasis on correct answers may be typical of what goes on in junior secondary classrooms across Canada, it is not identified as an important goal of school science by most teachers. The summary report of the Canadian portion of the Second International Science Study noted that:

> ...teachers favoured curricula which: (a) emphasize learning how to learn rather than basic skills and facts, (b) include a parallel students textbook, and (c) use small group rather than whole class instruction (Connelly et al., 1984, p. 13).

It would seem that although teachers may state a preference for an approach to teaching which does not emphasize learning facts, the reality for the average classroom teacher is large classes, and a curriculum which is not only conceptually difficult for many students, but is also too extensive to be taught for understanding in the time available.

CONCLUSION 1: The constraints of time and the complexity of the concepts of heat and temperature resulted in the major emphasis being placed on identifying the "correct answers."

Although the teacher did make extensive use of class discussion, she did not use discussion as a means of identifying students' prior beliefs. As has been mentioned, this is a relatively new approach to teaching which has not been widely implemented in teaching. The suggestion that providing students with scientific knowledge is not sufficient to persuade them to abandon their alternative beliefs (Osborne, 1982; Osborne and Wittrock, 1983; and Posner et al., 1982) is supported by the findings of this study. If we wish to replace students' alternative beliefs with scientific knowledge, the students must be shown that their alternative beliefs are inadequate and that the scientific view is preferable.

CONCLUSION 2: The teacher did not identify students' prior beliefs as a starting point for instruction, nor did she emphasize discrediting alternative beliefs as she attempted to replace those beliefs with the school science view.

7.1.2. Scientists' Science and School Science

Some key concepts have been simplified and/or otherwise modified for school science, presumably to facilitate student understanding. These include the particle model, the definition of temperature as "hotness or coldness" and the school science concept of heat energy. As was shown in Chapter VI where instruction was examined, this process of simplification appeared to raise as many problems as it may have resolved.

CONCLUSION 3: Inconsistencies between scientists' science and school science appear to be attempts to simplify some of the more difficult science concepts in order to facilitate student understanding. These attempts were not successful, as the topics which were simplified were among those causing the greatest difficulties for the students.

7.1.3. Children's Science: Beliefs About Heat and Temperature and the Particulate Nature of Matter

The prior beliefs expressed by the students on the pretest and during the pretest interviews were consistent with children's ideas previously described by Albert (1974), Erickson (1975, 1979, 1980, 1985), Novick and Nussbaum (1978, 1981 and

Nussbaum and Novick, 1982), Shayer and Wylam (1981), Stavy and Berkowitz (1980), Tiberghien (1980) and Triplett (1973), although most of those studies dealt with younger children. Alternative prior beliefs were not completely revised following instruction, although all but three girls in the class demonstrated gains in scores from pretest to posttest. Doyle (1983) concluded that because students are striving for maximum levels of achievement, it cannot be assumed that written performance reflects beliefs. The findings of this study support Doyle's conclusion, as some students expressed one idea on the teacher-made unit test and another on the posttest.

CONCLUSION 4: Students' beliefs about correct answers were not necessarily the same as their beliefs about what was true.

Alternative beliefs were identified from ten topics which were found to be particularly problematic and resistant to change.

CONCLUSION 5: Alternative beliefs previously described in studies of children's ideas about the particulate nature of matter and about heat and temperature were also expressed by the grade nine students in the study, both prior to and upon completion of the unit.

7.1.4. <u>Learning and Instruction</u>

Three measures of learning were contrasted: school science marks, posttest scores and pretest-posttest gains. Success in school science was significantly related to the lowest level of questions (Level 1) on the posttest. It was not related to posttest questions which required higher level understanding of heat and temperature concepts (Levels 2 and 3). This finding supports the view that school science is neither taught nor evaluated in a way that encourages meaningful learning. This is contrary to the espoused aims and objectives of the British Columbia junior secondary science curriculum. Radical changes in the content and/or time allocation for this unit (and probably many other units in the junior secondary science program) would be necessary if meaningful learning were to be achieved by most students. If meaningful learning is not an achieveable goal of school science, given the current junior secondary program, then curriculum developers should provide a rationale for teaching science as it tends to be taught--that is, in a way that requires many students to learn by rote memorizing.

CONCLUSION 6: The concepts of the heat and temperature unit, as presented in school science, were not well understood by many of the grade nine students. Students appeared to cope with the demands of the content by memorizing school science definitions and facts.

CONCLUSION 7: Students who demonstrated highest levels of understanding of the concepts of heat and temperature on the posttest were not necessarily those whose school science achievement was highest.

School science marks and pretest scores were not significantly different for boys and girls. The absence of significant differences in achievement of boys and girls in school science marks may be assumed to indicate that no differences exist. However, in this study, boys' posttest scores were significantly higher than girls' scores, and boys' gains from the pretest to posttest were also significantly greater. Boys also participated in class discussions to a significantly greater extent than did girls.

CONCLUSION 8: The absence of significant differences in achievement of males and females in school science does not necessarily indicate that differences do not exist in other measures of learning. In this study, significant gender differences were found in posttest scores for Levels 2 and 3, but not for Level 1.

Increased class participation was related to superior performance on the posttest. This cannot be assumed to be a cause and effect relationship, however. It may be simply that more able students contribute more to class discussions than those who are less able. The students who did participate most in class discussions (that is, the students who were earlier referred to as "the talkers") did take advantage of opportunities to question matters they did not understand, even though that questioning did not always resolve their difficulties. Some of the students' alternative beliefs were not identified by the teacher because many students did not ask such questions.

CONCLUSION 9: The analysis of covariance revealed that student participation in class discussions accounted for a significant amount of variance in the posttest only for Level 3 questions.

Persistant alternative beliefs were identified from ten topic areas. Although the teachers' guide identified many of these topics as being problematic for students, not all difficulties were identified. When the instruction provided for these topics was examined, one or more of five factors appeared to be involved in most cases:

1. The school science explanations of some heat phenomena were presented in terms of mechanical energy, a school science concept which was not well understood by the students.
2. The scientists' science explanation of the phenomenon was omitted, either by the teacher and/or the textbook, presumably because it was thought to be too difficult for the students to understand.
3. The alternative beliefs had not been identified by the teacher, the curriculum guide or the teachers' guide.
4. The students were unable to relate a scientific model to the phenomenon which was being explained.
5. The teacher attempted to provide an explanation that the students would understand, but the explanation was not successful.

Alternative beliefs which appear to be related to the omission of scientific ideas included the belief that the characteristic property of density accounts for the phenomena of different materials having different specific heat capacities and different thermal conductivities, and the belief that the temperature of matter always increases when matter is heated. Many students seemed unconcerned about school science telling them their own beliefs were incorrect. However, some of the more able students appeared to be striving unsuccessfully to find explanations which made sense to them. In particular, Joe, Alan and Brian were visibly frustrated when they could not understand school science explanations. None of the students indicated a good understanding of the school science explanation of these concepts.

CONCLUSION 10: The more competent students were frequently frustrated by observations which were not expected, which they did not understand and which were not adequately explained.

CONCLUSION 11: The more competent students were frequently not satisfied with overly-simplified explanations which were contrary to the students' prior knowledge of scientific phenomena.

There were two alternative beliefs which were not identified by the teacher. One was the belief that hot and cold are different entities. The other was the belief that temperature represented a measure of heat during the phase change investigation. Neither of these potential problems was mentioned in the teachers' guide.

CONCLUSION 12: Some alternative beliefs were not identified by the teacher throughout the period of instruction.

There was no evidence that the use of models facilitated understanding for any of the students. To the contrary, for some it raised difficulties, as the students appeared to have a very limited view of the role of a scientific model. For example, the school science model of the particle as the smallest unit of matter caused difficulty for Brian and Joe, and possibly others who did not speak out. Rejecting this model appeared to account for Brian not abandoning his belief that particles could expand.

CONCLUSION 13: Many students did not understand the relationship between a scientific model and the scientific phenomenon represented by the model.

No teacher is immune to an "off day" and, unfortunately, one of the most difficult ideas was discussed on one such day for this teacher. The distinction between heat and temperature was never successfully resolved for most of these students, and it was not presented well during class discussion. The teacher appeared to be unsure of some of the ideas herself.

CONCLUSION 14: Some of the difficulties encountered by the students could be attributed to the teacher providing incorrect information about a topic she did not understand well herself.

7.2. Recommendations

A number of recommendations can be derived from the conclusions of the study. The recommendations fall into two areas: recommendations pertaining to teaching school science, and recommendations for further research.

7.2.1. Teaching School Science

1. Teachers should establish strategies to elicit students' prior beliefs about science topics, so as to be able to address these alternative beliefs during instruction. In order to understand students' beliefs, it is important to identify the reasoning behind wrong answers.
2. Teachers should establish strategies to elicit participation by all students during class discussions.

3. Teachers should strive to encourage girls to participate in class discussions to a greater extent, and to relate school science to contexts with which girls can identify.
4. Teachers should be encouraged to use evaluation techniques which place greater emphasis on students' understanding of science concepts, with less emphasis on knowledge which can be acquired by rote learning.
5. If simplified models, such as the particle model, are to be used, teachers must be prepared to explain and justify their use to the satisfaction of students who question the accuracy and/or validity of such models.
6. More effort is needed to relate school science to students' prior experiences, in an effort to eliminate the perceived distinction between school science and the "real world."

If teachers are to implement the above recommendations, additional support from a number of sources will be required.

7. Research conducted throughout the western world has shown that school children of all ages tend to express similar alternative beliefs about heat and temperature concepts. Findings of studies on students' alternative beliefs about all science topics should be disseminated both to curriculum developers and to classroom teachers.
8. More support should be provided for teachers who are required to teach difficult concepts such as heat and temperature, particularly when the topics are beyond the teacher's area of expertise. Additional inservice-training may be one such support.

7.2.2. <u>Research</u>

9. There is a need for further classroom studies which will investigate strategies for identifying prior beliefs and determine the effects of basing instruction on students' prior beliefs.

10. Further study is needed to examine the differences in class participation and learning by male and female students.

11. The finding that participation in class discussion was related to success on higher level posttest questions should be further investigated.

12. Further investigations are needed to examine students' understanding of models used in school science.

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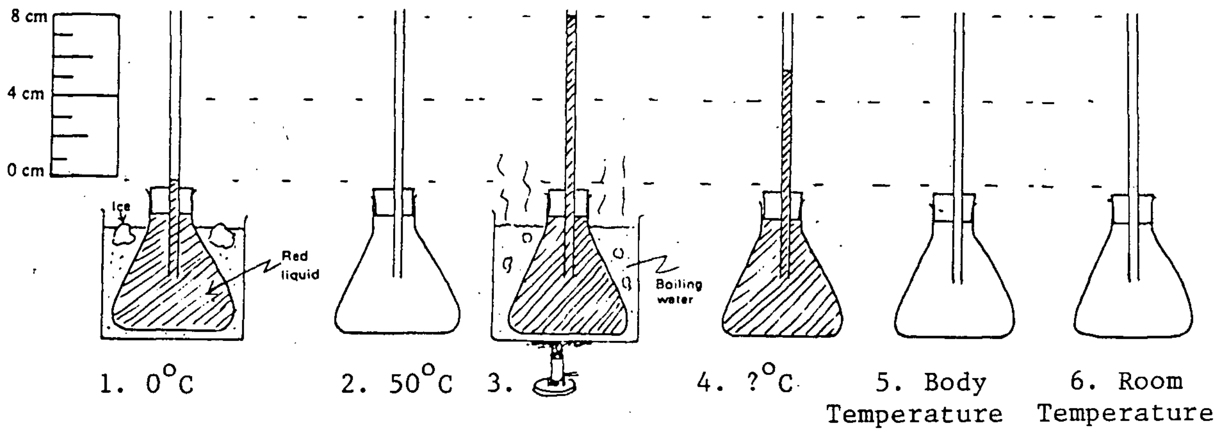
APPENDIX A

PRETEST/POSTTEST

HEAT AND TEMPERATURE

First Name .... Date ....

This questionnaire is called a "pretest." It will not count as part of your science mark. The purpose of a pretest is to tell us what you already know and believe about heat, cold and temperature, before we study these topics in class. We will use the information to help plan the lessons and activities on these topics. If you wish to go over your results with one of us, we will arrange to meet with you.[1]



A. 0°C is the temperature of melting ice.

1. What is the temperature of boiling water? ......°C

2. On the second diagram above, draw in the level that the liquid would be if its temperature was 50°C.

3. Why does the liquid rise when the flask is in boiling water?

4. Fred explains it by saying "hot water rises." Do you

---

[1] This introduction was omitted for the posttest.

think this is a good explanation? yes / no
Why do you think it is or isn't?

5. What is the temperature is the fourth diagram?

......°C

6. If you hold the flask until the red liquid reaches your body temperature, what will the height be? Draw in the level on the fifth diagram above. We don't expect an exact answer, just a good guess.

7. If you let the flask stand in the classroom, what would the height be? This time draw in the level on the sixth diagram.

8. What would the height of the red liquid be at 200°C?

......cm

9. Can you say what the height might be at 1000°C?

......cm Explain your answer.

10. Make a rough guess at the temperature of the following, and give a short reason:

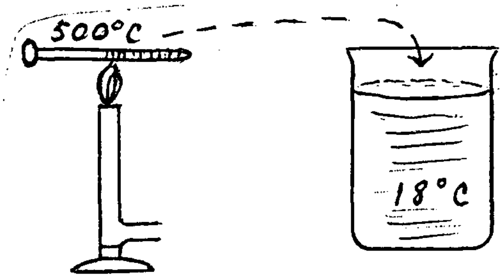
example: Temperature needed to bake bread. .200.°C
..it's hotter than boiling water......

i) frying chips ......°C ....

ii) a rabbit's body ......°C ....

Iii) freezing mercury ......°C ....

B. If you heat a large nail to 500°C, and then drop it into a glass of water which is at room temperature (18°C), what do you think will happen to:



1. the temperature of the nail? ....

2. the temperature of the water? ....

3. Explain how this happens.

4. Make a guess at the temperatures of the water and the nail after the nail has been in the water for:

	water	nail
Before adding nail to water	18°	500°
After 1 minute	.....	.....
After 5 minutes	.....	.....
After 10 minutes	.....	.....
After 15 minutes	.....	.....
After 30 minutes	.....	.....

C. If you have a large beaker of boiling water, and a small beaker of boiling water,

1. which beaker has the most heat? ....

2. which beaker is the hottest? ....

3. If you mix water from both beakers into a larger beaker, will the temperature of the mixed water be greater, less or the same as before mixing?

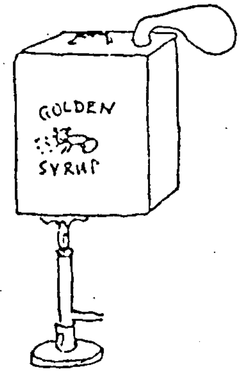
   Explain your answer.

D. In a classroom, where would you expect to find the warmest air?

near the ceiling / in the middle / near the floor

Explain why you chose that answer:

E. If you heated a can with a balloon on top of it, what would happen to the balloon?



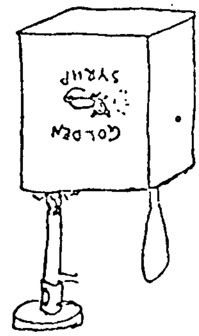
1. Why?

2. Would you expect the balloon to feel warm?

   yes / no

3. Why?

4. If you turned the can upside down, what would happen when the can was heated, and why?



5. Would you expect the balloon to feel warm now? yes / no

   If you answered YES, say how the heat got there.

   If you answered NO, say why the heat does not get there.

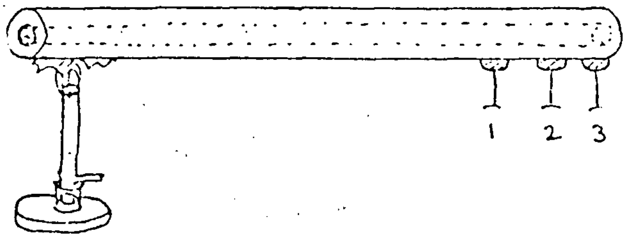
F. Can you think of two objects (A and B) where this would be true:

"A is hotter than B, but B has more heat than A."

Say why: A ....

B ....

G. The pins are stuck on to the metal tube with wax. After one end of the tube has been heated for a while, one of the pins falls off.



1. Which pin do you think falls off?

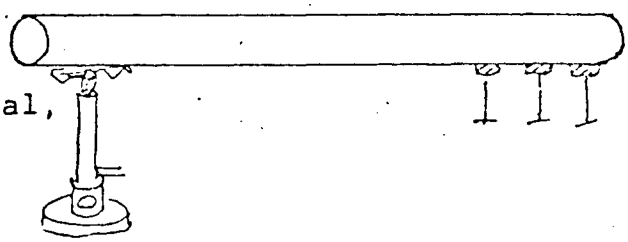
2. Why does it fall off?

3. Would you expect all of the pins to fall off at the same time? ..... Explain why.

4. In what way does heat move along the tube?

5. If you used the same flame to heat a solid rod of the same material, would it take:

   more / less / the same

   time before the pins dropped off?

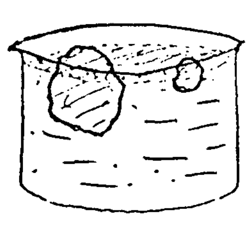
   Explain why:

6. If you used a glass rod instead of a metal one, would the pins drop off

   faster / slower / after the same time

   Explain.

H. If you have a large ice cube and a small ice cube in water, the small ice cube will melt first.



1. Are both ice cubes at the same temperature? yes / no

2. Why do you think the small ice cube melts first?

3. Do you think both ice cubes need the same amount of heat to melt them? Explain your answer.

4. What do you think happens to the temperature of the water as the ice melts?

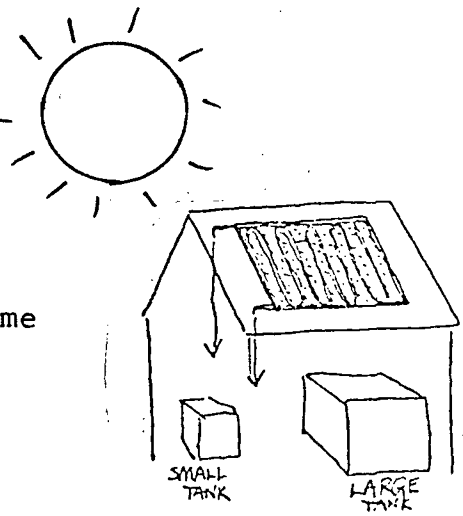
5. Jane says, "If you leave the ice out in the air, it will melt anyway, so that you don't need any heat." Do you agree? yes / no

   If YES, how could you stop it melting?

   If NO, where does the heat come from?

   And, how does it get into the ice?

I. A large solar panel can be connected <u>either</u> to a large water tank or to a small water tank.



1. Which tank do you think will store the most heat?

   large / small / both the same

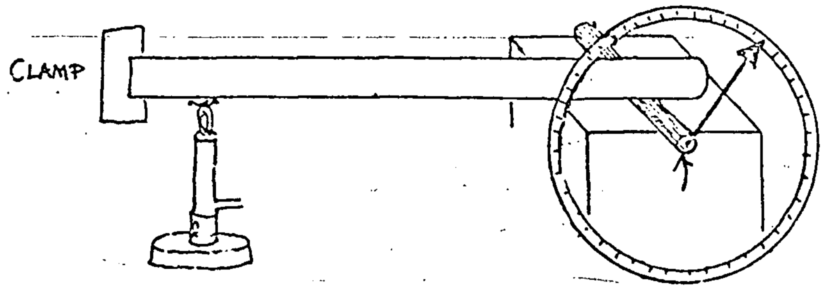
2. Explain why.

3. Which tank do you think will have the hottest water?

   large / small / both the same

4. Explain why.

J. A metal rod is fixed at one end, and the other end rests on a needle. A pointer is attached to the needle, and there is a dial fixed near the other end of the pointer.



1. Soon after the attached end of the rod is heated, the pointer starts to move. Why?

2. Look at your answer. Try to explain how the heat does it.

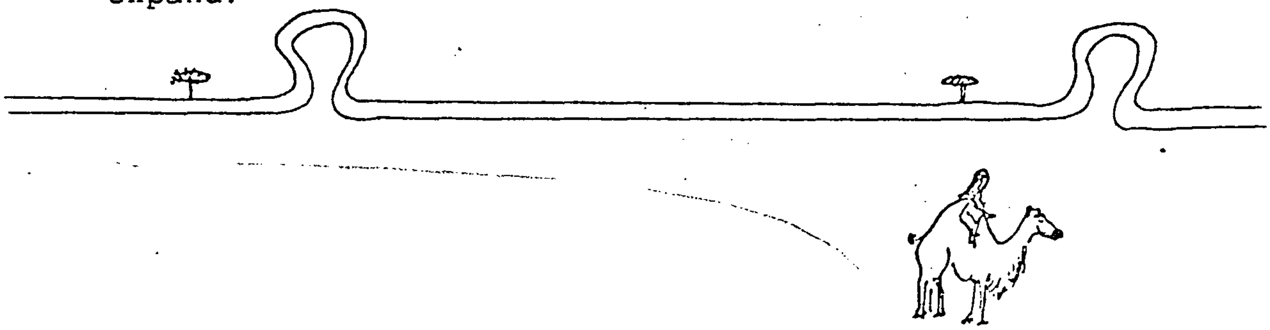
3. If the rod were cut in half, and a piece of insulator fastened between the two halves, what would happen when the rod was heated?

4. Jim says, "It's the heat which makes the pointer move, so if you go on heating for a very long time, the pointer will keep on moving." What do you think?

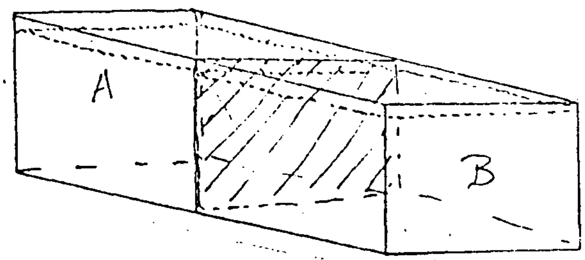
5. What will happen when the heat is removed from the rod?

   Why?

6. Oil pipes in the hot desert have bends in them so that when they expand they do not break. Why does heat make them expand?



K. This is a special box which has two sections. The wall between the two sections can be removed.



1. We fill side A with water at 25°C and side B with the same amount of water at 25°C. When we take out the wall in the middle, the water from A and B mix. What will be the temperature of the water after it has mixed? ......°C

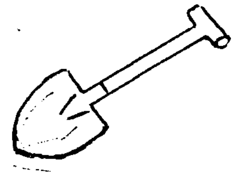
2. If we fill side A with water at 20°C and side B with the same amount of water at 40°C, what will the temperature be when they mix? ......°C

3. If you wanted the heat from A and B to even out, without letting the water mix, what material would you use for the wall?

4. How does heat get through the wall?

5. If we fill A with water at 30°C and we only fill 1/3 of B with water at 10°C, what will the temperature be when they mix? ......°C

L. If you leave a shovel outdoors on a frosty night, the metal feels much colder than the wooden handle.



1. Why does the metal feel colder than the wood?

2. Suppose the temperature of the metal is -3°C, what do you think the temperature of the wood might be?

   .....°C

3. What do you think the air temperature might be?

   .....°C

APPENDIX B

PROTOCOL FOR STUDENT INTERVIEW

I would like to ask you about some of the questions on the pre-test. I may ask you to explain a little more about your answer, or I may ask you to think a bit more about the question to see if you have changed your mind about the answer. Your answers may be different than when you wrote the test, but that's O.K. We won't talk about all of the questions, just some of them. Here is a blank test so you can follow along with me. Do you have any questions? Do you mind if I tape our conversation?

A. On the first set of questions there are six drawings of a flask that is filled with a red liquid and has a long tube sticking out of the top. The flask is at a different temperature in each drawing, and we see the liquid at different heights in the tubes.

1. If there is the same amount of liquid in each case, why does it go higher in the tube in some drawings than in others? (For example, here (#1) it is lower and here (#3) it is near the top. Why is that?)*

4. In question 4 it says that Fred says the liquid rose in the tube because "hot water rises." Is that another way of saying what you just told me? (If Fred was sitting beside you how would you explain to him why his answer isn't correct?)

In drawings 5 and 6 you were asked to draw body temperature

*Questions in parentheses would only be used if student has a particular misunderstanding.

and room temperature. What temperatures did you draw?

(11. At the top of the next page you were asked to guess at some temperatures. One of them was _____. What were you thinking when you chose _____^{o}C?)

Now we'll look at the hot nail in the beaker of water. You thought the temperature of the nail would drop and the water would get warmer.

3. How is it that those two things change temperature like that?

   When you say (the heat goes from the nail to the water), what is happening in the metal and in the water as their temperature changes?

   What's actually causing the temperatures to change? How does heat get from a hot thing to a cooler thing?

   Does this always happen if a hotter thing is put into a cooler thing?

   What conditions would be necessary for the nail and the water to stay at the same temperature?

4. What happens to the temperature of the water after the nail is put in?

   How does the temperature of the nail compare to that of the water?

   What would their temperatures be several hours later?

Now let's look at the question about the large and small beakers. Both contain boiling water. You said ____ has the most heat and ____ is the hottest.

(if same: Is there any difference in the meaning of these two questions?)

(if different: How would you explain how ____ can be hotter, if ____ has more heat?)

3. (If you combine the boiling water from the small beaker and the boiling water from the large beaker, you said the temperature would be ____. Why would it be ____?)

(You said the warmest air in a classroom is ____. Why do you think that?)

The next set of questions is about an empty metal can. It has only air in it and a balloon is placed over the opening. Now no more air can get in or out of the can.

1. First we place the can upright and heat the bottom. (We won't let it get hot enough to melt the balloon, so what would happen to the balloon before it could melt?)
   (What will be happening to the air inside the can as we heat the can?)
2. (Will it get warmer? As the air inside the can gets warmer, what will happen to the balloon?)
   (Why would the balloon be inflating/blowing up?)
4. In the second drawing we've taken another can, because the first can was too hot. This time it's upside down, so the balloon is at the bottom. What will happen to the balloon this time? Does it get warm?
   (What would the air inside the can be doing while the can is being heated?)

Are there any possible ways that you could have two objects, and one of them would be hotter, but the other one would have more heat? Can you give me an example?

The next diagram shows a metal tube being heated. Three pins are fastened to the tube with wax. What causes the first pin to fall off? (Why does the tube getting hot make the pin fall off?)

4. How does the heat get from the burner to the other end of the tube? (Does it go through the hole in the tube, or through the metal, or along the outside of the tube, or how?)
   How does heat move through air? through metal?
   Do you know the name for this process? (of heat moving through metal?)
6. You said that with a glass rod the pins would drop off faster/slower. Why do you think so?

In these next questions we have a large and a small ice cube in a beaker of water, You said they are both at the same temperature, but that the small one would melt first. How is that possible?

(3. Then you said they both need the same amount of heat to melt them. One of the other students said that the large ice cube needs more heat, because it is larger and it takes longer to melt? Do you agree with that? Why/not?)
   How could you explain your view to another student?
5. Jane says the ice cube will melt in the air, so that means heat isn't involved when it melts. (Jane doesn't mean you don't have to add any heat. She means that there is no heat involved at all when the ice cube melts.) Do you agree with Jane?

The next question is about solar heating. Do you have any idea how solar heating works? (The solar panel is made of a long tube of metal that twists back and forth, and is filled with water.

The tube is connected to a tank, and the water is pumped from the tank through the tube, and back to the tank. When the water is in the panel it is heated by the sun. The tank can then be used in place of a water heater.)

Suppose we have two identical houses sitting side by side, and they have identical solar panels. The sun is shining on both panels in the same way. Suppose one house has a large water tank and the other house has a small tank. On a sunny day you go to check the two water tanks. (Repeat questions 1 to 3)

4. (Why are they the same?) or
   (Why doesn't the hottest water have the most heat?)

(IF NO ANSWERS TO 1 - 5 in part J, deal with 6 first--return to others if student seems to grasp the idea of expansion)

6. Could you explain to me again why heat makes oil pipes in the hot desert expand? (Does all metal expand when heated?)

In the diagram above, the metal tube is being heated, and it is expanding. This plastic lid is like the dial in the diagram. If I roll the pin just a tiny bit, the dial turns much more. This allows us to detect a very small movement in the metal tube. Do you see how it works? In the drawing, the rod is heated and it expands. When it expands it pushes on the pin, just like my finger did, and the pin rolls a little bit, causing the pointer to move.

(IF STUDENT IS STILL UNSURE AT THIS POINT, GO ON TO THE NEXT SECTION)

2. Why does the rod push the needle when it is heated?
3. Will the pointer move if the rod has an insulator in it like in this diagram? Will it move the same amount as before/or

less/or more?

4. If the rod was heated for a long time, would the pointer keep moving?

   (if yes: Another student was certain it would soon stop moving. What would you say to him/her to explain your answer?)

   (if no: What would you say to Jim to explain why the pointer doesn't keep moving?)

5. What would happen to the pointer if we take the burner away?

Here is the box with the two sections and the wall between them can be taken out.

3. #3 asks what material you would use so the heat from A and B would even out without removing the wall. You said _____.

4. Why did you think _____ would be a good material to use?

   (Can you think of a material that would allow the heat to go directly from B to A THROUGH the wall?)

5. For #5 you gave ___^{o}C as your answer. How did you find that answer? (Did you make an estimate?)

The last section concerns the shovel left outdoors on a frosty night. Have you ever noticed that when it's cold outside that metal feels colder than most other substances?

1. Why does the metal feel colder?

2. Suppose you had a special thermometer so you could measure the temperature of both the metal and the wooden handle. The metal is -3^{o}C. What would the temperature of the handle be? What would the air temperature be?

Thank you very much for your help.

APPENDIX C

HEAT AND TEMPERATURE UNIT TEST

1. Explain the difference between heat energy, mechanical energy and temperature. (6:7)*

2. Give three examples of transformations to heat energy. (3:15)

3. Using a diagram explain the difference between a bar of iron at room temperature and at 100°C. Show the particles. (6:5)

4. If a cylinder of gas contains 30 particles and each particle has 3J mechanical energy, how much heat energy does the gas have? (2:20)

5. Explain how you could calibrate a mercury thermometer. (5:3)

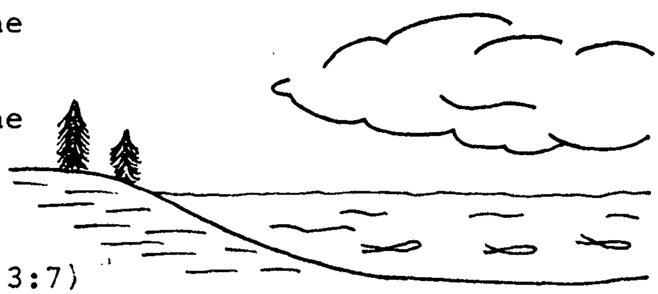
6. Explain how a bimetallic strip can be used as a switch. Use a diagram. (5:12)

7. List three factors which affect the heat energy of an object. (3:13)

8. List three ways heat energy may be transferred. (3:17)

9. Using the particle model explain how conduction occurs. (5:12)

10. At night, the land near the sea cools down to a lower temperature than the sea. Therefore the air above the land is cooler than the air above the sea. Make a drawing. Using arrows show the direction of the convection current. (3:7)



11. Describe the clothing you might wear at -60°C on a sunny day. Explain how it would keep you warm. (3:4)

12. How does the sun's energy reach us? (1:17)

13. Suppose you were outside on a hot day when the temperature is 30°C. Which radiates more--your body or your surroundings? What kind of clothing should you wear to stay cool? Why? (5:5)

*(X:Y) where X=number of marks for the question, and Y=number of students receiving full marks on the question

APPENDIX D

CONCEPTUAL BIOGRAPHY: JANE

Jane was identified by the teacher as the best student in the class. Her final mark in science was 94%, the next highest mark being 88%. She spoke out in class more than most other students, both in response to questions posed by the teacher, and to ask about things she did not understand. The teacher frequently acknowledged that Jane had a "good question" and never put off dealing with her questions indefinitely. If there was no time available at the moment, the teacher told Jane when she would be able to discuss it with her. Jane was one of a group of seven girls (of the 14 girls in the class) who sat in a cluster and worked closely together. Other students in the class, particularly the other six girls in this group, frequently asked Jane for assistance. If Jane and any other student expressed conflicting opinions, the class believed Jane. Even capable students yielded to her opinion, including on occasions when she was not correct. Thus it appeared that the students also considered Jane to be the most knowledgeable student in the class.

Jane's written work was completed neatly and on time. The wording of her answers tended to be almost exactly as presented in the text or by the teacher in class. She was one of the few students to submit a complete set of written assignments to the observer. In short, the overall impression was that Jane was an ideal student.

The Particulate Nature of Matter

On the pretest Jane understood that matter is composed of particles which are further apart in hotter matter than in cooler matter. For example, she said that a liquid rises in a tube when it is heated "because it is heated and it expands as the particles in the liquid spread apart." The oil pipes in the desert expand "because the particles get hotter and spread apart, therefore expanding the material (pipes)."

Heat Energy and Its Effects on Matter

On the pretest and during the first interview, Jane appeared uncertain about the nature of heat. During the interview she indicated heat was "warmth" caused by burning or friction or "something like that." However, in reference to questions dealing with heat transfer she favoured a fluid view. For example, in response to a question about how heat is transferred from a hot nail to the water in which it is submerged, she replied, "...and so it [heat] moves along, I don't know, I guess maybe between the particles of water or in the particles of the water and warms it up." That is, on the pretest and subsequent interview Jane did not seem to know that heating matter causes an increase in the mechanical energy of the particles. She confined her description to saying the particles were further apart. When explaining thermal expansion of a metal rod she said, "the particles of the material speed up." Again, she gave no indication of relating the increased speed to an increase in the mechanical energy of the particles. On Day 2, during a class discussion about how a mercury thermometer works, Jane explained, "it gets heated up and the particles move faster and farther apart and so it has to expand." Once more, the energy itself is not mentioned. During this particular discussion, Jane provided most of the answers to questions posed by the teacher. Later that period the ball and ring phenomenon was demonstrated by the teacher. Two other students stated that the ball expanded when it was heated because the particles expanded. Jane was then called upon to give her interpretation and again said the particles speeded up and moved apart. The teacher then asked, "How do they speed up? What kind of energy are they gaining?" Jane and several others responded "mechanical." Thus, at this early stage in the unit, Jane needed a probe from the teacher before relating heating to an increase in the mechanical energy of the particles. On Day 7, during the discussion of Investigation 1.45 (Heat energy and temperature in phase changes), the teacher asked, "What is heat energy?" Jane quickly responded, "the total sum of all the mechanical energy of the particles." By then the probes were no longer required. On the posttest questions about solar heating panels, Jane said the water in the large tank would store more heat because it has "more particles to gain mechanical energy," and the water in the smaller tank would be hotter because the "average mechanical energy of a particle would be greater." Here she clearly indicated an understanding of the school science definition of heat. She distinguished between heat and temperature in terms of kinetic molecular theory.

Jane also revealed some confusion about the distinction between heat and cold. She appeared to think of cold as being a distinct entity in itself. For example, compared to a smaller ice cube, a large ice cube will "keep the cold in more," and metal feels colder than wood because (on the pretest) "it conducts heat and cold well" and (on the posttest) "it conducts cold better." The question of the nature of cold is not addressed in the text, nor was it discussed in class. Apparently it is assumed that students will understand the nature of "cold" if they understand the nature of "heat." Jane's confusion on the matter suggests that this is not a valid assumption.

Temperature and How It Is Measured

Jane experienced no difficulty answering questions related to temperature and temperature scales on either the pretest or the posttest.

The Difference Between Temperature and Heat Energy

Jane did not clearly distinguish heat and temperature on the pretest or during the interview. Her difficulties on this distinction had largely been resolved by the posttest. For example, during the interview concerning the large and small beakers of boiling water, Jane said that the large beaker would be hottest because it had more water and therefore would give off more heat. On the posttest she recognized that neither beaker would be hotter because "both sets of particles have the same mechanical energy." When asked to give an example of two objects such that one is hotter and the other has more heat, Jane's posttest response was based on a kinetic theory explanation (which was taken directly from a problem that had been assigned earlier). She responded, "a cup of boiling water is hotter because average mechanical energy of particle [sic] is higher" and "swimming pool has more heat energy because it has so many more particles."

On the pretest question about the large and small ice cubes Jane said the small ice cube was warmer and would melt first because "it is less massive and has higher temperature." Both cubes would need the same amount of heat to melt, but the larger one would take longer to melt--it keeps the cold in. When questioned during the interview she reasoned that the ice cubes would be the same temperature when they were in the freezer and when first put into the water, and that they would require different amounts of heat to melt them. She seemed "ready" to understand what was happening to the ice cubes, but had not previously thought it through. On the posttest she provided a kinetic explanation--the small ice cube melts first because "there are less particles to spread apart." However, she still revealed some confusion (possibly due to haste and not carefully reading the question?) when she said that both cubes need the same amount of heat to melt but the larger one will take longer to melt. She was evidently confusing heat and temperature in this statement.

Heat Transfer

Jane's explanations of heat transfer changed greatly from the pretest to the posttest.

Conduction

Jane was initially unclear on the nature of conduction. On the pretest she said, "there is so much heat from the nail that it would diffuse through the water." During the interview she speculated that heat may move "between" particles of water and "through" the particles of a metal. Like some other students, Jane appeared to believe that the turning of the dial on the metal rod expansion apparatus was due to particles speeding up and hitting the needle more (i.e., agitating it), thus causing it to move. She was aware that some materials are better conductors than others, but as mentioned earlier, she referred to conduction of heat and cold as if these were two different "things". She did not give a kinetic explanation of conduction on the posttest. However, on the unit test given by the teacher (written during the same class period as the posttest, but which "counted" as part of her mark in science) the following question was asked: "Using the particle model, explain how conduction occurs." With this additional probing, Jane replied:

> When one end of an object is heated, the particles at that end gain mechanical energy and speed up. This causes them to bump/collide into "neighboring" particles and these latter particles gain mechanical energy. These in turn bump/collide the particles farther along the object, and in this way, heat energy is conducted.

<u>Convection</u>

Like the other students, Jane was aware that "hot air rises." On the pretest she predicted that the warmest air would be near the ceiling "because hot air particles are very light so they rise to the top of the room." She apparently confused the density of the air with the mass of the particles themselves. On the posttest she responded, "because hot air is less dense than cold air and it would rise." She knew that the hot air rises, but expected it to stay at the top of its container, rather than recognizing that an unlimited amount of air cannot keep expanding and rising when it is heated. For example, on the pretest question about the syrup can with the balloon on the bottom of the can, she said, the "balloon would be limp because the hot air would rise up, not go down." This belief was repeated in the interview. On the posttest she replied, "the balloon would expand because the air expands and has nowhere to go but down." However, she did not expect the balloon to feel warm "because the hotter air rises to the top of the can." She gave no indication of recognizing this situation as an example of convection. This is particularly surprizing, because only two days earlier she had related the thermal expansion of a fluid to convection during a class discussion. The teacher had asked for someone to "explain how convection would work." Jane replied:

> If you have some water and you heat up part of that water, and the water that you heat up, the particles will move farther apart, the water will have more heat energy, so the heated water gets lighter than the cold water, so the cold water is heavier and it pushes the hot water and so that's how it's moving around.

Although this explanation is more accurate than Jane's posttest description of the air moving in the heated can, there are still some problems. Density and mass are confused and there is the notion of the cold water "pushing" the hot water. On the assigned questions about convection Jane also referred to colder air pushing "less dense warm air up." On another of the assigned questions, she stated that "heat energy always rises naturally, and will not go in any other direction unless it is forced to by unaturally [sic] means." This confusion may have its origins in the class discussion. The teacher had stressed the point that one distinctive feature of convection is that heat is always transferred upwards in convection, unlike conduction and radiation where heat can be transferred in any direction. The assigned reading on convection explained convection in relation to both hot air and hot water heating systems. Moreover, on the unit test Jane correctly diagramed convection currents of air masses over a land-sea interface. In spite of these varied ways of looking at convection, Jane appears to have a limited understanding and to be unable to transfer that understanding to a different system, namely the convection of air in the closed can, as was required on the pretest/posttest question.

Radiation

On the pretest Jane expressed the belief that a larger amount of boiling water is hotter than a smaller amount because it gives off more heat. This belief probably derived from a partial understanding of radiant energy. On the posttest Jane said that both beakers of boiling water were the same temperature.

On the unit test Jane responded that the sun's energy reaches the earth by radiation, that a human body radiates more heat than an object which has a temperature less than body temperature and that color influences the amount of radiant energy that is reflected or absorbed by an object.

Conclusion

In conclusion, Jane's achievement in science, her performance on the pretest and posttest, and her status among her classmates, all support the teacher's perception of Jane as the "best student" in the class. However, in spite of this, Jane still revealed some basic misunderstandings about heat upon completion of this unit. Moreover, Jane showed no evidence of a particular flair or feeling for science (unlike Alan and Joe, who appeared to be genuinely intrigued by findings they had not anticipated). Jane's answers to questions seemed drawn directly from the text or from the teacher's comments in class. She appeared to accept the school science view without question. Only when probed did she show signs of puzzling out something for herself. She was not inspired to question unexpected results, but rather assumed something must be wrong with the experiment.

APPENDIX E

THE PHASE CHANGE INVESTIGATION (INV. 1.45)

Jane, Joe and Alan conducted Investigation 1.45 (Heat Energy and Temperature in Phase Changes) as a "demonstration" for the class. The procedure was to heat ice cubes and record the water temperature every two minutes until half of the water had boiled away. The students had been not notified in advance that they would be doing the laboratory and hence the first 15 minutes of the period were spent reading the directions and setting up their notebooks. The teacher then asked, "May I have a volunteeer to be the scientist for the day? Do this experiment?" One girl suggested Jane and she declined. Joe volunteered and the teacher agreed to have him do it. The teacher then asked for a volunteer recorder. Again, Jane's name was proposed; again, Jane declined. However, after some discussion the teacher persuaded Jane to agree to record the data. As Joe was setting up the apparatus, Alan began to assist him, and took over the task of timing the observations. Meanwhile the other students were told to complete their preparation while Jane, Joe and Alan did the investigation. Jane recorded the data on the overhead projector while Joe took the readings and Alan did the timing. The data was not as the students expected, and during the investigation there was a great deal of discussion among the three about this problem. The final version of the data, as recorded by Jane, differed somewhat from Joe's actual readings.

The first three readings were 2°, 6°, and 4°. Jane said the third reading could not be 4°, and protested vigorously. Joe and Alan discussed the dilemma and speculated that the position of the thermometer with respect to the heat source might account for this unusual data. Jane continued to protest, and Joe suggested reversing the two readings, but instead Jane omitted the 6° reading, and recorded a temperature of 2° for the second reading. She then omitted the time "0" reading completely.

All went well until the ice had melted and the temperature increased from 17° to 35° during a two-minute interval. Jane refused to accept the latter reading.

Alan: Lookat! All the ice melted!

Joe: All the ice melted? In between eight and ten minutes--no, in between 10 and 12 minutes.

Jane: 11 and 12 minutes?

Joe: [muttering to himself, trying to decide just when the ice melted]

Jane: Between 10 and 12, Joe?

Joe: Yeah.

Joe: [about a minute later] 35!

Jane: What is it?

Joe: It's 35 right now.

Jane: [sarcasticly and laughing] Oh right Joe.

Joe: It is. Come and look.

Jane: It went from 17 to 35 [her tone indicates disbelief].

Alan: It is 35.

Joe: O.K. Put down, umm, 20.

Jane: 20.

Alan: Yeah, that looks good.

Joe: It is 35.

Jane: Oh yeah, you guys [she still doesn't believe them].

Joe: Well, you just (unintelligible).

Jane: Oh yeah [laughing].

Alan: [again looking at the thermometer and talking to himself] This is very interesting. [Jane continues to express her disbelief as the boys are thinking about the temperatures]

Joe: I think the thermometer's broken. [he takes the thermometer to the water tap and places it under running water] Hey! It's going up! [Joe then notices he had turned on the hot water. He changes it to cold] Now it'll go down. [Joe puts the thermometer back in the beaker, and he and Jane continue to discuss the data]

Joe: [next reading] 40, umm, 46.

Jane: 46!! 46 ehh?

Joe: Put down 35 where the 20 was.

Jane: Are you serious?

Joe: Yes.

Jane: 17 to 35?

Joe: Yes!

Alan: It's very possible.

Joe: Sort of like the (??) point.

Alan: It is very possible.

Jane: How possible? [Jane still doesn't believe the data is possible--her tone continues to be one of disbelief]

Joe: Don't put 30. Put down 25.

Jane: What do you want me to put down? What was it? 35?

Joe: [laughing] 25.

Jane: [laughing] 25, you want 25?

Joe: Yeah.

Jane: [after a brief pause] O.K. Now what?

Alan: We're still working on 20 [i.e., the temperature at the 20 minute mark].

Jane: Oh yeah, well.

Alan: [interjecting] It's going to 60 now! Hey! It's going to 60! Shoot! It's going to 60 now. It <u>is</u> 60! [Jane protests with comments such as, "get serious" all the time Alan is exclaiming. Joe sticks his finger in the beaker--he doesn't believe it]

Joe: It's hot! [shaking his hand]

Jane: Well, what is it now? Probably 80 or something.

Joe: It's 58.

Alan: Are you kidding? We're still working on 20 minutes.

Joe: No, we're not.

Alan: 22.

Joe: It's longer than 20 minutes. [Jane is changing the data] I'm the monitor.

Jane: Oh yeah? [laughing]

Joe: O.K. It went up to, [pause] I'll measure it if you want, let's say 76. [At this point the other students begin to complain about all of the changes in the data--there is quite a bit of background noise]

Joe: There it is. 72. [this is for 24 minutes]

Jane: [a short time later] What's the temperature now?

Joe: 80.

Jane: 80? 32 minutes? [it is actually 26 minutes, but Jane has inserted some additional times to spread out the increase]

Joe: 81. No, put 80.

So they continued, with the boys preferring to record the data as observed and Jane insisting it was impossible. Joe pointed out that water boils very quickly when it is heated "to make tea or coffee." The teacher soon interjected to discuss the investigation with the class. The "scientists" were no longer able to discuss their results, and all additional readings were taken quietly. By the time the water began to boil, the period was nearly over. The teacher advised the students to leave the water for another two minutes because "we should have two readings the same."

The students were told to complete their laboratory reports for the next day, and the investigation was discussed. During that discussion there was no suggestion that the data had been altered in any way.