AN ABSTRACT OF THE THESIS OF

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Norman G. Lederman

A large amount of research has been conducted that establishes that students of all ages hold conceptions about a variety of science topics that are not in line with accepted scientific beliefs. These preconceptions have been identified in a variety of ways in research situations; this study focused on how secondary science teachers actually attempt to diagnose students' preconceptions in the classroom and the understanding the teachers have about these preconceptions. The use the teachers made of any information gathered in a diagnosis and the reasons for a lack of diagnosis were also investigated.

Four experienced science teachers were studied in depth, they were interviewed three times and classroom observations were conducted for nine weeks. The teachers' classroom practices, questioning techniques, understanding of students' preconceptions, and assessment of students' understanding were all analyzed.

In this study, the teachers did not use any formal strategies for diagnosing students' preconceptions such as concept mapping, interviews, journals, or writing prompts. The teachers studied claimed that it was important to conduct diagnosis

but only one teacher was seen to actually do so. The teacher who did use class discussions as a strategy for diagnosis was the most experienced teacher of the four and also the teacher with the strongest subject matter background. The other three teachers all claimed that they did do diagnosis of preconceptions by questioning their students but they were not seen to do this in their classes.

The conclusions from these results are that the teachers did not have a complete understanding of the concept of diagnosing students' preconceptions in order to use that information to attempt conceptual change. The teachers' beliefs were not consistent with their practices in this situation; they may have had certain constraints on them that inhibited the translation of their beliefs into practice.

The implications are that preservice and inservice teachers may need to be trained about the importance of, the strategies involved with, and the justification for diagnosing students' preconceptions in the regular classroom environment. Teachers must have an understanding of students' preconceptions and the effect they have on students' learning.

Investigating Teachers' Understanding and Diagnosis of Students' Preconceptions in the Secondary Science Classroom

by

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Judith A. Morrison, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

Table of Contents (Continued)

INVESTIGATING TEACHERS' UNDERSTANDING AND DIAGNOSIS OF STUDENTS' PRECONCEPTIONS IN THE SECONDARY SCIENCE CLASSROOM

Chapter 1

The Problem

Introduction

The science education reforms of the past years have called for more emphasis on inquiry-based science programs based on the philosophy that student understanding is facilitated by active involvement with authentic scientific inquiry. In order to increase student understanding, science teachers are being asked to select science content and adapt and design curricula to cover the interests, knowledge, understanding, abilities, and experiences of their students (NRC, 1996). As all knowledge is considered to be built upon the learner's existing knowledge, it is essential for a teacher to be aware of students' prior knowledge of science concepts. For teachers to develop instruction based on students' prior understanding, it will be essential for teachers to have adequate comprehension of an individual student's past experiences, current understanding and interest in the topics presented. Teachers are expected to be "aware of and understand common naive concepts in science for given grade levels, as well as the cultural and experiential background of students and the effects these have on learning" (NRC, 1996, p. 31). When planning instruction, teachers must consider the background of their students as well as the special characteristics of the material (AAAS, 1990).

The pedagogical characteristics described in the reforms are based on constructivism. According to von Glasersfeld (1993), knowledge is the result of a constructive activity and cannot simply be transferred to a passive receiver. Knowledge has to be built up by each individual knower. According to this theory, all knowledge must be individually and socially constructed and based on the learner's existing knowledge and experiences. Ideas cannot be transferred into students' minds intact; students must construct their own meanings from the words and images with which they are faced. When undergoing this construction of meaning, what the student already knows is of central importance (Treagust, Duit, & Fraser, 1996). It is essential for science teachers to have an intimate knowledge of their students' prior knowledge of, and experiences with, any specific science content. Changes in scientific understanding cannot be brought about without an understanding of the depth and tenacity of students' preexisting knowledge (Carey, 1986). According to Wandersee (1986), " The most important things students bring to their science classes are their concepts (p. 581)."

Teaching based on constructivist epistemology requires that teachers elicit their students' prior knowledge before attempting to restructure students' ideas. Conceptual change strategies have been proposed by a number of authors (Champagne, Gunstone, & Klopfer, 1986; Driver & Scott, 1996; Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982). One common factor in conceptual change instructional approaches is the need for teachers to identify students' prior knowledge before attempting to affect their ideas.

Statement of the Problem

How the knowledge students bring to the classroom aligns with the accepted scientific concepts varies from complete understanding to tenacious misconception. The terminology used to describe prior knowledge that does not fit the accepted scientific concept is diverse and often dependent upon the author and the subjects being described. The term "alternate conception" is now preferred by many researchers over the term "misconception" because it does not state that the conception is wrong, only different from the accepted scientific view (Wandersee, Mintzes, & Novak, 1994). Gunstone (1989) states that "alternative conception" implies more tolerance for existing conceptions; the term "misconception" is negative and does not fit into the constructivist view of learning. Many of the terms used to describe prior knowledge apply specifically to very young children (children's science, naive theories or children's ideas) and do not fit the conceptions that secondary students may hold. The term "prescientific conception" has been coined by Good (1991) because it is less negative than "misconception," it can be used for older students and adults, it is specific to science, and because it implies that the learner may not yet have reached the accepted scientific conception. The term of choice in the following work is "preconception." This term has the advantages of Good's term "prescientific conceptions" and since this work deals solely with science conceptions, the word "scientific" is unnecessary. It is also important to use a term that allows for the possibility of the student having correct prior knowledge; secondary students especially, may already have correct scientific conceptions in place before instruction occurs. "Preconception" will therefore be used to represent any conception that a student holds before the teacher begins the specific science instruction.

Reams of research have been produced in the last 20 years (Wandersee, Mintzes, & Novak, 1994) verifying that students enter classrooms with ideas about science that have been influenced by their prior experiences, textbooks, teachers' explanations, or everyday language. Much of this research has focused on identification of students' preconceptions in various subjects. Influential studies (Erickson, 1979: Novick & Nussbaum, 1978: Stavy, 1990) have used interviews to identify students' conceptions. Gilbert, Watts, and Osborne (1985) used a specific interview procedure "interview-about-instances" in their search for student misconceptions; Novick and Nussbaum (1981) and Osborne and Cosgrove (1983) provided students with a demonstration and then conducted interviews or written tests to search for students' concepts. Other significant studies (Bar & Travis, 1991; Brooks, Briggs, & Driver, 1984; Hesse & Anderson, 1992) have incorporated both a written test and an interview when seeking to identify students' concepts. In all of these studies, the researchers attempted to identify the conceptions that students held about specific science content. All of these studies were done in situations outside of everyday classroom settings.

Arising from this "preconceptions" research has been a number of proposed models of conceptual change (Champagne, 1989; Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982). Many of the models of conceptual change teaching and learning have generated specific recommendations about instructional strategies. What they recommend may be difficult to actually do in the classroom, for example, in-depth interviews with individual students are often too time-consuming for teachers. According to Duschl and Gitomer (1991), the classroom climate and culture seem to be often ignored in these models. Despite this fact, many methods have been proposed for teachers to use to identify their students' prior knowledge in the classroom. Concept maps, interviews, discussions, small group work, specific activities, journals, and pencil and paper quizzes have all been suggested as techniques that may be used to elicit students' ideas in the classroom.

Concept mapping (Wandersee, 1990; Novak & Gowin, 1984) has been put forth as a useful way for teachers to allow students to map their understandings. Concept maps, which were developed from Ausubel's assimilation theory of cognitive learning, "depict the hierarchy and relationships among concepts and are intended to provide evidence of a student's thinking in that the relationships between concepts are presented clearly and alternative conceptions can be identified easily" (Duit, Treagust, & Mansfield, 1996, p. 25). Duit et al. also discuss the strengths of concept mapping: they take a short time to complete once students are trained to use them, they may be used with classes of any size and students of any level, and "their nonverbal form can expose vagueness in conceptions that are disguised easily in verbal responses" (p.26). This method has the disadvantage that it does take a certain amount of time to train students to initially construct the maps. Concept maps may also be difficult to interpret and evaluate; they are also limiting due to being two-dimensional and static.

Bell, Osborne, & Tasker (1985) point out that interviewing students in the classroom is an excellent way to gain insight into their preconceptions. There are inherent problems associated with this strategy: the interviewing skill of the teacher is crucial, the tone of voice used, facial expressions, phrasing questions or providing clues may all impact the answers received from students. Possibly of utmost concern is the time the interviewing procedure may take. It would take a classroom teacher many hours of nonclass time to interview every student or many specially organized classes to conduct interviews during class time.

Students may be interviewed on specific topics in science. Interviews about Instances or Events (White & Gunstone, 1992; Osborne & Freyburg, 1985) are interviews focusing on specific situations or incidents that are usually represented by a single or a series of line drawings. Piaget, who employed actual objects and events to probe children's constructions of concepts, used this technique. In these interviews, students are asked to explain their understanding of specific instances or events. To properly utilize this method, the interviewer must have a set of questions in mind to use, should strive not to be judgmental, and should work to build a rapport between himself/herself and the students (White & Gunstone, 1992).

By asking students to perform a set of three tasks: making and justifying a prediction, observing an event, and providing an explanation, information is provided about their understanding. White and Gunstone (1992) discuss how a predicting, observing, and explaining task (POE) provides crucial evidence of students' understanding of a specific event.

Classroom discussions in which students' preconceptions are elicited have also been suggested as a way to determine students' preinstructional knowledge of science concepts (Driver & Oldham, 1986). But some students will not speak out in a large group discussion especially if they are in any way confused or uncertain about the material being discussed. Although very time-consuming, effective questioning by the teacher or discussion leader is essential if any information on individual students' understanding is to be collected in a large-group setting.

Small-group work has also been suggested as a way to allow students to reveal their preconceptions (Basili & Sanford, 1991). Students may be asked to tackle a specific question or problem in a manner that involves discussion or justification of their current views on the topic involved. In a small-group setting where the group members are given roles and all are asked for input, the elicitation of preconceptions is facilitated.

Driver and Scott (1996) have proposed activities especially designed to bring out students' ideas as a way of introducing a specific science topic. These orientation activities allow students to describe and explain simple phenomena, then share their preinstructional ideas in groups, discuss other students' ideas, reach a consensus among all members, and finally prepare a poster advertising the group's idea(s). These activities and group work allow students to present their concepts, strive to be explicit about them to other group members, and have their ideas inspected by the group. Students are able to "become aware of their own thinking and of the fact that other students possibly are thinking in different ways. By such means, the concept of the work begins to assume personal relevance and students are drawn inside the problem" (Driver & Scott, 1996, p.100).

Journal writing in science classes has been proposed as a way to motivate students to write about what they know concerning a certain science concept and then reflect on any changes in their knowledge as they progress through instruction on that concept. Fellows (1994) describes having students write an entry in their journals about what they know about a concept, another entry after instruction occurs and then reflection on any differences.

Hewson (1996) has recommended a way to use pencil-and-paper quizzes to educe students' preconceptions. The teacher might start the science topic by giving a noncredit quiz that students answer individually and which includes questions having a range of options that cover the common misconceptions held on the topic. After the quiz, the teacher identifies the range of answers given by students and asks them to explain their choices. This strategy allows the use of multiple-choice pretests that are easy to administer but allow assessment of students' understanding of the concept. Most objections to the use of traditional diagnostic tests come from the fact that higher levels of students' understanding are not easily assessed with these methods.

All the recommended strategies are valuable and have been shown by past research to identify students' preconceptions about science topics; however, most of these techniques are very difficult to implement in regular classroom settings. The question of this current research revolves around whether, and how, teachers diagnose students' preconceptions before teaching a specific concept on a regular basis in the classroom. The research questions that will drive this research are as follows:

1. If teachers do diagnose students' preconceptions, what are the strategies used?
2. If teachers do diagnose students' preconceptions, do they use the information they gather?
3. If teachers do not diagnose students' preconceptions in the classroom, what are the reasons for the lack of diagnosis?

Significance of the Study

To teach in a constructivist manner, teachers must identify their students' prior knowledge of the concepts to be taught. By building upon this preinstructional knowledge, teachers may be able to help students bring their preconceptions closer to the accepted scientific view. In this study, the diagnosis of students' preconceptions by their teachers in the classroom has been focused upon. The teachers' interpretations of "constructivist teaching" have been analyzed, as well as the beliefs the teachers held on the importance of the identification of students' preconceptions. The strategies teachers used to diagnose students' concepts before instruction were analyzed. This information is important for preservice teachers and other teachers striving to teach in a more constructivist manner. Many strategies derived from research situations have been recommended for use in the classroom but the manner in which teachers actually diagnose students' ideas in a secondary school classroom are of greater importance. The methods used to collect information on students' preconceptions seen in previous research are not methods that may be easily employed in a classroom situation. Teachers do not have the time or resources to interview students in an attempt to diagnose preconceptions. The reality of what teachers actually do in the classroom is of greater value than strategies derived from simulated, nonclassroom situations.

After many years of research on students' preconceptions in science, a catalog of common preconceptions has evolved. Rather than continue to identify more and more preconceptions, it is now essential that emphasis be placed on how these student preconceptions are uncovered in the daily classroom environment. Research studies in which the researcher interviews students and identifies yet another preconception need to be replaced by studies in which teachers' methods of identifying preconceptions in the classroom are the focus.

The ways that teachers use any information found when diagnosing students' preconceptions is also of interest to beginning teachers and those leaning toward more constructivist instruction. Research has shown (Smith, Blakeslee, & Anderson, 1993) that this information can be used to increase students' understanding of science concepts; how a teacher in a regular classroom environment utilizes the information gathered about students' preconceptions is of more practical value to teachers than research recommendations.

The conclusion that teachers were unable to regularly diagnose their students' preconceptions has significance because it allows the problems involved with diagnosis of students' preconceptions to be discussed. The reasons that teachers are not aware, or do not value the importance of students' preconceptions, were examined in this study. In itself, this lack of recognition of students' ideas holds significance since the reforms call for teachers who are aware of and value the significance of students' preinstructional concepts in science.

The results of this study have practical value for teachers who are involved in the diagnosis of students' views. This study will provide them with strategies that have been tried and tested by other teachers, it will also provide them with the justification they need for continuing to attempt diagnosis in the classroom. The importance of this research is that it provides a reasonable compromise between the strategies recommended in the literature and what can actually be done in the classroom.

The results of this study show that teachers do not regularly diagnose students' preconceptions in the classroom, therefore future research will need to be focused on this point. It will be important for research to be carried out to determine why teachers are unable or unwilling to do some type of diagnosis of students' preconceptions in their daily classroom activities.

This study has significance for future research on conceptual change strategies. All instructional strategies used by teachers to diagnose students' preconceptions and the ways in which the teachers use that information will be of importance to future research on conceptual change. No research has been seen that involved the study of teachers' strategies for attempting diagnosis of students' preconceptions. No research was found on how the theoretical steps of conceptual change actually translate into classroom use. Since no research of this kind is available, an attempt to provide research in the area of teachers' diagnosis of students' preconceptions has been made in the present study. This study provides data on the first step of conceptual change: teachers' identification of students' preconceptions.

Chapter II

Review of the Literature

Introduction

In this study, the diagnosis of students' ideas by their secondary science teachers was analyzed. The manner in which teachers used any diagnostic material in planning or teaching their lessons was also considered. The literature reviewed to support this study included studies on diagnosis of students' preconceptions, studies on how the knowledge students bring to their classrooms affects learning, and studies on strategies used to identify and change students' preconceptions. When reviewing this literature, the terminology chosen to describe preconceptions by the authors (misconceptions, alternative conceptions, or preconceptions) has been used in discussion of each study in order to adequately portray the authors' personal perspectives.

Identifying Students' Preconceptions

The cornerstone of the preconception research, according to Wandersee, Mintzes, and Novak (1994), is the assertion that learners come to their science classrooms with a diverse set of preconceptions concerning natural objects and events. Identification of these preconceptions by researchers has led them to believe that there are relatively few preconceptions on each distinct science topic, the common preconceptions secondary school students hold have been catalogued and described by Driver, Squires, Rushworth, and Wood-Robinson (1994) and Pfundt and Duit (1991). The studies reviewed here were carried out by researchers in order to identify students' preconceptions at specific grade levels or as they matured through a variety of grade levels. A number of different instruments were used to identify students' ideas on topics such as solubility, the nature of matter, heat and temperature, energy, and properties of gases. These studies are indicative of the research performed to catalog the common preconceptions held by secondary science students.

In order to document the concepts that secondary school students hold about the particulate nature of matter, Brooks, Briggs, and Driver (1984) analyzed students' written responses to six short-answer questions. The authors were also interested in the extent to which secondary students use, in a meaningful way, the ideas they have been taught in school. A small interview study was also carried out in which students were given questions in both a written and oral form.

The sample for this study was made up of 15 year-old students who took the national Assessment of Performance in Science (APU) survey in England. Students were selected at random to take the survey. Each of the six questions designed by the authors was included in approximately 700 APU test booklets; therefore, a different group of 700 students answered each of the six questions. From the 700 responses to each question, the authors chose a smaller sample of 300 answers for this study. The APU sample and the smaller sample (300) were compared in terms of ability, the groups were analyzed as to the percentages of students in each of six categories of ability which were dependent upon examinations the students were entered to take. One of the questions was also included in an APU survey given to 13 year-olds.

In order to analyze the results, the authors established four main categories in which the responses could be listed. These categories were: (a) responses including components of an accepted answer, (b) responses using alternative ideas about particles or applying particle ideas inappropriately, (c) responses entirely at the macroscopic level, and (d) uncodable responses.

Although the authors admitted that the type of response given by a student depended ultimately on the context of the question, they were able to make some generalizations due to the fact that they found a fairly consistent pattern of responses across the six different questions. After calculating the percentage of responses in each of the four categories for each question, they were able to say that more than half of the students did use particulate ideas in their answers. They found that less than one in five students applied taught ideas about the particulate theory accurately and less than one in 10 had a thorough understanding of the particulate theory of matter. The authors also concluded that one in three students used ideas that could not be included in an accepted response.

The common misconceptions that were seen in this study were discussed in detail by the authors. The percentages of each of the following misconceptions were listed for four out of the six questions. The main misconceptions observed were: (a) forces do exist between gas particles and do not exist between solid particles, (b) the characteristics of solids, liquids and gases were mixed up, (c) phenomena were explained in everyday terms, and (d) there was no consideration of the intrinsic motion of particles. On the average, one in four students gave only simplified macroscopic responses even when clued in the question that particles would be important in their responses.

The interviews were conducted to enrich the data compiled from the written tests. The authors recognized the fact that written tests may not adequately show the concepts held by students. The 35 students interviewed were 14-15 year-olds of all abilities from two comprehensive schools in Leeds, England. All of the students were given the written test prior to being interviewed, 27 written tests were administered two weeks before the interview, and eight were given immediately before the interview. The interviews lasted between 10 and 15 minutes; one researcher interviewed the student in the presence of a second researcher who asked any additional questions required after the initial interview. The interview questions were the same as the written questions; the students did not have access to their written responses during the interview. No mention was made of the validity of either the test or interview questions.

The fact that "over half" of the students proposed similar ideas on their written tests and in their interviews was interesting. The authors suggested that this similarity in the responses reflected an internalized framework rather than the first idea that came to a student's mind. Other findings from the comparison between written and oral tests were that the students answered written questions with greater confidence than their oral questions, these were tentative in comparison. Interviews seemed to give students a chance to reflect on their own ideas; therefore the interview data was more expansive.

The authors discussed the implications that their research may have on teaching in great detail. One of their main points was that students need to be introduced to models carefully, care should be taken to see that students are aware of "which features of the theory the model is representing, and which features to ignore" (p. 120). The terminology of particles can be confusing to students and consistency needs to be achieved. Also, the ideas that students bring with them to class need to be discussed and alternative theories should be tested out in the classroom.

Renstrom, Andersson, and Marton (1990) studied the conceptions of matter that are held by 13-16 year-olds. The authors felt that a detailed description of students' conceptions of matter was needed; to obtain this, they used a research approach termed phenomenography. Phenomenography "aims to reveal the qualitatively different ways in which people see, experience, conceptualize and understand various phenomena in the world around them.... These differing understandings that phenomenography seeks to reveal are seen as human-world relations; in other words, they are not psychological entities located in individuals but rather different ways in which the world appears to individuals. Thus an individual is not said to have a certain understanding of a phenomenon but rather is said to act and reason in accordance with one" (p. 556).

The authors stressed that in phenomenography, the categories of description are what make up the main results of the research. Therefore, their research was focused on identifying the categories that describe how students conceptualize matter.

Twenty students were randomly selected to participate in individual interviews; these were four students from grade 7, six from grade 8 and 10 from grade 9. The students participated in interviews at the end of the academic year, they had all had at least one year of chemistry. The interviews lasted for approximately 40 minutes and consisted of questions "specified in advance." The researchers also carried on a dialogue with the student being interviewed that varied from student to student. The materials used in the interviews were all everyday substances such as water, oil, air, oxygen, carbon dioxide, wood, aluminum, iron, and salt. The questions asked were divided into three problems, the first concerned the structure of the substance, the second concerned the division of the substance into smaller pieces and the third concerned the changes that occurred due to heating, cooling, and dissolving.

The interviews were transcribed word for word and then analyzed; the authors mentioned that "a nonalgorithmic, interpretative, 'discovery procedure'...resulted in a set of related categories of description" (p. 557). The reliability for the categorization of the students' interview statements was achieved by asking two "judges" to categorize 20 answers and the result was interrater agreement of 84.2%.

The analysis of the data resulted in a number of ways that the students thought about matter; the authors stressed that this was not a description of the students but a description of the variation in conceptions of matter. Six different categories were defined and described. Each of these was given an alphabetical label, A – F.

Conception A was the category in which matter was seen as a homogeneous substance, it was seen to be the same throughout the substance. There was no concept of matter being made up of anything smaller or having any type of internal structure. Students who held this conception thought that matter could come from nothing and could also disappear. These students did believe that changes could take place, they thought that different substances could exist within each other and pass through each other. A substance was seen as a combination of substances, therefore, as the combinations changed, so did the matter.

In the second category, conception B, matter was seen as specific units that had various parts such as a shell or peel and a nucleus. This concept was more particulate in nature than concept A but the parts were seen as concrete pieces of varying size. Students evidently believed that as the parts of the unit changed the substance itself changed.

Conception C was matter seen as a substance unit consisting of small atoms. The substance unit from conception B was thought to exist "studded with 'small atoms' or small particles of some kind, just like a cake with raisins in it" (p. 560). It is interesting to note that, unlike concepts A and B, this concept is not one that can be seen in the history of science, the authors attributed this to the education students have had about particles without totally understanding them.

In conception D, matter was thought to be made up of small particles that were infinitely divisible, either seen as homogeneous material to the matter or as "atomic" particles made up of something else. Students seemed to be focused on the idea that all things are made up of particles, particles were thought to be made up of more particles; even atoms consist of atoms.

Conception E was different from D in two aspects: a particle was not thought to be infinitely divisible and it held certain characteristics all its own. Students still thought of the particles as being made up of the substance; for example, they might have described water as being made up of water molecules and that the water molecules consisted of water. Students in this category had trouble conceiving or describing relationships among particles of a substance.

In conception F, matter was thought to be made up of particle systems and the relationship between particles was taken into account. The characteristics of the substance were not thought to be the characteristics of the particles. Students in this category had trouble conceiving the idea of space between particles, not one of the 20 participants was able to do so.

The authors stressed that the six categories described were not meant to be thought of as a hierarchy or as the way students develop in their understanding of matter, rather they were "categories of descriptions by which the distinctly different ways in which students conceptualize matter can be characterized" (p. 567). They also pointed out that the six conceptions are not five wrong and one right conception but different levels that each contained new insights for complete understanding of the accepted scientific view of matter.

There does seem to be some educational significance to describing the ways in which people conceptualize the world around them. The authors felt that examining the categories they identified would allow them to form a "realistic picture of the extent to which science teaching actually succeeds in developing the students' understanding of the phenomena being taught" (p. 567). They also felt that by looking at the different conceptions they could get an idea of the sources of the misconceptions.

Textbooks are often a source of misconceptions, according to the authors. Many of the models used to depict atoms and molecules both in texts and by teachers can be misleading to students. To portray atoms as hard, solid spheres with a nucleus and shells, usually separated from other atoms by sticks or springs could lead to misconceptions similar to those seen in this study. The authors suggested that a clear distinction needs to be made between models and reality and that teachers should spend time stressing and explaining the concept of models and what each model represents.

In a study designed to examine the knowledge students have about the key ideas incorporated in Boyle's Law, de Berg (1992) studied the understanding that students have about the pressure of a gas, the volume of a gas, a fixed amount of a gas, a fixed temperature of a gas, and any relationships among these concepts.

The participants involved in this study were 101 students, age 17 to 18 years, from two colleges in the Leeds district of Yorkshire, England. They were all enrolled in a variety of sixth-form courses (similar to high school senior courses) at the A, O and CPVE (pre-vocational education) levels.

The participants were given a demonstration by their classroom teacher and they were asked to make observations, the teacher then discussed the observations with the whole class and the students were given a form on which to record their explanations of the demonstration observed.

The demonstration consisted of an open burette containing colored liquid; the liquid flowed out of the burette until the teacher put a rubber stopper in the top of the burette. The liquid flow stopped even though the burette tap was still open. Students were asked to think about the situation and then write their explanation of why the liquid stopped flowing when the stopper was inserted.

The students' responses were analyzed by the researcher. By identifying the main focus of the explanation used by each student, the researcher was able to devise three categories of explanations. A few (11) of the explanations fell into two of the three categories but most of the students' explanations clearly fit into one of the three focus categories. Only one student provided an explanation that approximated the scientific explanation of the demonstration: the colored water stopped flowing because the stopper caused an equilibrium between the pressure acting on the tip of the burette and the atmospheric pressure.

The three focus categories of students' explanations encompassed the misconceptions that occurred about this demonstration. Category A was described by the author as the concept that enclosed air has different properties from open air. Seventy-four percent (93) of the participants used some variation of this concept, their main explanation involved the idea that enclosed air exerted no pressure on the liquid and that the enclosed space (full of air) in the burette acted as a vacuum. The author found that many students thought of a vacuum as something that sucks or holds back rather than the absence of air. This misunderstanding is a good example of terminology causing confusion and misconceptions in students.

The author conducted a chi-square test using the three enrollment categories, A-level, O-level and CPVE, and found no significance at the 0.05 level in the percentage of students that used a category A explanation. Even though a larger percentage of A-level students were studying chemistry or physics at the time of the study, they still had misconceptions that fit into category A.

Category B was described as the idea that the action of placing the rubber stopper in the burette caused the water to stop flowing. A number of the students thought of pressure as something that holds back rather than exerts a force: "Inserting the bung pressurizes the tube and stops the liquid flowing." The 12 students that used this explanation were distributed across the three enrollment categories.

Out of the 101 participants, 17 students used explanations that fit into category C. This category encompassed concepts dealing with pressure differences and balances. These students were also distributed across the three enrollment categories. Two of the misconceptions provided by the author to illustrate this category were: "pressure on the outside is greater than the pressure on the inside" and "the liquid stopped because the pressure sucking the liquid back equals the gravitational force on the liquid" (p. 302).

The author concluded that the misconceptions categorized were held by students in all the enrollment categories and very few of the students held conceptions that were near the accepted scientific view.

Griffiths and Preston (1992) were concerned with the misconceptions that high school students hold about the nature of atoms and molecules. They were interested in identifying the concepts that are misunderstood and thereby limit student understanding of other relevant topics in chemistry. The authors also looked at how the misconceptions differed among students of various academic abilities and science class enrollment.

This study took place in Newfoundland, Canada and the sample consisted of 30 grade-12 students from 10 high schools selected by stratified random sampling. To analyze a cross section of ability and science class enrollment, there were three subgroups of students set up: Academic-science (academic average of greater than 75% and enrollment in at least three science courses), Academic-nonscience (academic average of greater than 75% and enrollment in less than three science classes), and Nonacademic-nonscience (academic average of less than 75% and enrollment in less than three science classes). Each subgroup consisted of 10 students.

A pilot study was carried out on six students using a "partially structured" interview guide. This pilot study allowed the researchers to develop an interview guide consisting of two groups of questions, one relating to characteristics of molecules and the other to characteristics of atoms.

The interviews, lasting about 30 minutes, were conducted during school hours and were tape-recorded and later transcribed. The authors noted specifically that students were asked to respond both verbally and with diagrams, questions about molecules and atoms were separated to avoid confusion, and a balance of simple and difficult questions were included to both maintain students' confidence and probe their conceptions.

Both reliability and internal and external validity were discussed by the authors in more detail than is found in most similar studies. By having one of the researchers conduct the semistructured interviews and consistently receive guidance and feedback from the other author, consistency of administration was addressed. Repeat questions were included in the interviews and consistency of the students' responses was observed to be over 90%. The authors stated that their research design had internal validity due to the refinement of the interview questions during pilot studies using feedback from several independent science educators. The authors stated that "external validity was controlled by stratified random sampling from a group of students representative of the target population" (p. 615). No other information on validity was provided.

The interview transcriptions were analyzed in a three-phase process. In the first phase, the authors inventoried the concepts held by each of the students, the misconceptions identified were then placed into categories that had been predetermined by the authors. The second phase involved finding the most common misconceptions according to the three categories of students (academic-science, etc.). Then in the final phase, the authors conducted a summary of the misconceptions found to occur in the areas of molecular and atomic characteristics.

The structure of molecules was the topic of the first six questions in the interview. Subjects were asked to draw what a molecule of water would look like if they could look at it under an extremely powerful microscope. About one quarter of the students thought that a water molecule was a closed figure with no definite shape. Other misconceptions that were observed were that molecules are spherical with particles spread throughout and that molecules are composed of one or two solid spheres. This latter misconception was seen primarily in the academic-science group of students which led the authors to speculate that this concept may originate from some part of the students' science instruction.

The composition of molecules questions were formulated to elicit students' concepts about the type and number of atoms in a molecule and how composition might change with change in state. Forty percent of the students thought that a water molecule was made up of components other than oxygen and hydrogen, they thought that water, chlorine, nitrogen or minerals made up water molecules. Other misconceptions were that water molecules are not all made up of the same atoms and that they contain more than three atoms, "responses such as '...hundreds of thousands of atoms' and '...you would find millions of atoms in a molecule,' were not unusual" (p. 618). The authors noted that the academic-science students had relatively few misconceptions about molecular composition, the other two student groups "showed substantial misunderstanding of the composition of molecules" (p. 618).

The size-of-water-molecules category showed misconceptions such as a water molecule being as big as a germ, a speck of dust, the point of a pencil, or a "dot." Students thought that the size of a molecule would change as the state of matter changed, that water molecules in the solid phase are larger and those in a gaseous state are the smallest. The only explanation that students were able to propose for this size variation was that temperature affects the size of molecules.

Student misconceptions about the shape of molecules were that molecules are flat, they have differing shapes dependent upon the state, that both temperature and the shape of the container affect a molecule's shape and that pressure may affect the shape of a molecule.

The weight of a molecule was difficult for students to describe, typical responses included: "a molecule weighs about as much as a fly's leg," "light as a piece of dust," and "light as a feather" (p. 620). Students also thought that weight was dependent upon the state of the matter. Of all the interview questions, those from the weight category seemed to push students the farthest away from what they already knew, very few people have ever tried to compare the weight of a molecule to something of their choice.

In the bonding of molecules category, the most common misconceptions were that molecules exist in water touching each other with no space in between them, that there is no pattern or arrangement in the molecules of ice and that some external force holds the molecules together. Molecular energy questions uncovered misconceptions that molecules in all phases move at the same speed, that size determines speed, and that available space to move determines the speed of a molecule.

The students were also asked to pretend they could look through a powerful microscope and see an atom and then to sketch what they might see. Some of the misconceptions were that an atom is a solid sphere, that an atom is a sphere with components floating around inside, or that an atom is made up of randomly distributed dots or circles. The authors noted that these misconceptions were seen equally in all three of the student categories. Most of the students did indicate that there were smaller components inside an atom but none of them suggested anything other than electrons, neutrons or protons. Students had trouble conceiving what existed between atoms, many thought that matter, air, gases or electrical charges were what surrounded an atom.

Questions about the size of an atom uncovered fewer misconceptions than questions about the size of a molecule. Some students did believe that atoms could be seen under a microscope (possibly due to the interview question), that atoms were larger than molecules, that all atoms were the same size, and that heat and collisions could change the size of an atom.

Most students said that atoms of differing elements had different weights, the single misconception seen in this category was from a few students (7) who thought all atoms weigh the same. More than one half of the students interviewed thought that atoms were alive or that just organic atoms were alive. When students were asked to explain why they thought atoms were alive, the majority responded that because molecules could move, they were alive.

The authors did conclude, after applying a chi-square with a Yates correction, that there were no significant differences in the misconceptions held by the students in the three categories ($p=0.05$).

In an interview study, Novick and Nussbaum (1978) assessed pupils' conceptions of the particulate nature of matter. These interviews were described as the probing, Piaget-type of interview, the topics covered were confined to gaseous characteristics and phenomena. The five concepts that were analyzed in this study were: (a) a gas is composed of invisible particles; (b) gas particles are evenly scattered in an enclosed space; (c) there is empty space between particles; (d) particles are in motion from internal forces; and (e) two different substances interact to form a third.

The sample for the study was chosen from the eighth grade classes of nine urban schools in Israel. The interviewers randomly chose three high-ability, four middle-ability and three low-ability students from each class. It was mentioned by the authors that all the students chosen for the interviews had had instruction in the particulate nature of matter in their seventh grade science.

The interview's structured questions were revised and finalized during a pilot study with 20 eighth grade students from two separate classes. The structured part of the interview included three phenomena and eight tasks

In the first demonstration, the students were shown a one-liter flask containing air and a hand vacuum pump, the pump was connected to the flask and the air was evacuated. Students were then asked to draw what the air inside the flask looked like both before and after pumping. Then they were shown pictures other students had drawn and were asked to pick the best picture. When shown pictures of a particulate model of air in the flask, students were asked what was between the particles and why they did not fall to the bottom of the flask.

The second demonstration involved two flasks of colorless liquids, concentrated ammonia and concentrated hydrochloric acid. Each was opened separately and tested with indicator paper, one strip turned blue and the other turned red. The students were asked to explain the color changes in the indicator paper and also how the substance rose from the liquid to the paper.

The third demonstration again involved two flasks of colorless liquids. Two drops of each liquid were placed on cotton plugs inserted in small corks, the corks were then placed simultaneously into each end of a 30 cm glass tube. After a minute or two, a white smoke ring appeared in the tube, closer to one end than the other. The smoke ring was composed of ammonium chloride from the two gases, ammonia and hydrogen chloride. Students were asked what the white smoke ring was composed of and how it was formed, then they were asked to make a sketch. They were also asked why the smoke ring did not appear in the middle of the glass tube.

The responses to the interview questions were categorized according to the five aspects of the particulate model of gases that were discussed above. The authors found that, according to their data, 60% of the students consistently used a particulate model of matter to explain the observed phenomena. Twenty-one percent used a continuous model throughout their explanations and the remainder of the students either changed from one model to the other as the interview progressed or held neither model to be true.

For the concept of gas particles being evenly scattered in any enclosed space, the authors found that 30% of the sample failed to describe this characteristic of gases in their interviews. Apparently, even when this group was shown a correct picture of the space filling model, two-thirds of them persisted in their misconceptions of gases being non-space filling.

Of the students that held the concept of a particulate nature of matter, 46% clearly described that empty space exists between the particles, 16% were doubtful and apparently the rest were totally unconvinced. These students gave a variety of explanations as to what they thought was between the particles: "Dust and other particles," "Other gases such as oxygen and nitrogen," "Air, dirt and germs," and "Maybe a liquid."

The students were asked about the motion of gas molecules and 54% in one task (task 4) and 52% in another (task 6), thought that this motion was internal motion, 26% thought it was from other internal forces and the rest of the responses fell into the categories of external motion or no response. The authors were unclear about the number of students who answered the interview questions on this topic, task 4 had n=99 and task 6 had n=85.

When students were asked to use the concept of chemical combination to answer the last task involving the white smoke formed from the two gases in the tube, 55% of the particulate students answered that it was a compound compared to 18% of the continuous students. The authors had apparently divided the sample into "particulate" and "continuous" students.

From this study, the authors concluded that a significant portion of the sample had failed to internalize important aspects of the particulate model. They suggested that curricula often are structured logically and do not take into account the psychological structure of the learner. This psychological structure involves changing from an intuitive model of matter (matter is continuous) to a more abstract model (matter is particulate). The authors suggested that the particulate model might even contradict a student's sensory perception of matter.

Novick and Nussbaum felt that misconceptions may have occurred when students were asked to move from the intuitive, continuous model to the abstract, particulate model of matter. "The aspects of the particle model least assimilated by pupils in this study are those most in dissonance with their sensory perception of nature. These aspects are empty space (the vacuum concept), intrinsic motion (particle kinetics), and interaction between particles (chemical change). It appears then that this dissonance between the continuous and particle pictures may have resulted in the assimilation of a distorted particle model by many pupils" (p. 280).

Novick and Nussbaum (1981) wondered if students' conceptions of matter change as they are exposed to additional information in progressively higher grades. The authors confined their study to five specific aspects of the particulate model of matter in order to trace how conceptions changed in pupils as they progressed through school. The sample was comprised of 83 elementary students, 339 junior high students, 88 high school students, and 66 university sophomore non-science majors.

The students were given a paper and pencil test developed by the authors: Test About Particles in a Gas (TAP). The test required participants to complete nine items each involving a phenomenon or experiment. The test was made up of drawings, completions, short explanations and multiple choice questions. The test was administered by either the primary researcher or the classroom teacher; all students had as much time as they needed for completion.

The authors suggested that the TAP test had construct validity due to the fact that the test questions were taken from an interview study conducted in Israel. Apparently, free responses by American youth on the TAP test were similar to responses given by Israeli students in the interviews.

The students' drawings and explanations for the questions on the TAP test were analyzed separately by the two authors; they developed a scheme of categories to use in describing the students' responses. These categories were five main conceptions that the authors encountered in the responses.

The first of the five concepts analyzed was the concept: gas particles are uniformly distributed in a closed system. As would be expected, there was an increase in the percentage of students who favored a uniform particle distribution as the grade level increased. The authors reported that "most" students at or above junior high level have a mental picture of gases being uniformly distributed in a container even after air was removed from the container. Thirty percent of junior high students and 10% of the senior high students had misconceptions about this concept. The two most common misconceptions involved drawing the gas particles concentrated at the bottom of the flask when some of the gas was evacuated or drawing the particles concentrated at the opening of the flask when evacuation occurred.

The second concept discussed was that of particles in constant motion. Tasks on the TAP test probed students' understanding of the idea that inherent particle motion was the cause of uniform particle distribution in a gas. According to the authors, the low percentage of correct responses to the tasks showed that students continued to hold the view that gas particles were static even after they had been taught the kinetic gas model in school.

Students were provided with two tasks on the TAP test to probe their knowledge of the third concept: heating and cooling cause changes in particle motion. When asked to explain how heating and cooling affected gas particles, most students (40- 50%) described the processes as particles expanding or being forced apart, rather than mentioning actual particle motion. The authors suggested that high school students may attribute the volume decrease of a gas when cooled to increased attractive forces rather than to decreased molecular motion.

The fourth concept the students were asked to describe using a drawing was liquefaction as a change in particle density. Beginning with junior high students, 70% of the participants described liquefaction as particles coming together at the bottom or sides of the container.

The final concept was the existence of empty space between particles in a gas. Over 60% of the students above junior high level did not picture empty space between gas particles and most believed that particles are not separated from each other. The authors concluded that there was a "persistent and widespread preconception of matter as essentially a continuous medium."

The authors made two summary statements regarding their study. They stated that the study's results supported previous findings that students "internalize" aspects of scientific models differently. They also stated that this cross-age comparison of students brings forth concepts that are difficult and often not grasped by students even at the college level.

Looking at what mental images children aged 9-15 hold about matter and its properties, Stavy (1990) carried out individual interviews involving two tasks. The sample for this study consisted of six age groups, fourth through ninth grade, with 20 students in each group.

The interviews involved questioning the students about two demonstrations and the materials involved. The first demonstration involved two identical test tubes containing one drop of acetone. One of the test tubes was heated until the acetone completely evaporated. The student was asked about the conservation of matter, the conservation of the properties of matter (smell), the conservation of weight and the reversibility of the process. The second task involved two identical test tubes, this time containing one small crystal of iodine. One of the test tubes was heated until the test tube was filled with a purple gas. As in the first task, the questions asked were about the conservation of matter, the conservation of properties of matter (color), the conservation of weight, and the reversibility of the process.

To report the results, the author calculated the percentage of children in each age group who had "succeeded in each of the tasks." The author then divided the students into four principle groups according to the patterns seen in the responses. In the acetone evaporation task, a pattern seen in the younger students was a belief that if matter is invisible it does not exist and its weight and properties disappear when it disappears. This pattern was evident in 30% of fourth graders and declined to zero in eighth graders. Another pattern was seen in the belief that when acetone disappears, its weight also disappears but the smell is left behind. This pattern was seen in 45% of fourth graders and declined to zero in the seventh grade. The third group identified by the author was made up of the students who perceived that matter and its properties were conserved but did not see that weight was conserved. This pattern occurred in 15% of the fourth graders, 40% of the seventh graders and 20% of the ninth graders. The members of the last group were those students who believed in both conservation of weight and properties and therefore, according to the author, also were able to answer the question on reversibility correctly.

The second demonstration, involving iodine sublimation, differed from the acetone demonstration in that the evidence of matter (colored gas) was still present after heating. The author again slotted the students' answers into four pattern groups which were apparently defined after the responses were analyzed. The first group was comprised of the students who did not identify conservation of matter in the iodine sublimation. This group was small in comparison to the similar group in the acetone demonstration. The second group was for those students who believed the property of matter (smell) could exist independently from the material. Unlike the acetone answers, there were no answers that fit this pattern. The third pattern was comprised of the answers of students who believed in the conservation of matter but not of its weight. The last pattern group was made up of those students who believed in both conservation of matter and weight. A graph was included detailing the percentage of correct answers in each of the four patterns over age group. Correct answers in all four patterns increased with age as would be expected.

The author's conclusions were that in the conception of matter, students grasp matter as a concrete, solid object made up of a material core with nonmaterial properties such as smell and color and that matter only exists when there is evidence of its existence. Weight is not seen as an intrinsic property of matter so weight may be seen to change with the state of matter. She also concluded that 15% of the eighth and ninth graders start to view matter from a particulate perspective. The author suggested that the reason the number of students using a particulate view is so low may be due to the lack of understanding of conservation of matter seen in all ages.

The purpose of Osborne and Cosgrove's (1983) research was to investigate the variety of conceptions that children hold about what is happening when water boils, condenses, and evaporates and when ice melts.

The sample consisted of 43 students ranging in age from 8 - 17, these participants were chosen by the teachers of a range of classrooms on the basis of the students being average to slightly above average in scholastic ability. The 8-15 year-olds were studying integrated science and the 16-17 year-olds were studying one or more of the subjects chemistry, physics or biology.

The students were given an interview of about 30 minutes during which the researcher demonstrated a series of events involving water boiling, condensing, evaporating and ice melting. These events were shown using everyday kitchen equipment. The students were asked to describe each event centering on what was happening and then what had happened. For example, when steam from a kettle condensed on a plate held above it, the questions asked were: What is the steam made of? What is on the saucer?

A follow-up study was conducted to identify the prevalence of certain views that were seen in the interviews. Surveys were sent to a random selection of seven schools in which a representative sample of 12-14 year-olds studying integrated science, 15 year-olds studying general science, and 16-17 year-olds studying chemistry was selected to be given the survey. The survey sample size was 725 students. This "representative sample" was assumed to consist of ranges of ability as was the interview sample.

The number of students in each age group holding a specific view on a concept was tallied and listed after a description of that view. The total percentage of students that chose that view on a multiple-choice question on the survey was also tallied and then graphed.

The first concept to be discussed was that of boiling. Younger children tended to describe what was happening in great detail compared to the older students. The authors conjectured that older students might consider these types of detailed observations too trivial to mention. The various answers to the question

"What are the bubbles made of?" gave an idea of the students' alternative conceptions about boiling water. The four views that the authors discussed were: the bubbles are made of heat, the bubbles are made of air, the bubbles are oxygen and hydrogen, and the bubbles consist of steam. The most common view in younger children was that the bubbles were either made from air or heat; the older students viewed the bubbles as either oxygen and hydrogen or steam. It was important to remember that these senior level students were all enrolled in a science class and could possibly have more advanced views than students of the same age not enrolled in science courses.

The authors next looked at students' views about steam and condensation from steam. Most students could identify steam but had trouble describing what it actually was, some thought it air and some thought it water. When steam was shown to condense on a saucer above the kettle, most younger students could only say that the plate was "sweating" or the steam had changed back to water but not the same water as was in the kettle. Older students thought that the hydrogen and oxygen in the steam recombined to form water. Seven students out of the 43 interviewed mentioned water molecules cooling and moving closer together as the reason for condensation.

Students' views about evaporation were elicited in the interview procedure. When asked what had happened to water on a wet plate as it dried, younger students said it had gone, left or dried up, or changed into air but could not explain why. Older students again seemed to be obsessed with the need to bring oxygen and hydrogen into the discussion; they often mentioned that the water split into oxygen and hydrogen atoms as it dried up. A survey question was given on this topic and the graph of the students' answers showed that the younger students surveyed believed that the water went either into the plate, into the air or into oxygen and hydrogen. Older students still tended to believe in the oxygen and hydrogen explanation but a higher number than in the interview said the water was still water but in "smaller bits" suspended in the air.

Students being interviewed were asked about what was occurring when water condensed on the side of a jar of ice water. The four views that predominated were again made into a multiple-choice question for the survey. The four common views held by students were: the water comes through the glass, the coldness has gone through the glass and produced water, the cold surface and the oxygen and hydrogen in the air react to form water, and the water in the air sticks to the glass. It was interesting that 60-70% of the students aged 12 to 15 seemed to believe in the oxygen and hydrogen explanation while very few, 20-25%, believed in the explanation that the water came from the air. Older students, presumably after having a chemistry course, started to believe in the water from air idea and disregarded the oxygen and hydrogen explanation.

The final concept described was that of ice melting. Most students could only say that the ice was melting and changing into water. A few students, seven out of the 43, said the ice was above melting temperature and eight said that heat made the particles move farther apart.

Osborne and Cosgrove generalized four findings from this study. Students are often able to associate the correct scientific term with its phenomenon even though they have but superficial knowledge of what is occurring. Older students often hold nonscientific views about phenomenon and then support the views with scientific ideas. Some nonscientific views are seen more in older students than in younger, for example, the use of the oxygen and hydrogen explanations in evaporation and condensation. Models are often too abstract to apply to everyday occurrences.

Benson, Wittrock, and Baur (1993) identified preconceptions that students at varying ages hold about the nature of gases. They were not trying to analyze the changes in conceptions that may occur due to instruction but were most interested in what preconceptions the students took into the classroom.

Four groups of students were tested in this study. From a number of private college-prep schools that emphasized science and math, 103 students in grades 2-4, 197 students in grades 6-8 and 191 high school biology, chemistry and physics students were tested. Six hundred and seven university chemistry students from a major state university were also tested. The testing procedure involved a demonstration (for all but the university students) of two airtight flasks, both open to the air and then closed. One of the flasks was left "full" of air while the other had "about half" of its air removed using a syringe. This demonstration was only described and not demonstrated to the university students. The students were then given a paper with outlines of the two flasks and asked to draw the air particles as if they were wearing "magic magnifying spectacles". The students were specifically asked to draw their mental images and to be sure to show the “partial vacuum” in the second flask.

The students’ drawings were classified as either particulate or continuous. This classification was dependent upon whether the representation of air was with discrete dots, circles or other objects, or if the air was drawn as a continuous fluid. Five percent of the drawings did not fit into either of these categories. The 95% that were able to be classified as particulate or continuous were then subdivided into either "concentrated distribution" or "expanded distribution" (air filling part of the flask or air filling the whole flask).

The researchers then looked at the frequencies in percentages of the various categories and subcategories at each grade level of student. Two of the important trends that were seen in these results were that the proportion of the top vacuum drawings decreased from 83% in grades 2-4 to 3% in university students. In the same grade span, the particulate, expanded drawings increased from 1% to 64%.

A chi-square analysis showed a significant difference between misconception and grade level (X^2: 804.69; df: 84; $p = 0.0001$). This may simply be what would be expected from increased education in the higher grades. The authors were careful to state that this significance does not justify a generalization to any other student population.

Analyzing the trends seen in the drawings, the authors concluded that younger students do not accept the idea that gases expand to fill their containers as readily as older students. The authors also suggested that the young students might believe that air behaves as a liquid does when in a container, they have observed liquids daily but not gases.

The results of this study show that 33% of the university students tested carry an idea that gas particles are tightly packed. These results led the authors, as it has others, to the idea that many people have difficulties conceiving empty space between particles.

In an attempt to identify misconceptions about phase changes from liquid to gas, Bar and Travis (1991) analyzed how students ranging in age from 6-14 explained everyday phenomena. The authors were also interested in establishing the sources of any misconceptions identified.

The research was carried out in three distinct stages or phases. The first phase involved a group of 83 elementary students from a middle-class school in Jerusalem, they ranged in age from 6-12 years. These students were given an open-ended, individual oral test that involved demonstrations by the interviewer. The test was carried out as a dialogue with the student; through questioning and probing, the students' conceptions about boiling and evaporation were collected. The authors wanted to find out if the students' views on boiling were different from those on evaporation.

During the second phase of research, the researchers utilized a multiple-choice test consisting of nine questions. The sample in this phase consisted of 132 students ranging in age from 10-14 years. The description of the multiple-choice test was brief; it was stated that the diversions for the nine problems came from the students' views of boiling and evaporation recorded in the first phase of the study. The nine questions all fit into one of the following concepts: (a) evaporation, (b) boiling, (c) condensation, and (d) the permanent existence of vapor in the air. No description or example of the type of multiple-choice questions used was provided in this article, neither reliability nor validity was mentioned for this test.

The third phase of this research study was comprised of three "open-ended," written questions that were presented to two groups of students. The subjects were between 11 and 15 years old and were of the same background as the students in the first two phases. The two groups that these students were divided into had 134 students in one and 132 in the other. The only difference in the testing of these two groups was that the first group was exposed to the “floor” problem, and the second group was exposed to the “saucer” and “laundry” problems.

In justification of using the three phases in this research study, the authors stated that, "The need to use all these methods derived from the fact that different test methods may lead to a different distribution of the results" (p. 367). The authors evidently wanted to find out if the differences in student responses on an oral test and a multiple-choice test are caused solely by the differences in the tests themselves. "The open written test (Phase III) was added in order to see (a) whether the different results recorded in the oral and in the multichoice test are due solely to the differences between closed (multichoice) and open tests; (b) whether they may be attributed to differences between oral and written tests; or (c) whether they are affected by the context or the age range" (p. 369).

The results and discussion section of this article detailed responses seen in each of the topics, evaporation, boiling, matter in bubbles, and condensation. Observations in each of these categories, revealed that the students had a number of misconceptions in the younger ages and that the more mature students expressed or chose the correct answers. The authors also analyzed the effect of the type of test upon the students' responses and they claimed that the type of test did affect the results: "The effect of the format of testing on the distribution of the results is again manifested.... This is attributed to the fact that many participants chose wrong answers from those suggested to them as diversions in the multichoice test" (p. 372).

The authors were interested in looking at the development of the conceptions that students hold about phase changes from liquid to gas and gas to liquid. They found that views about evaporation and the nature of the matter in boiling bubbles change with age as students are able to conceive the existence of air. Older students had more knowledge about water and its ability to evaporate, about evaporation and about the matter inside bubbles in boiling water. Younger students tended to provide concrete explanations of phenomena (for evaporation: "the water changed into air and disappeared") while older students gave more abstract answers such as "the water changed its form and scattered in the air."

Students were able to master the more concrete concept of boiling before mastering the more abstract concepts of evaporation, according to the authors, because the change from liquid to gas can be seen and heard, the source of energy is directly observable, and the whole process is relatively quick. After students understand that water can change into vapor, according to Bar and Travis (1991), they are then able to understand the processes of evaporation and condensation. Since a greater level of abstraction is necessary to understand these processes, children may take longer to understand them.

The authors found that students tended to choose a wrong answer on the multiple-choice test if that answer had a more "scientific" sound to it. For example, 5% of the students chose the answer "hydrogen and oxygen" to explain the matter inside boiling bubbles on the multiple choice test whereas no student gave that answer in the oral interview test.

Students who held the concept that energy is a form of matter seemed to show a number of misconceptions about the phenomena of boiling, evaporation, and condensation. They thought that heat could fill the bubbles and that coldness could change into water.

One conclusion that the authors made from this study was that science teachers need to be aware that students often only understand scientific terms superficially. Students may be able to answer questions using the correct terminology but when asked for an explanation, they may show misconceptions and misunderstandings. Another conclusion and recommendation for science teachers was that misconceptions may be persistent even when instruction has occurred. The authors stated that this persistence may be due to the fact that students rarely use the abstract models they have been taught when explaining everyday phenomena such as were discussed in this study.

The purpose of Abraham, Williamson, & Westbrook's (1994) study was to investigate the influence of grade level and reasoning ability on the understanding of five selected chemistry concepts. Two other research goals were also listed: to trace from junior high through college the number and type of misconceptions held by students and to trace the use of molecular and atomic explanations through the same levels of students.

The sample of the study was 100 junior high physical science students, 100 high school chemistry students and 100 college, first semester, general chemistry students.

Prior to testing these students, five broad chemistry concepts were identified for the focus of the study: chemical change, dissolution of a solid, conservation of atoms, periodicity and phase change. The five teachers of the three groups of students were asked to review these concepts prior to the testing. All teachers confirmed that the material had been covered either by student reading in the text, teacher lecture or a combination of classroom activities. The five concepts were also presented in terms of atomic and molecular models in the texts available to the students.

Two tests were used to measure reasoning ability: "Mr. Tall," a modified Karplus ratio task and "The Letters Task," a measure of combinatorial logic. Neither the validity nor the reliability for these two tests was discussed. The frequency and percentage of each of four levels (Concrete, Transitional, Early formal and Fully formal) were calculated for reasoning ability.

One test item was given for each of the chemical concepts to measure concept understanding. The answers to these items were then scored according to a rather general rubric which awarded a numerical value of 4 and "sound understanding" to an answer that contained "all parts of the scientifically accepted concept" and a value of 1 and "specific misconception" to a "scientifically incorrect response." The values of O, 2 and 3 with their corresponding labels were also employed. The authors had designed this test to compare students' concepts with scientifically accepted concepts.

The frequency of the use of the terms "atom" and "molecule" was recorded and misconceptions were analyzed for their type and frequency.

A two-way analysis of variance (ANOVA) was done for each chemical concept (1-5) and the total mean concept score in order to look at the effect of grade, reasoning ability and the interaction of grade and reasoning ability. No significant interaction effects were observed though some cases had significance at the alpha=.05 level. The findings showed that there was an increase in conceptual understanding with grade level (p=.0001). Students' spontaneous usage of the terms "atom" and "molecule" was very low (2% - 13%) in junior high and increased (6% - 46%) in college students.

The chemical concepts were analyzed individually for the frequency of specific misconceptions; those seen most often in this group were discussed. For example, misconceptions concerning chemical change were held by 73.3% of the students, 28% had misconceptions regarding dissolution, 32% had misconceptions about conservation of atoms while 32.7% had no understanding of that concept. In the concept of periodicity, 8.7% had misconceptions but 68.7% had no understanding and in phase change, 40.3% had misconceptions while 47.7% showed no understanding. Each of these misconceptions was described in detail and the percentages of students holding partial and sound understanding were listed.

The authors of this study discussed three main conclusions. They asserted that reasoning ability and experience with concepts account for understanding and that the limited reasoning ability in younger students should affect the curricular materials they are given. Another conclusion from this study was that students at all levels tend not to use atomic and molecular explanations. The authors believe that this lack of explanation is an essential problem in teaching chemistry and that students should be encouraged to link concrete experiences with abstract models. The researchers saw no pattern in the frequency of misconceptions relative to experience with the concept. Misconceptions were seen to increase with grade level, decrease or even stay the same. The authors concluded with the idea that instead of being concerned with what these misconceptions are, it is important to be concerned with their resistance to change.

The research reviewed supports the conclusion that students hold preconceptions about their physical world. These studies have shown that there are certain common preconceptions that students hold about such topics as the particulate nature of matter, phase changes, solubility, heat and temperature, energy, and the nature of gases. These preconceptions have been described and categorized in these studies. The majority of studies reviewed show that most students do hold preconceptions about their physical world that are not in line with the accepted scientific beliefs.

The research done by de Berg (1992) and Griffiths and Preston (1992) maintains that the academic level of the student has little effect on the number or type of preconceptions that are seen. All students in these studies, regardless of their level, held preconceptions that were unlike the accepted scientific concepts.

An important conclusion made by Bar and Travis (1991) and Osborne and Cosgrove (1983) was that students may use the "correct" scientific terminology when describing events but have little idea of the meaning behind their terms. Students may learn the words and know when to use them but may still have little understanding of the actual concept. As students mature, they tend to use scientific terms more readily but still may have little understanding of the concepts.

The method used to identify the preconceptions in the research reviewed was predominantly interviews conducted by the researchers outside the regular classroom environment. It was concluded by Bar and Travis (1991) that interviews seem to allow better identification of students' preconceptions than multiple-choice tests. A few studies (Abraham, Williamson, & Westbrook, 1994; de Berg, 1992; Novick & Nussbaum, 1981) employed tests in the classroom to identify preconceptions. It was not clear whether the tests were administered by the researchers or the regular classroom teachers. Most of the studies that used paper and pencil tests were negligent about reporting on the validity of these tests. It can only be assumed that the authors did not assess the validity and failed to recognize the importance of its inclusion.

Identifying students' preconceptions has been done most often outside the classroom by researchers other than the teacher. Due to limited time, it would be an overwhelming task for a teacher to attempt to identify every student's detailed conceptions on a topic before beginning to teach that topic.

The implications inferred from this identification research are that most students do enter their classrooms with ideas very different from the accepted scientific concept of the physical world. If the goal of science teaching is to help students begin to understand their physical world and how it works, then teachers must start by analyzing the preconceptions students have in place before beginning instruction in order to develop instruction based on students' prior understanding.

The Effect of Prior Knowledge

That students enter the classroom with preconceptions concerning natural phenomena is undisputed. It is also recognized that these preconceptions may affect the students' consequent science learning. Students' prior knowledge provides an indication of the preconceptions as well as the scientific conceptions they may have. The research reviewed here is focused on the effect prior knowledge may have on science learning and achievement.

Osman and Hannafin (1994) examined the effects of high-level, concept-relevant orienting questions and differences in prior knowledge on learning, participation, and attitudes. The authors described how 107 tenth-grade students were divided into two prior knowledge groups (high and low) based on their science scores on the California Test of Basic Skills (CTBS). The students in the two prior knowledge groups were then randomly assigned to one of three treatment groups. The treatment groups established were basic lesson, basic lesson with embedded orienting questions, and basic lesson with embedded orienting questions plus rationale.

The basic lesson was a control comprised of two sessions of General Biology in which the topic of genetics and probability were presented in nine sections; neither questions nor rationale were provided. In the basic lesson with embedded orienting questions, students were presented with two to three orienting questions (focusing on everyday knowledge and conceptually related to forthcoming lesson material) before each of nine sections on genetic probability.

The questions were designed to activate students' concept-relevant prior knowledge and did not require concept-specific prior knowledge. The third treatment group involved presenting students with the same basic lesson with the orienting questions but with a rationale for their use. The rationales were designed to promote understanding of the value of the questions, make students more conscious of the questions, and to use them to relate forthcoming material to prior knowledge. The treatments took two 50-minute periods of the General Biology class; on the third day, students were given a posttest and attitude survey. The 33-item posttest was multiple choice and assessed both factual knowledge and problem solving. Content validity for the posttest was 0.93, reliability was 0.76. No mention was made of any observations of instruction.

The learning effects were analyzed using ANCOVA, the overall reading subtest score on the CTBS was the covariate to minimize the influence of reading differences. Means for significant effects were compared using Tukey's multiple comparison test with a minimum p of 0.05. A significant main effect was seen for lesson version, $F(1,201)=23.68$, $p< .001$. Students in the "questions only" group answered 56% of the posttest questions correctly, students in the questions plus rational group answered 61% correctly and those in the basic lesson treatment group answered an average of 46% correctly.

A main effect was also seen for differences in prior knowledge, $F(1,201)=20.898$, $p< .0001$. High prior knowledge participants answered an average of 59% of the posttest questions correctly and low prior knowledge participants answered 51% correctly.

Students' responses to the embedded questions in the two treatment groups were evaluated as either meaningful or nonmeaningful. If a student answered a question with a plausible (although not necessarily correct) answer or by using conceptually related information, their response was considered meaningful. A nonmeaningful response was one that was ambiguous, imprecise, irrelevant, a blank response or a statement of uncertainty. High prior knowledge participants answered more questions meaningfully than did low prior knowledge participants.

The authors found from the mean responses to the attitude questionnaire that students with low prior knowledge preferred the basic lesson format over the other two lesson types. The participants with higher prior knowledge scores rated the lessons with embedded questions and questions plus rationales as more useful and profitable than the basic lesson.

The conclusions made by the researchers were that by incorporating orienting activities into this specific lesson, students were able to activate prior knowledge, making associations with what they already knew. If their prior knowledge was high, they did better on a posttest than those students with lower prior knowledge.

Chandran, Treagust, and Tobin (1987) investigated the role of four cognitive factors in chemistry achievement. They looked at how formal reasoning ability, prior knowledge, field dependence/independence, and memory capacity affected students' achievement in chemistry. The students involved in this study were all enrolled in a grade 11 chemistry course, the number in the sample ranged from 276 to 359 students completing all the instruments, and the students were from eleven high schools in the Perth metropolitan area.

Measures of the four predictor variables were obtained when the students entered their grade 11 chemistry course at the beginning of the year. Formal reasoning ability was measured using the Test of Logical Thinking (TOLT), and prior knowledge was assessed using a multiple-choice test. The internal consistency reliability coefficient was 0.87 for the prior knowledge test and its test-retest reliability was 0.65. The field dependence/independence variable was assessed through the administration of the Hidden Figures Test, and memory capacity through the Figural Intersection Test. After 21 weeks of teaching, the students were assessed in three areas of chemistry achievement: laboratory application, chemical calculation, and chemistry content knowledge.

Product moment correlations were calculated measuring the relationship between the four predictor variables and the achievement variables. Multiple regression analyses were used to determine the amount of variance accounted for by the predictor variables and each of the three achievement variables. Standardized regression coefficients were used in a path analysis for each of the three dependent achievement variables and the four cognitive predictor variables.

The product moment correlations showed that formal reasoning ability was significantly related ($p<0.001$) to prior knowledge, field dependence/independence, and memory capacity, other correlations between the predictor variables were not significant at this level. Prior knowledge correlated significantly ($p<0.001$) with laboratory application, chemical calculation, and content knowledge as did formal reasoning ability. The remaining correlations were not statistically significant at this level. The results of the three multiple regression analyses indicated that formal reasoning ability and prior knowledge accounted for a statistically significant proportion of the variance in each of the three achievement variables when the variation in field dependence and memory capacity were conjointly considered.

The authors stated that a different test of prior knowledge could result in stronger coefficients but concluded that prior knowledge is a significant predictor of chemistry achievement. The implications discussed in this study are that teachers may need to engage students with low prior knowledge in individual tasks and small group work in chemistry classes so that these students have an equal opportunity in participation and achievement.

In a study by Trumper and Gorsky (1993), the relation between students' alternative frameworks on energy prior to instruction in physics and their cognitive level of operations was evaluated. Also, the relations between students' success or failure in learning about physics and their prior alternative frameworks, cognitive level and their tendencies towards open or closed mindedness were analyzed.

In the first part of the study, 60 ninth-grade students were given a written questionnaire about energy in order to determine their preconceptions on the subject. Students were asked to write their first three word associations with the term energy, write sentences linking their words with the term, choose the most appropriate definition or description of the term energy from five alternatives, and choose three out of eight pictures that showed the concept of energy most clearly. Content validity was determined by 17 experts in the fields of curriculum development, physics teaching and research in science education. The students were retested with the same questionnaire one month after the first administration and the chi-square coefficient between responses on the two occasions was calculated, no significant difference between students' two answers was seen. The cognitive levels for the students were determined using a videotaped group test which involved 12 tasks on control of variables and proportional, probabilistic, combinatorial, and correlational reasoning. Content validity was determined by a panel of science educators, internal validity was 0.82, and interjudge scoring procedure agreement was 91%. Using this test, the students were divided into two groups, preformal (concrete or transitional) and formal cognitive level.

For the two cognitive level groups, the responses to the energy preconceptions questionnaire were analyzed. The chi-square coefficients between the responses of the formal and preformal students were calculated and no significant differences found. Students at both cognitive levels had similar associations, chose similar pictures and definitions, and adhered to similar preconceptions.

In the second part of this study, 29 students (16 ninth-graders, 8 tenth-graders, and 5 eleventh-graders) were measured on their preconceptions about energy, cognitive level, open or closed mindedness, and their success or failure in learning the energy concept. The first two characteristics were measured using the instruments described above. The students' open mindedness was measured using a 20-item instrument requiring participants to rate their agreement or disagreement with short statements. This test was based on Rokeach's type E dogmatism scale, the reliability for this instrument was 0.71. A period of instruction occurred after the diagnostic tests, conceptual change strategies were employed to help students see energy in a "cause and product" framework. Success or failure in learning the energy concept was then determined using a posttest, students answering all 12 questions on the test correctly were considered successful.

The students were divided into two groups, those who acquired the concept of energy (success on the posttest) and those who did not (failure on the posttest). The mean scores of the two groups were compared using t tests. The two groups differed significantly in the mean scores measuring their cognitive level, they did not differ significantly in their tendency towards open or closed mindedness. The students, both at formal and preformal levels, who held the "cause and product" framework for energy prior to or during instruction seemed more successful in learning.

BouJaoude and Giuliano (1994) investigated the relationships among students' approaches to studying, prior knowledge, logical thinking, and their performance in a freshman nonmajors chemistry class. The subjects were 220 students enrolled in the second semester of a freshman nonmajors chemistry course. They were given a demographic questionnaire and seven of the 16 subscales from the Approaches to Studying Inventory during the first week of the course. The internal consistency reliability coefficients ranged from .56 to .75 for the subscales used in this study, no mention of validity was made. The students were also given the TOLT during the first and second weeks of the course. The TOLT has a reported internal consistency reliability coefficient of .84 and a value of .74 for this study, no validity was mentioned. Students' grades from the first hour long exam and the final exam for the course were used as a pretest and posttest respectively.

Pearson correlation coefficients between the final exam and pretest were significant. A multiple regression analysis showed that the pretest, TOLT and meaning orientation were all significant predictors of the final test score, accounting for approximately 32% of the variance on that score. The TOLT and meaning orientation scores were significant but small compared to the pretest score.

The authors concluded that prior knowledge was the best predictor of achievement followed by formal reasoning ability, especially when the instruments used to measure achievement were mostly made up of multiple choice items. The implications from this study, as stated by the researchers, are that the results underscore the importance of prior knowledge as a predictor of achievement in chemistry and this should be emphasized in instruction.

In a study to test the effects of knowledge maps and prior knowledge on the recall of science lecture content, Lambiotte and Dansereau (1992) compared map overheads used as a lecture aid with outlines and lists of key terms. The authors rated these three aids on a degree of structure continuum with lists being the least organized, maps the most and outlines in between. Seventy-four undergraduate students were the subjects in this study, they were recruited from psychology classes and not enrolled in a specific science class. The students' familiarity with the lecture material (circulatory system) was assessed to determine prior knowledge.

The participants were divided into three groups for a lecture on blood cells and vessels, the groups were shown knowledge maps, outlines and lists of terms as study guides during the lecture. Two days later the participants were asked to take a free-recall test in which they wrote down all the material they could remember from the lecture.

The experiment involved a 2 x 3 factorial design with low versus high prior knowledge as one factor and the three treatment groups as the other, percentage scores for central ideas and details on the recall test were the two dependent measures. The scores were subjected to a two-way MANOVA, which showed a significant main effect for prior knowledge, $F(2,67) = 32.15$, $p< .001$. Univariate tests showed that prior knowledge was a significant factor for both central and detail ideas. A post hoc comparison revealed that the difference between central ideas scores of high and low prior knowledge students who viewed lists was significantly ($p < .05$) greater than the difference between central ideas scores of the low and high prior knowledge students who viewed either maps or outlines. Students with low prior knowledge recalled a significantly higher percentage of fragments on the tests than did students with high prior knowledge. Students who viewed lists recalled a significantly ($p < .05$) higher percentage of fragments than did students who viewed maps or outlines.

Although the authors did not find the hypothesized advantage of maps over lists or outlines for students in general, they did find that students with low prior knowledge recalled significantly more central ideas when they viewed maps than when they viewed outlines or lists. Students with stronger prior knowledge of the topic recalled significantly more when they viewed lists of terms than when they viewed maps or outlines. One of the implications of these findings discussed by the authors is that mapping approaches (expert-provided or student-generated) are useful for different types of students at different stages of learning.

Hewson and Hewson (1983) investigated the effect of instruction that made explicit use of students' prior knowledge on their acquisition of specific science concepts. The participants in this study were 90 Form 2 students (grade 9), the students were divided into two groups, experimental and control, and the conceptual similarity of the students in the two groups was established using a pretest.

The authors had previously generally identified students' conceptions of mass, volume and density and then developed instructional materials using students' prior knowledge of these concepts. The experimental group of students were given a pretest, taught by one of the authors using the developed instructional materials, and then given a posttest. The control group was given a pretest, taught by the same author using traditional material, and then given the posttest. The difference between the two sets of instructional materials was that the experimental materials explicitly dealt with students' alternative conceptions and prior knowledge while the control materials did not.

The mean change scores of the two groups showed that the experimental group gained more scientific conceptions and lost more alternative conceptions than the control group. The authors concluded that the instructional strategy used with the experimental group was responsible for the acquisition of a significantly greater number of scientific concepts of density, mass, and volume, and rejection of a significantly greater number of alternative conceptions of mass and volume than the instructional strategy used with the control group. The implications discussed by the authors were that instructional materials that take into account students' prior knowledge and alternative conceptions may cause better acquisition of the science topics involved and lead to a decrease in students' alternative conceptions.

Not surprisingly, the research reviewed (BouJaoude & Giuliano, 1994; Chandran, Treagust, & Tobin, 1987; Osman & Hannafin, 1994) supports the idea that students higher in prior knowledge have more success in learning science concepts and that prior knowledge is a significant predictor of students' achievement. "Despite the differences in types of prior knowledge, researchers have consistently found that learners with high prior knowledge perform better than learners with low prior knowledge" (Osman & Hannafin, 1994, p. 11). This conclusion supports the constuctivist view of learning that what students already know when they enter a classroom or begin a new topic is of utmost importance to their consequent learning. All new knowledge is filtered by the conceptions already in place.

The research reviewed here also brings to light what students with low prior knowledge may be like. They may be unable to ask meaningful questions or relate new information presented to prior conceptions (Osman & Hannafin, 1994) or they may do better when viewing knowledge maps during instruction than when viewing lists of terms or outlines (Lambiotte & Dansereau, 1992).

Research reviewed (Trumper & Gorsky, 1993) showed that the cognitive level of the students has no bearing on the preconceptions they may hold. This research also showed that students' preconceptions may actually help them learn about energy.

The implications of this group of research articles are that teachers should be aware of which of their students are high and which low in prior knowledge. Also, teachers need to know which students hold preconceptions before new material may be taught successfully. If teachers are aware of who are the high and low prior knowledge students in a classroom, they may be able to provide differing learning experiences for each. Students with low prior knowledge may need to view knowledge maps while high prior knowledge students view lists of terms during instruction (Lambiotte & Dansereau, 1992). Students with preconceptions may need to be taught new concepts using materials that specifically address these preconceptions (Hewson & Hewson, 1983; Trumper & Gorsky, 1993).

Cognitve Change Strategies

In order for teachers to introduce a new concept to their students, they need to be aware of their students' understanding of that concept. This constructivist premise is based upon the tenet that the conceptual understanding a student brings to the classroom will affect their learning of new material. They may hold tenacious preconceptions formed through prior experience with physical phenomena, from peer culture, language, or from prior teachers and textbooks (Wandersee, Mintzes, & Novak, 1994). These preconceptions need to be addressed by the teacher so that conceptual change may be facilitated.

The following is a review of research on strategies used to identify students preconceptions and the procedures used to attempt cognitive change. The research has been chosen for review in this section only if it dealt with middle, secondary or post-secondary science students, involved some diagnosis of students' preconceptions or prior knowledge, and analyzed specific conceptual change teaching strategies in the classroom.

Basili and Sanford (1991) used a pretest-posttest control group experimental design to assess the potential of small groups incorporating conceptual change strategies to change students' preconceptions. The study included 62 students enrolled in four sections of a community college introductory chemistry class; the four sections were similarly heterogeneous with regards to sex, age, race, and previous chemistry experience. Two instructors were involved, they each taught one treatment and one control group.

At the beginning of the course, all students in the four groups took a pretest then were presented with the same course content, identical homework problems and exams throughout the term. The treatment groups were given questions to elicit student misconceptions and then spent one class period out of six in small groups discussing these questions. The small group tasks were designed to bring students' misconceptions to light where they could be examined by the students in contrast to the correct concepts presented through direct instruction. The treatment groups were also asked to design concept maps over the course material, discuss the maps in their groups and reach agreement on a single map for their group. Three lecture/discussion, group work, and exam sequences were completed before a posttest over the laws of conservation of energy was administered. Two sequences were completed before the posttest on the particulate nature of matter. The control groups' sequences were exactly the same except on the sixth day when the treatment groups were working in small groups, they watched a demonstration related to course content but not specifically addressing target concepts. No discussion of any observation of the instruction that took place in this study was provided.

A chi-square analysis of the pretests was done to determine the initial equivalence of the groups with regard to students holding misconceptions. No significant differences on the pretest data ($p < 0.05$) were found when treatment and control group students and students of the two instructors were compared on the five concepts tested (matter, energy, gases, liquids, and solids). Posttest comparison using chi-square analysis showed that the students in the treatment groups who had engaged in small group work had a significantly ($p < 0.05$) lower proportion of misconceptions for four of the five concepts on the posttest than did the control group. There were no significant differences ($p < 0.05$) regarding the proportion of the students holding misconceptions on the posttest when the students of the two instructors were compared. When looking at a group comparison of the number of percent correct on the posttest, the treatment groups' correct concept understanding exceeded the control groups' on all five concepts tested.

The conclusions made by the authors were that in small group settings, provocative questions that link science concepts with everyday phenomena may provide students with an opportunity to see the concepts as solving real-life problems. Peer discussion of these questions may allow students to clarify the scientific view until it is understandable and becomes a part of their worldview.

In a study by Hynd, McWhorter, Phares, and Suttles (1994), the effect of three instructional variables on students' conceptual change in physics was assessed. The effectiveness of demonstration, refutational text, and discussion to promote conceptual change was measured by tests of knowledge and application on a pretest and posttest. The concept that was targeted for this study was the idea that an object launched horizontally or carried and then released forms the path of a parabola as it travels to the ground because of the combination of its forward motion and gravity.

The participants in this study were 310 ninth and tenth graders in 26 separate classes. The original sample included 520 students, only the students assessed as having conceptions unacceptable to scientists were retained in the study after the pretest. The pretest consisted of three sections: (a) relatedness pretest, in which 10 words were used to measure students' knowledge of Newton' laws of motion; (b) true-false pretest in which ten items, included common misconceptions, were used to assess students' knowledge of Newtonian theory; and (c) application pretest where students picked one of four possible paths a cannonball would take when shot horizontally from a cliff and provided an explanation of their choice.

The sections in the pretest were assessed for reliability and validity separately. The relatedness pretest had been used in a previous study and had test/retest reliability of .79. The pretest was reviewed and approved by a group of physical science teachers for validity. The true-false pretest items were checked for accuracy by a physics professor. The application pretest had been used in previous studies, had a test/retest reliability of .67, and was checked for validity by the physics professor.

Two weeks after pretesting, students were randomly assigned (within their classes) to one of eight groups: (a) Demo-Discussion-Text; (b) No Demo-Discussion-Text; (c) Demo-No Discussion-Text; (d) Demo-Discussion-Unrelated Text; (e) No Demo-No Discussion-Text; (f) Demo-No Discussion-Unrelated Text; (g) No Demo-Discussion-Unrelated Text; (h) No Demo-No Discussion-Unrelated Text. The demonstration students watched two 10 minute demonstrations on the concept, the discussion groups were asked to come to a consensus upon a projectile's path and the reasoning behind it, and the test students read a refutational text about Newton' ideas regarding motion.

After the instructional strategies had been completed, the students took a posttest consisting of the same relatedness, true-false and application sections as the pretest. After two weeks, the students were given the true-false and application posttest once again. The posttest items were identical to the pretest items that had been checked for validity by the physics professor.

The effects of the instructional variables were tested using five separate 2 x 2 x 2 analyses of covariance. The independent variables were the two levels each of demonstration, discussion and text, the dependent variables were the posttest results. The results of the analyses showed that reading refutational text had the strongest overall affect on conceptual change. There were no main effects for the demonstration or discussion variables; the interactions effects showed that students who participated in discussions seemed to be less susceptible to the effect of other variables; what students learned in their group discussions seemed to be unaffected by other instruction.

The authors concluded that students could have injected naive beliefs into discussions thereby influencing other students; therefore, when counterintuitive concepts are introduced, teachers may need to be a part of the group discussion. The conclusions on the lack of effect from viewing a demonstration were that since the students did not discuss the demonstration with a teacher, the effects were not lasting. Students who saw the demonstration and read the refutational text outperformed the students who participated in all three activities. The conclusion of the authors was that reading the refutational text allowed students to consider their prior knowledge and reflect on their intuitive ideas and the new science concepts.

In an attempt to identify the conceptual change strategies used by middle school science teachers, Smith, Blakeslee, and Anderson (1993) designed a classroom observation system that provided quantifiable descriptions of classroom teaching strategies. The authors also investigated the relationships between teachers' use of the observed strategies and student learning measured by conceptual change-oriented tests.

Thirteen 7th-grade science teachers participated in the study. They were randomly divided into three treatment groups: four teachers attended two half-day workshops on specific conceptual change teaching strategies, five teachers attended no workshops but used curricular materials (for two out of the three units studied) written by the researchers and based on typical student misconceptions and various recommended conceptual change teaching strategies, four teachers attended workshops and used conceptual change curricular materials for the third unit only. The three units studied were photosynthesis, cellular respiration and matter cycling in ecosystems. Each of the 13 teachers was observed teaching all three of the units, the number of lessons varied according to the teacher. Data were collected on all sources of information given out in the classes (teacher, texts, audiovisual, etc.) and on work done by the students (worksheets, questions or other tasks).

Students were given pretests and posttests over the material included in the three units. The tests included both knowledge and explanation questions; no mention of validity was made. For each topic, the minimum score that represented a reasonable level of understanding was determined and then the number of students in each class that scored at or above the minimum was calculated.

Three types of data analysis were performed. First, descriptive statistics were developed, mean frequencies of use of classroom discussion strategies were calculated on a lesson-by-lesson basis. Second, treatment effects were assessed; the teacher was used as the unit of analysis in comparing frequencies of the strategies and student learning with and without workshops and experimental materials. Lastly, the relationships between the frequency of use of the various conceptual change strategies and student learning were analyzed.

The results show that no observable differences in teaching strategies were associated with workshop participation. When the conceptual change curricular materials developed by the authors were used, more than twice as many prediction questions and explanation questions were asked by the teachers, often based on everyday phenomena. Interestingly, similar numbers of memory questions were asked by teachers with and without the materials. When teachers were using the conceptual change materials, more students articulated misconceptions and teachers made more contrasts between misconceptions and scientific conceptions. Statistically significant correlations were present between conceptual change strategy and student learning in 23 out of 58 possible instances, the authors stated that this result was nearly twice as many as would be expected by chance with a criterion of $p < 0.2$. Asking open-ended questions and memory questions were consistently negatively correlated with posttest performance.

The conclusions drawn by the authors from these results were that the recommended strategies do help to promote conceptual change. Also, teachers need the help of the specially developed materials to carry out the strategies, merely attending a workshop did not instill the strategies into the teachers' practice. The authors stated that conceptual change teaching should be thought of as a collective approach to teaching rather than a collection of individually useful strategies.

Fetherstonhaugh and Treagust (1992) carried out a study in which they gathered data on students' understanding of light, designed materials involving a teaching strategy to elicit conceptual change and focusing on students' own ideas, and then evaluated the effectiveness of the strategy. To collect data on students' understanding of light and its properties, two groups of 8th-graders were given a diagnostic pretest which addressed known student conceptions from the literature. Three experienced physics teachers validated this test. One of the groups of students was subjected to the conceptual change teaching and then given a posttest. Also, from the same group, six randomly chosen students were interviewed and 10 original members were given a delayed posttest three years later. The other group was apparently not posttested for any conceptual change in their ideas about light.

The results showed that the mean scores of the two initial groups of students had no statistical differences between them ($t = 0.01$, $p > 0.05$). The diagnostic test identified nine conceptions that were similar to those found in the literature, these preconceptions were listed and the numbers of students in each group holding them were detailed by the authors. The mean number of acceptable responses changed from 6.60 ($SD = 2.660$ to 10.50 ($t = 4.35$; $p< 0.005$) on the posttest and to 13.50 ($SD = 1.78$) ($t = 3.42$; $p < 0.005$) on the delayed posttest.

The conclusions made by the authors were that the teaching module was successful because a greater number of students were able to construct significantly more scientifically correct answers on the posttest than on the pretest. The nine student preconceptions that were addressed by the teaching strategy all occurred less on the posttest than on the pretest. The results of the delayed posttest showed that in all but one instance, the scientifically acceptable concepts about light were retained by the students.

Thijs (1992) evaluated a constructivist teaching approach that used students' prior ideas as a starting point and promoted conceptual change through practical experiments and class discussion on the topic of force. The study involved four teachers in seven classes of form 3 (grade 9 equivalent); the total number of students was 110.

The course revolved around student inventory worksheets, one was given at the beginning of the course and considered a pretest, another was given after lesson nine and considered a posttest. During lesson 10, the students were made aware of the changes in their ideas by comparing their answers on the two inventories. During the intervening lessons, the students were involved in practical activities and spent time doing worksheets designed to make students come to conclusions about what they observed. Also, the students were involved in presenting their ideas and taking class polls about concepts. Class discussions followed presentations and students were encouraged to try to convince each other of the correctness of their ideas. At the end of the group of 10 lessons, students are presented with the correct scientific explanations and asked to explain why the other answers were wrong.

The total scores (percentage of correct answers) on the two inventories given to students in this study were compared and the "learning effect" was given as 14%. A regression analysis was carried out to determine which particular students had benefited most from the course. The following information was used: pretest and posttest scores, previous physics course grade, ratings of student opinions from a course appreciation questionnaire, and gender. The results showed that there was no difference in appreciation of the course and its constructivist approach between bright or weak students or between boys or girls. Learning effects showed no significant effects between these groups. The learning effect was higher for those students who proclaimed appreciation for its constructivist approach, the author stated that this confirms the teachers' impression that the course benefited those students who took pleasure in elaborating their ideas.

The author concluded that this course helped students to articulate their own ideas in classroom debates and group discussions. Practical activities triggered students' involvement in the conflicting ideas presented and enriched the arguments that students used in constructing a concept of force.

The preceding review of research on conceptual change strategies has shown that conceptual change materials designed with students' preconceptions as the focus (Basili & Sanford, 1991; Fetherstonhaugh and Treagust, 1992; Smith et al., 1993; Thijs, 1992) have been successful in moving students' conceptions closer to the accepted scientific view. Using catalogued or collected preconceptions about specific topics to build a curriculum has been a successful way to force students to confront their own or their peer's ideas, discuss these ideas, and ultimately resolve any conflicts as they reach the accepted scientific concept. Using this strategy in small groups has been shown to be effective (Basili & Sanford, 1991) and having students face common preconceptions in a text format has also had success (Hynd et al., 1994). These teaching strategies are essential when involved in changing students' preconceptions but teachers may not be able to instinctively use them (Smith et al., 1993) and may need to have curricular materials supplied for them in order to attempt conceptual change teaching.

According to Wandersee, Mintzes, and Novak, (1995) conceptual change research is "relatively recent in origin and, although promising, is probably best described as exploratory in nature. Many of the studies have relied on small sample sizes, untested methods, anecdotal records, and relatively nonrigorous research designs lacking control-group comparisons" (pg. 192). These research characteristics were seen in the articles reviewed, two of the studies (Fetherstonhaugh and Treagust, 1992; Thijs, 1992) lacked control groups when data from them would seemingly have been easily collected.

Another concern when researching students' conceptions is whether the method used when identifying preconceptions is accurate in supplying data. The studies reviewed used a relatively small variety of methods to identify students' preconceptions; all used some sort of written pretest or inventory to diagnose students' ideas before instruction. These methods are certainly the most practical for use in a regular classroom situation when time is a factor, but other methods such as concept maps, journals or interviews may elicit more accurate preconceptions.

Also a concern is the fact that only a few of the studies reported validity for the written pretests or posttests. This lack of attention to validity detracts from the conclusions made in these studies.

An implication drawn from this research is that materials designed with students' ideas in mind may be more successful than "traditional" materials in accomplishing a conceptual change. In a classroom situation, the teacher would need to first identify the predominant student preconceptions; once these preconceptions are identified they could be used by a teacher involved in facilitating students' conceptual change. The curricular materials employing students' preconceptions on a topic in order to force students to confront their ideas before moving closer to the accepted scientific concept have all shown success. There are many ways in which teachers may incorporate these methods into a science class; the use of questions in a small group, refutational text, or class discussion have all been used successfully.

Conclusions and Recommendations

Research has shown that students do hold preconceptions on many science topics; the academic or cognitive level of the student does not seem to affect the type or number of preconceptions held. Interviews outside the science classroom have identified a variety of students' preconceptions but little data has been gathered on how teachers identify students' preconceptions in the classroom. No research was available involving teachers' diagnosis of students' preconceptions in the classroom.

Prior knowledge provides an indication of the preconceptions held as well as the accurate scientific concepts held by a student. Students' prior knowledge of science concepts affects their consequent learning of new material; students with high prior knowledge may learn differently than those with low prior knowledge.

Using collected preconceptions about specific science topics to build a curriculum has been shown to be a successful way to force students to confront their own and their peer's ideas, discuss these views, and ultimately resolve any conflicts as they reach the accepted scientific concept.

If teachers are to teach in a constructivist manner and attempt to affect the preconceptions that students bring to the science classroom, teachers need to be aware that students' ideas may not be congruent with the accepted scientific concepts. The research has shown that there is a multitude of preconceptions held by students on various science topics. If teachers could be aware of the major preconceptions that might be seen in their field, they would be able to recognize similar preconceptions in their own students. The research has catalogued the most prevalent of these preconceptions; knowledge of the most general preconceptions likely to be seen in their students would be useful for teachers. Rather than focusing more research on identification of preconceptions in nonclassroom situations, it is essential to focus research on how these preconceptions are identified by teachers in their daily teaching practices.

Teachers need to be aware of the prior knowledge level of their students in order to design curricula accordingly. Teacher awareness of students' preconceptions allows the teachers to design materials using the preconceptions, thus enabling students to move towards the scientific view.

Due to time and curricular constraints, in-depth interviewing of students in the classroom is usually not feasible. Teachers need to be provided with strategies for efficiently identifying students' views; diagnosing students' preconceptions in the classroom will allow teachers to adapt curricular materials to enable students to overcome their preconceptions. The most feasible, useful strategies that could be adapted by teachers, such as small group lessons, class discussions, pretests, or journals, should be made available in a format teachers could understand and incorporate into their teaching. The methods used by experienced teachers to identify students' preconceptions need to be documented to provide beginning teachers with viable strategies for diagnosing students' preconceptions.

Chapter III

Design and Methodology

Introduction

Teaching based on constructivist epistomology must adhere to the principal that ideas cannot be transferred into students' minds intact; students must construct their own meanings from the words and images with which they are faced. When undergoing this construction of meaning, what the students know is of utmost importance (Treagust, Duit, & Fraser, 1996). It is essential for science teachers to have an intimate knowledge of their students' prior knowledge of, and experiences with, any specific science content. Constructivist teaching, therefore, requires that teachers elicit their students' prior knowledge before attempting to restructure the students' ideas.

Over the past 15 years, the large number of research studies conducted on students' preconceptions has led to a number of publications (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Osborne & Wittrock, 1985; Treagust, Duit, & Fraser, 1996; White & Gunstone, 1992) that make recommendations to teachers on how to diagnose students' prior knowledge in the classroom. These recommendations include such strategies as interviews, class discussions, journal entries, concept maps, activities, pretests, and small group work. Suggestions such as these present teachers with possible strategies for the diagnosis of students' understanding prior to attempting conceptual change. These suggestions stem from research done in contrived classroom situations; it is important to analyze the methods teachers actually use to diagnose students' preconceptions in the regular classroom environment.

The present study involved intense observation of teachers in their classrooms, interviews with teachers about their classroom strategies, analysis of teachers' lesson plans, and analysis of students' written work to determine whether any diagnosis of students' preconceptions occurred before the teachers taught a specific science concept. The research questions defining this study were focused on the strategies used by secondary science teachers to diagnose their students' preconceptions in the regular classroom environment, the ways that teachers use the information gathered in a diagnosis, and also the reasons for any lack of diagnosis. This information is important to preservice as well as inservice teachers as they are trained to teach in a constructivist manner.

The classroom observations carried out in this study were a major data source; they provided information on how the teachers taught science, the strategies they used, and their interactions with students in the classroom. These observations also supplied information on the students, their questions, their answers, and their reactions to the teachers. Classroom observations also allowed the researcher to compare the teachers' responses in the interviews to actual classroom practices documented in the observations.

The interviews provided information about each teacher's beliefs on the importance of diagnosing students' prior knowledge, perceptions of how they themselves diagnosed students' ideas, knowledge of any common preconceptions seen in all students, and knowledge of conceptual change teaching and constructivism. The stimulated recall interview supplied data about the teachers' thoughts and reflections on their teaching; this interview specifically provided data that linked teacher thinking and classroom practices.

The teachers' planning was analyzed and their students' work was reviewed to determine the emphasis the teachers placed on understanding students' preconceptions in the classroom. The researcher's notes and comments also were used as an important data source.

Subjects

The teachers observed in this study were secondary school science teachers who had been teaching for at least five years and who were currently teaching in their field of licensure; they had taught the specific class being observed for at least five years. Berliner (1987) maintained that after teaching for five years, a teacher may be designated as experienced and it may be assumed that these teachers were consistent in their instructional strategies.

It was also important to have teachers involved in this study that were considered exemplary. Exemplary teachers have been shown to have a concern for assisting students to learn with understanding and the key to their teaching with understanding is often verbal interactions that enable them to monitor their students' understanding of science concepts (Tobin, Tippins, & Gallard, 1994).

To ensure that the sample in this study consisted of teachers that had the potential to diagnose students' preconceptions, purposeful sampling was employed. According to Bogdan and Biklen (1992), this type of sampling allows particular subjects to be included in the sample to facilitate the expansion of the developing theory. Since exemplary teachers have been shown to have a concern for student's understanding and would be more likely to pay attention to students' conceptions than normal teachers, including only exemplary teachers in the study increased the chances of observing diagnosis of students' ideas. If exemplary teachers do not attempt diagnosis, it is even less likely that a nonexemplary teacher would be found to diagnose students' ideas.

To involve teachers who were considered exemplary, the superintendents of two local school districts in Southeastern Washington were contacted. These administrators either provided a list of exemplary secondary science teachers or wrote a letter to the principals of the high schools in the district requesting their recommendations. The administrator supplied the names of six teachers he considered exemplary in his district; the two principals each supplied the names of four teachers in their school that they considered exemplary.

A letter requesting their participation in this study was sent to the 14 recommended teachers (Appendix A). Five teachers volunteered to participate in the study; a preliminary meeting was held with each of the five teachers to discuss their schedules, their participation in the study, and their background. Due to class schedules and travel time, four of the five teachers were selected to be participants in this project.

Having four teachers in this study allowed the researcher to observe daily in each classroom. A larger sample size would have meant that much less time was spent with each teacher. These in-depth classroom observations were very valuable in this study; it was possible to observe the teachers every day, every interaction between teacher and students pertinent to this study was recorded. If a larger sample size had been used, the daily classroom observations would not have been possible and the observations would not have been as valuable as a data source. With a larger sample, the researcher would not have been able to interview and interact with the participants to the degree that was necessary for this type of study.

The teachers selected were from two high schools in the same school district. Two of the teachers were biology teachers, one teacher taught physics, and the fourth taught earth science. The four teachers all had five years of experience, their years of teaching ranged from 6 to 34.

After the four teachers were selected, the researcher met with the principals in each school to discuss the study. The principals gave their permission for the researcher to observe classes daily and to interview the teachers when necessary. A letter to be sent home to students' parents (Appendix B) was approved by each principal.

Students were not direct participants in this study. They were, however, indirectly observed and videotaped in the classroom as their teachers' interactions with them were studied. Some student work was also viewed by the researcher; any written work that involved diagnosis of preconceptions through teachers' questions to students or students' responses to teachers' questions or prompts was collected by the researcher.

Data Sources

The data collection for this study began during the second week of school in the fall of 1998. Over the next three months, the researcher conducted the preliminary interview, the pre-instructional interview, observed in each classroom every school day, and conducted the stimulated recall interview and post-instructional interview. Data from these events formed the majority of the data collected. The teachers' planning, students' work, and the researcher's notes were also significant data sources.

Prior to conducting the pre-instructional interview with the teachers, the researcher met with the teachers to discuss the research project in a preliminary interview. So that the teachers were not aware that the researcher was looking specifically for their diagnosis of students' preconceptions, which could affect their actions when under observation, the focus of the study was described as research on teachers' lesson planning and teachers' assessment of students' understanding. This description of the study allowed the researcher to discuss with the teacher long term planning in order to determine when new concepts were going to be introduced to students and also to justify collection of all student work that the teacher used in the assessment process. Other topics that were discussed in the informal, preliminary interview, prior to beginning the classroom observations, were the teacher's background information, videotaping, the researcher's placement in the classroom, the collection of teachers' lesson plans and students' work, and scheduling the pre-instructional interview.

Pre-instructional Interviews

The actual collection of data began with a semi-structured interview with the teacher; these interviews were conducted in the teacher's own classroom at the end of the school day. The interviews lasted from 30 to 40 minutes, were audiotaped and later transcribed. The purpose of this interview was to gather information on the teacher's planning for instruction, their beliefs on the importance of the diagnosis of students' preconceptions, and on their planning for diagnosis of preconceptions. The researcher also questioned teachers about how they assessed students' understanding and how they would rate their students' understanding of the text, their own lectures, and overall class material. Teachers were asked about what they knew and believed concerning conceptual change teaching and constructivism. It was important to ask teachers about their knowledge of the current science education reforms in order to provide data about why or why not teachers use strategies to diagnose preconceptions. The general questions that were used to guide the interviews follow. These questions were reviewed for validity by a panel of five science education experts; 80% agreement among the experts was achieved to assure validity.

Pre-instructional Interview Questions:

1. What are your main concerns when planning for a unit of instruction? For a lesson?

2. What information/resources do you use when planning a unit?

3. Is it important to know students' prior knowledge (personal conceptions) before teaching a new concept? Why or why not?

4. Do you attempt to find out what ideas students might have on the topic(s) before teaching a unit? A lesson?

5. What does "conceptual change teaching" mean to you?

6. In general, how would you rate your students' understanding of their text? Of your lessons? Students' overall understanding of the class material?

7. How do you assess students' understanding?

8. What does the term constructivism mean to you?

9. Could you describe any science education reforms that have been proposed for secondary science teaching? Please describe in detail.

10. Have these reforms affected your teaching? Why? Why not? Describe any changes.

Classroom Observations

Following the pre-instructional interview, the classroom observations began. These classroom observations were the primary data source in this study. The researcher began observations in the classrooms at the beginning of the third week of school. The students had returned their consent forms and been introduced to the researcher. For nine weeks, every class period was videotaped; the researcher also took extensive observation notes and filled out a classroom observation form for each class. One of the classrooms was only observed for six weeks due to the student teacher taking over the class earlier than was originally planned. Fortunately, during those six weeks the teacher had shown evidence of well established routines and a definite pattern of strategy use.

The researcher sat at the back of each classroom next to the video camera. In order to minimize the researcher's presence in the classroom, she did not get up to move around the room except to change the camera to a different perspective during labs. The teachers wore a remote microphone so that all conversations with students could be recorded.

The observation notes made each class period by the researcher encompassed everything that occurred in the classroom. A global scan was made throughout the class period, the researcher usually wrote continuously for the whole 50-minute period. Next to the report of classroom occurrences, the researcher wrote comments, both during the class observations and during later reviews of the data.

In order to collect data on the myriad of possible student and teacher interactions that occured during classroom observations, an observation form was developed. This form was adapted from Smith, Blakeslee, and Anderson (1993) and presented a quantitative element of data collection. This form was used during each classroom observation to record the teachers' questions, students' questions, the presentation of information, and any written work that involved potential diagnosis of students' understanding. The frequencies of the specific strategies observed were tallied for each teacher. Five science education experts validated this form; 80% agreement among the experts established content validity. The classroom observation form is included in Appendix C.

After all the observations were completed, the researcher transcribed the videotapes that involved student and teacher interactions; video segments of tests, students working individually, or classroom videos were not transcribed unless they involved student and teacher interactions. The classroom observation forms were reviewed at the end of each day, compared to the observation notes, and filled in more completely if necessary.

The classroom observations were essential as a data source in this study. The researcher was able to get an idea of the reality of the teacher's classroom and did not have to rely solely on the teachers' interview responses of how they said they taught. By comparing the teachers' actual classroom practices and their responses in the interviews about those practices, the researcher could draw more accurate pictures than if interviews had been the major data source.

The teachers' lesson plans were also compared to the teaching observed during daily observations. Unfortunately, the teachers did not use detailed lesson plans so it was impossible to determine if they were planning for diagnosis of students' preconceptions.

The researcher observed everything that occurred during each class period but a few situations were given special note. Any class discussions in which the teacher asked the students questions and solicited their responses were given close attention. Special attention was also paid to the questions posed by students to the teacher and the questions that the teacher asked the students, both as a group and individually.

The questions asked in the classroom, the answers supplied and the conversations between teacher and student that contained reference to students' understanding were of utmost interest. For example, two levels of diagnosis of students' prior knowledge can be delineated: A teacher may possibly ask a general, curricular identification question such as " How many of you have talked about atomic structure in other science classes?" This type of question may be informative for the teacher for planning purposes but does not comprise any in-depth diagnosis of students' understanding. A second level of diagnosis might be if a teacher asks "Can anyone describe the structure of an atom?" This type of question allows a teacher to see what students understand about a concept and was of most use in this research.

The questions asked by the teachers were analyzed carefully; also of importance were the ways that the teachers responded to the students' attempted answer. Often a teacher asked the students a question that required the reply of a single correct answer. If the students did not provide this answer, the teacher's next step was to supply the right answer. In contrast, if a teacher were interested in the students' ideas, he/she might ask for a variety of students' own answers and concepts, discuss these, and finally compare them to the correct answer.

It was important in this study to distinguish between a teacher's attempt to diagnose students' preconceptions and a teacher's attempt to simply involve students. For example, a teacher may ask students a question about their prior knowledge of a topic simply in order to bring the students into a class discussion without any thought by the teacher of diagnosing preconceptions. If the teacher asked this type of question, the researcher recorded it. Then during the stimulated recall interview with the teachers, the researcher asked the teachers about their motivations for this type of question. If the teachers described their motivation for questioning the student as simply to involve the student with no intention to use the information elicited from the student, then it was not considered a diagnosis. But the teacher may have garnered information from such a question and used it in planning future instruction. If evidence of this type of information use was seen, the teacher's planning was analyzed, it was discussed with the teacher, and the question was considered a diagnosis.

Other Data Sources

Other sources of data included teachers' lesson plans, samples of students' written assignments, tests and quizzes that had been corrected by the teacher, and samples of any written work done by the students but not graded by the teacher. The teacher was asked to allow the researcher to photocopy lesson plans every two weeks. This focus on their plans may have affected the teachers being studied by motivating them to write lesson plans in a different manner than they would normally. More attention to lesson plans by the teachers would not affect the data as the teachers' planning was not actually being researched, only how they might plan to diagnose students' preconceptions.

The students' written work was photocopied after being corrected by the teacher and then returned to the teacher as soon as possible. Any informal work that the researcher needed to photocopy was collected from the teacher, photocopied and returned immediately. Students' work was used to determine if any of the teacher's written questions or prompts had elicited preconceptions or had allowed the students a chance to describe their own views on a topic. The students' test and quiz responses were analyzed for evidence of preconceptions.

Stimulated recall Interview

At the end of the classroom observation period, the researcher and individual teachers participated in a stimulated recall interview in which the teachers were asked to view a short video segment of their teaching and reflect upon their thinking and teaching during that segment. The researcher chose a number of video segments to view with each teacher. The video clips chosen for these interviews covered situations where some sort of teacher and student discussion had taken place. Segments were selected if they involved the teacher asking students about their prior knowledge or experiences. Examples of situations where a diagnosis could have occurred, but did not, were also selected for discussion with the teacher; the nonexamples of a diagnosis were presented in order to determine if the teacher recognized it as such.

The teachers were asked about their motivation behind certain questions, planning for events, and reasons for using certain strategies. By using this interview procedure, a more accurate idea of the teachers' thinking behind their actions was achieved. The researcher was able to compare the teachers' responses during the stimulated recall interview to their actual teaching practices observed during classroom observations. Any discrepancies between the teacher's and the researcher's definitions of diagnosis, student preconceptions, or student understanding became evident through the stimulated recall interview.

The question protocol for the stimulated recall interviews was the same for each teacher. The teachers were asked to stop the video at any point if they wished to make a comment or review a section of the tape. None of the teachers did this although the researcher did stop the video player to ask what they were doing at specific points and also to review sections that were hard to hear or understand. During and after the teacher and interviewer watched the video clips together, the stimulated recall interview questions were asked each teacher.

Stimulated recall Interview Questions:

1. Please describe what you are doing in this segment.
2. Why are you doing this?
3. What did you think the students already knew about this topic prior to this episode?

4. What were you thinking as you did this?
5. What did you learn from doing this?
6. Was there any specific planning that you did prior to this episode?
7. Did you make any changes in your subsequent lesson plans due to this episode?

The length of time that elapsed between the stimulated recall interview and the pre-instructional interview was 10 weeks for two of the teachers and 11 weeks for the other two. This time was enough to assure a minimal effect from the researcher's questions asked in the first interview on the teachers' responses in the stimulated response interview.

Post-instructional Interview

Following the classroom observations and stimulated recall interview, a post-instructional interview was conducted with each teacher. The focus of this interview was to gather information on the teachers' views of their assessment practices, their views on students' preconceptions and their views on the diagnosis of students' prior knowledge before introducing science concepts. If the teachers said that they attempted to carry out some form of diagnosis in the classroom, these strategies were discussed with the teacher; they were asked about how they carried out diagnosis, the inherent problems with it, and their future plans for using it in the classroom. The teachers were asked about reasons that might prohibit the use of regular diagnosis of students' preconceptions in their classroom. To achieve validity, the questions used to guide these semi-structured interviews were reviewed by a panel of five experts; the 80% agreement among the science education experts was a determination of validity. The interview questions used in the post-instructional interview are as follows:

Post-instructional Interview Questions:

1. Have you ever attempted to diagnose students' preconceptions in your classroom? Please describe.

2. If you have never attempted to diagnose students' preconceptions, please explain the reasons why.

3. What are some of the approaches that might be used to accomplish this type of diagnosis?

4. How do you rate your students' understanding of the information you provide (high to low)?

5. What are some of the pros and cons of conducting regular diagnosis in the classroom?

6. How might you use information gathered in a diagnosis of students' preconceptions?

7. Are there any common preconceptions (misconceptions) that you have found that students regularly have on a specific topic you teach? How were these found?

8. Have you ever used this knowledge of common preconceptions (misconceptions) when planning your materials?

<u>The Researcher</u>

The researcher was a source of data in this study. Throughout the collection of data, the researcher recorded "observer comments" on all field notes. According to Bogdan and Biklen (1992), the researcher should record any important insights and when words, events or circumstances recur, these should be mentioned and speculated upon in the researcher's notes. In this study, a journal was kept by the researcher to record any reactions to what occurred in the field and to write down thoughts that surfaced about the data being collected. The researcher strove to make entries in this journal after each interview or class observation. "The idea is to stimulate critical thinking about what you see and to become more than a recording machine" (Bogdan & Biklen, 1992, p. 158).

During the interview sessions, the interviewer had an effect on the data collected by manner of the questions asked of the interviewees. The set of general questions produced by the researcher was used as a guide to conduct the interviews; other questions were asked as the interviews proceeded dependent upon the participant's responses. "Far from being a robotlike data collector, the interviewer, not an interview schedule or protocol, is the research tool" (Taylor & Bogdan, 1984, p. 77).

It was important for the researcher to have a working knowledge of the common misconceptions held by students that have been identified in recent research. In order to recognize potential erroneous conceptions held by students as they conversed with the teacher in the classroom, the researcher became conversant with the various common misconceptions outlined in Driver, Squires, Rushworth, and Wood-Robinson (1994).

The classroom experiences of the researcher aided in recognition of students' preconceptions and also teachers' attempts at diagnosis. After receiving a

BS in Zoology followed by course work to achieve a teaching certificate in biology and chemistry, the researcher spent six years teaching general science, physical science, advanced and general biology, and advanced and general chemistry in grades 7-12. A seventh year was spent substitute teaching in these areas. The researcher then received a MS degree in Science Education and is currently a doctoral candidate in Science Education. The researcher has also had four years of experience working with preservice teachers both in the classroom and in the field.

The researcher's beliefs about teaching had an effect on the data analysis. A strong commitment to constructivist teaching may have biased the researcher's views on the teaching observed. An admission and evaluation of this bias allowed the researcher to step back and view all teaching as simply what was occurring in the classroom. It is undeniable that the researcher's views affected the analysis. It was essential to record these views along with any other reactions to the data in the researcher's journal. According to Bogdan and Biklen (1992) the differing theoretical perspectives held by the researcher will shape how he/she approaches, considers, and makes sense of the data.

Data Analysis

The analysis of data began during the collection of data, continued throughout the data collection process, and was not complete until all the data had been reviewed numerous times.

According to Bogdan and Biklen (1992), a small amount of data analysis may be conducted in the field when doing qualitative research. They recommended that a general type of analysis be done after conducting an observation and then specific leads should be pursued in the next data-collection session. Memo writing or summarizing about the data should be done after five or six observations. In this study, the researcher attempted to write up a general, speculative summary after each set of five observations. In this way, any emerging patterns were noted at the outset and were then followed throughout data collection. These summaries composed part of the final data analysis.

After data collection was complete, the researcher organized the data to facilitate the generation of a coding system. The transcripts from all interviews, field notes from all observations, data from classroom observation forms, the researcher's memos and journal, and information from the teachers' lesson plans and student work were sorted. The researcher spent time at this point reading and rereading the notes in an attempt to recognize any patterns, topics or regularities leading to coding categories. The coding categories encompassed those topics for which there was the most substantiation as well as topics that were of special interest to the study (Bogdan & Biklen, 1992).

The categories listed on the classroom observation form (Appendix C) were a starting point for developing categories. These descriptions of student-teacher interactions were used to begin the categorization of data. For any data not fitting into one of the observation form categories or data that seemed to fit into too many of the categories, a new category was developed.

After the data had been parceled into categories, the data in the categories of specific interest to this study were analyzed in greater detail. These specific interest categories were: Predict, Preconceptions, Prior knowledge, Student question w/preconception, Nonrecognition, Science concepts, Contrast, Discrepant event, Discussion, Pretest, Maps, and Prompts (see Appendix C). Some of the data from these categories could be placed into subcategories. For example, if a teacher did not recognize a student's preconception but the researcher did, this episode was placed in the Nonrecognition category. Then subcategories, such as preconception elicited by the teacher, preconception seen in student's question, or preconception seen in student written work, were developed depending upon where and how the student's preconception was identified by the researcher.

Categories were also developed from the data taken from teachers' lesson plans, interviews, students' work, and researcher's journal. These categories focused on teachers' diagnoses of students' understanding. For example, from the teachers' lesson plans, some of the categories were: teacher plans a review session, teacher plans a quiz or test, teacher plans a class discussion. Some of the categories developed from the interview responses were: teacher talks about the value of knowing students' preconceptions before instruction, teacher views on constructivist epistemology, teacher views on student assessment, and teacher's value of student understanding.

When the coding categories had been generated, the researcher labeled the data with coding category abbreviations, breaking any general categories into subcategories at this point. All comments made by the researcher were labeled as such in order to be differentiated from actual classroom observations. The data were scrutinized repeatedly and placed in the appropriate categories.

In order to answer the first research question (What are the strategies used if teachers diagnose students' preconceptions?), the teachers' classroom practices and interview responses were analyzed. The classroom observation form (Appendix C) was used to tally strategies used by each teacher. These strategies were discussed with the teacher in the final interview and the labeling of the strategies was a cooperative effort between the researcher and the teacher.

The second research question (How do teachers use the information they gather in a diagnosis?) was answered through analysis of classroom observations, teachers' planning, students' work, and teachers' responses to interview questions. Teachers were questioned about the use they made of the information and the students' work was analyzed for evidence of the teacher's use of the information. For example, a teacher might have held a class discussion prior to beginning a topic to elicit students' ideas about that topic. The teacher may then have planned consequent lessons based on the information they gathered in the class discussion; this planning was considered evidence, as was any work that the teacher created for the students. For instance, the teacher might have used the preconceptions uncovered in the discussion as distractors in a multiple-choice test.

Possibly, the teacher may have used information on students' preconceptions gathered from students they had in previous classes. The experienced teacher may have built up a working repertoire of students' ideas through exposure to hundreds of students and their various preconceptions over years of teaching. If a teacher used general information on students' preconceptions without specific diagnosis of current students' ideas, the researcher questioned the teacher about the origination of this information during the final interview.

In order to answer the third research question (What are the reasons for a lack of diagnosis?), the teachers' responses to the question of whether they have ever attempted any type of diagnosis were evaluated. They were asked why a diagnosis of students' preconceptions might be hard to carry out in the classroom. Also, the teacher who did employ diagnosis was questioned about the reasons it was difficult to diagnose students' preconceptions.

A detailed profile of each teacher and their classroom practices was prepared. The coding categories provided a structure to outline the teachers' practices and particularly address their use of strategies to diagnose students' preconceptions. These profiles were then used to compare and contrast the teachers in terms of their teaching experience, strategies for diagnosis of students' preconceptions, and interview responses. The teachers were specifically compared as to their classroom demeanor, questioning of students, beliefs about the importance of diagnosis, and understanding of students' preconceptions.

Chapter IV

Results

Introduction

The purpose of this study was to investigate the strategies teachers use to identify students' preconceptions and the use teachers make of this information. The data collected in this research study were analyzed to paint a picture of how the teachers studied identified and diagnosed their students' preconceptions in the secondary science classroom. The teachers' understanding of the strategy of assessing students' preconceptions was also investigated. In this description of the research results, each of the four teachers studied are described in depth; their background, classroom, common practices, strategies for identification of preconceptions, and interview responses will be reported. The teachers were each assigned a pseudonym to protect the anonymity of the participants.

The results of the classroom observation form is reported for each teacher. The researcher filled out a classroom observation form (see Appendix C) to count the types of questions and the classroom activities of both teacher and students for each class observed. The teacher's questions, students' questions, methods of presenting information, and types of written work done in each period were documented for each classroom observation made.

Following this description of the results, the four teachers are compared and contrasted. The similarities and differences of their identification practices are discussed.

Helen

Description of Teacher, Classroom and Course

Helen holds a BS in General Science and a Master of Arts in Teaching (MAT) degree. She has been teaching for five years and is certified to teach Earth/Space Science. Helen has taught Chemistry and Chemistry in the Community on occasion but has always been an Earth Science teacher. During the observation period, she was not involved in extracurricular activities but has been coach of a Science Olympiad team, Environmental Club advisor, and a Freshman and Sophomore class advisor.

Helen's sixth period Earth Science class was observed for nine weeks. This class was made up of students who needed science credit but did not want to take biology. Most of the class was freshmen and sophomores; there were also five juniors and seniors. According to the teacher, the students were not seriously motivated students; most were just trying to pass the course. A few of the students seemed truly interested; a few were definite behavior problems. The students' attendance was not good; the teacher had to deal with a lot of absences and a few suspensions. Except on early release and assembly days, the class was 50 minutes long and the last class of the day. The classroom was large, the 28 students sat at individual desks in the front part of the room, and the back of the room was filled with eight lab tables each with four chairs. The class was observed from the third week of the year through the end of the12th week. During this time, the teacher covered chapters 2, 7, 3, and 4 in the Earth Science textbook in that order.

The teacher began each week with an announcement of that week's schedule, making sure students knew about any quizzes or tests, homework assignments, and lab activities. Helen left the weekly schedule up on the board all week; she also had a schedule of when she would be available for extra help. The typical class began with the teacher asking for any assignments that were due, she would often stamp completed assignments with a rubber stamp before reviewing them with the students; sometimes she simply collected them without going over the correct answers. Helen presented new material using the overhead projector; she had handwritten notes from earlier classes on the overhead that she asked students to copy. While the students copied the information, she read the notes and elaborated on the material.

Helen gave her students a homework assignment every class period, although many of these the students finished during the class period. She assigned textbook readings and questions, worksheets, crossword puzzles, vocabulary word puzzles, and pre-lab write-ups as homework. Possibly due to the competence level of the students, this teacher gave them from 15 – 30 minutes daily to work on their assignments in class. A common occurrence was that students were given 15 minutes to work on the assignment alone, 15 minutes to work on it with other students, and then the teacher would go over the correct answers in class. The assignment was then due the end of the period or the following class period. Students were asked to keep all returned homework papers in their notebooks. This teacher would periodically conduct a homework check. The homework check entailed students being asked for the correct answer to randomly chosen homework questions from the last three to five assignments. They were only allowed to use their notebook containing old assignments to answer the homework check.

Helen did two demonstrations during the observation period. She had some materials that she described and then passed around to the students. These were not demonstrations in which anything happened, they involved simply showing objects that were being discussed.

Helen used an Earth Science text that had a fairly low reading level, she described it as being at the eighth grade level. Reading assignments were given for each chapter; the teacher often had the students read the text aloud in class, one student at a time. Chapter questions were assigned for homework and then reviewed in class.

Helen typically gave a quiz every week about halfway through each chapter. These quizzes were comprised of fill-in-the-blank and short answer questions. Each quiz usually had a question that required the students to use some of the skills they had been working on in the class such as map reading or electron configurations. A chapter test was given at the end of each chapter, these were made up of multiple-choice questions and short answer questions; they also had a question or two that involved some type of low level problem solving. Both the tests and quizzes were a conglomerate of textbook questions and teacher-generated questions. Prior to the tests, the teacher spent one class period reviewing the material that would be on the test; she also wrote down exactly how many questions would be on the test and what they were about on the overhead. The students always had a review sheet to complete before taking the chapter test.

Helen had labs or activities for students to do about twice each week. She assigned pre-labs as homework the day before each lab; these pre-labs had to be stamped by the teacher before the student could begin the lab. The teacher often reviewed the procedures for the activities the day before they were done in class; these activities did not require a prelab write-up. The teacher required the students to do all the questions involved in the activities and labs, she reviewed the correct answers before the students turned in their work. Students in this class did not work well on their own in the lab. Many used it as a time to socialize, others had trouble working independently and continually asked for teacher guidance.

Helen showed numerous videos during the observation period. Some of these videos were quite short, five to ten minutes long, while others were much longer and took most of the class period. She required that students pay close attention to the videos, giving them topics to write a sentence on or assigning questions to be answered using video information. Helen sometimes asked questions about the video material on the quizzes. Students did well watching the videos, most tried to jot down a few notes while watching, usually on the topics assigned by the teacher. The quality of the videos was generally good but a few were old and outdated.

Helen's planning book was collected every two weeks. Her planning was always done for one to two weeks in advance. She wrote down the main activity for each day and also any assignment to be given. The entry for each day had typically two to three listings, for example Thursday, October 1, had the items: "begin Map Scale Activity, Review for Quiz, and HW: study for Quiz." No greater detail was seen in any of the entries.

Classroom Observation Forms

Helen's questioning strategies were analyzed for all the classes observed. She asked recall questions for facts or definitions a large majority of the time. This teacher asked open-ended questions about half as often as recall questions. The open-ended questions asked in this classroom were most often about material already covered in earlier sessions. The teacher did ask questions about students' prior experiences and prior knowledge and a few questions that called for explanations or clarifications by the students, these questions did not happen often. No questions to directly elicit students' preconceptions or that asked for students' predictions that might show up preconceptions were observed. Students did not ask many questions in this class. A few occurrences were observed when students asked for explanations or offered input. The majority of student questions were asked when students were in the lab, asking for help and for directions on how to do the lab work.

Helen usually presented material in a lecture format; she conducted two demonstrations during the observation period and was observed to explain phenomena using scientific concepts twice. No incident of using a discrepant event to uncover preconceptions or conducting a class discussion to elicit students' ideas was observed. As far as written work, Helen's classes had occurrences of all written work except pretests, writing prompts, or concept maps.

Teacher's Strategies for Diagnosis

Helen was not observed to use any formal strategies for identification of her students' preconceptions. She was not seen to use concept maps, pretests, interviews, discussion to elicit students' ideas, or writing prompts as methods for diagnosing students' ideas. Helen mentioned when interviewed that questioning was a way that she identified her students' preconceptions; therefore, this strategy was analyzed as a possible strategy for the diagnosis of preconceptions.

Helen used oral questioning of students when she reviewed material or introduced new information; she attempted to find out what her students knew by asking them a variety of questions on new material and material already introduced. These questions were most often general and involved the teacher asking the whole class for an answer. For example, the teacher asked the question: What is the difference between weight and mass? She received a variety of answers, all incorrect, and she then repeated the question. After the second try, she gave the class the scientific definition and explained the difference. Helen did not seem to pay any attention to the students' incorrect answers; she was looking for the correct answer only. When she did not get it, she supplied it herself. She used this method for presenting the new information.

The teacher also asked students for their definition of a word in an attempt to get them thinking about new terms.

Teacher:	Lots of students think it's like the opposite of organic in the grocery store, like inorganic means used with pesticides, that kind of thing. Inorganic means what instead?
Student 1:	It's like dead.
Teacher:	Little more than dead, cause something dead was once living.
Student 2:	Artificial
Teacher:	What do we mean by artificial?
Student 2:	It's not real
Student 3:	Man-made
Student 4:	Never alive
Teacher:	Okay, man helped make it, we're getting closer. But there are rocks in the earth that man didn't help make and they are still inorganic. So what is the true meaning of inorganic? Organic actually means what?
Student 5:	It was made by plants, dinosaurs, animals…
Teacher:	Excellent, so there were not plants or animals involved, one thing you're going to see in all plants and animals is that they're organic, carbon. If something is inorganic, it means it doesn't have carbon. Your book says "not formed by any process involving plants, animals, or other organisms."

Helen was not observed to spend time attempting to change the students' incorrect prior knowledge while she was asking oral questions. She did not focus on or discuss any preconceptions that were vocalized by students. This teacher was observed backing up and rephrasing her questions or asking another student for an answer when one of her questions uncovered a preconception.

Another questioning strategy observed in Helen's classes was when she asked students to make a prediction about a specific phenomenon. She listened to their predictions and then responded with the accepted scientific answer. Helen was not observed attempting to change the incorrect ideas uncovered as students made their predictions. In this excerpt, she asked for students' predictions about magnetic declination:

Teacher: How come it is different? Somebody take a guess. What would be your first hunch? If I'm following my compass and I think I'm walking north but really I'm not walking true north, it is just magnetic north. Why might there be a difference?

Student: Cause, uh, it is something magnetic around you, it could be distracting the compass.

Teacher: Yes, right, if I'm walking over a whole bunch of magnetite, that could deflect it. Any other guesses? So one person said the rocks around you could affect it. The concise science dictionary, your book didn't really give a definition, says "the source of the difference is not really known but believed to be associated with the action within the earth's liquid core."

Helen was observed a number of times to use polls to collect information on students' ideas. She would ask the students to raise their hands if they thought a certain answer was right; she also asked students to simply raise their hands if they had a specific answer. This teacher tried to get students to think about the answer by posing a question and then asking how many students thought the answer was "yes" and how many thought it would be "no":

Teacher: We're going to talk about the electrons in the atom; specifically, the electrons around the nucleus of the atom. So we know how the color was produced, so are all the atoms starting in the same place? So if I have a calcium atom and a potassium atom, are their electrons, calcium has 20 electrons, potassium has 19, are calcium's 20 electrons all starting in the same spot as the potassium atom's? How many think yes? How many think no? So in other words, are all the electrons starting in the same spot when they jump up? Yes?...No?...

Students: [a few raise hands for yes, a few raise hands for no, several mumble a yes or a no]

Teacher: The answer is no, the electrons that jump up might be in different spots.

The data collected by these polls was not seen to be used by Helen. She was never observed to count the numbers of students responding to her queries. Her next step after asking students to raise their hands was to give the accepted scientific answer. No attempt to change any of the students' preconceptions was observed. The teacher's main concern in all her questioning strategies was to get the correct answer vocalized and to move on as quickly as possible.

Teacher's Responses to Interview Questions

The teacher was interviewed three different times. The first two interviews involved questions about the teacher's background and teaching practices. The last interview incorporated a stimulated recall interview and a short interview about the teacher's identification of her students' preconceptions.

Helen was asked if she thought it was important to know what her students' prior knowledge or personal conceptions were before teaching a topic. This question was asked during the first interview; this interview occurred 10 weeks prior to the second interview and the stimulated recall interview. She felt strongly that it was important and felt that talking to the students helped her to get a feel of what the students' ideas were before beginning a topic:

> Well, yeah, you have to find out, you try to find out as much as you can, I guess, and if you don't find out and they've had the stuff they'll tell you, usually, they'll tell you. If they have honestly heard something, if it's a complete repeat, they'll either finish their assignment like in two minutes and then you have a clue that you should have probably gone a little deeper or something or they're just so bored it could even be the opposite, they're so overwhelmed that they've never seen anything like it. Then you need to break it up into baby steps. But talking to them helps and kinda watching

> them and sometimes the first assignment is a big deal for them, you just have to look at them in class.

The teacher seemed to equate students having preconceptions on a topic with whether they had previously had the material introduced to them. Helen seemed to be saying that if students had heard of a concept, they would automatically have an understanding about it and would have no preconceptions about it.

During the interviews, Helen was asked if she attempted to find out what ideas students had on a topic before she taught a unit. In her reply, Helen mentioned that she had been required to pre-assess students while student teaching and had used a paper and pencil instrument to do this assessment; she mentioned that she did not feel it worked as well as a class discussion:

> Usually, well, when I start out the lesson, we'll kind of, I'll see where they're at. Like, for metrics, I had them estimate, and I had them tell me what they were estimating in; so, it's kind of, I had something where we could kind of work together as a class. And, usually by discussion, if, sometimes they're way ahead, but, usually I can see where they're at by that way. It's, usually it's discussion; it's a pretty informal pre-assessment. It's not a, I used to have to do the paper where they had to write down what they knew, and uh, I don't think it was as effective as... Discussion works just as good, it seems like. The discussion is more usable to me. I can figure out their attitude-- their attitude is a big part of it. So I can kind of guess their attitude and figure out their, what their knowledge is, pretty fast. The paper kind of worked but it wasn't that effective.

When Helen was asked why she felt that the paper pre-assessment was not as effective as discussion, she responded that it was easier to tell what the students knew by talking to them than by having them write down something on paper. When asked about the talking she did with the students when attempting to identify their ideas, Helen felt that in a discussion, when a question is posed to a student, that they had to answer; she said they wouldn't say "I don't know." She also said that if she heard a student say something in class that was "way off," she would try and correct it. "At least you have to point it out and say 'No, you are not exactly right, that's not how it is.'" This teacher was not observed holding any type of class discussion that involved students expressing their ideas.

Helen was asked about other methods that might be used to attempt to find out students' preconceptions. She answered that she sometimes found out the students' preconceptions by looking at the short answers they provided on tests. She said, ideally, she would like to write in the correct answer on each test but she said she did not have time. What she did do was go over the test in class, provide the correct answers and hope the students corrected their own. "I hope that at least by hearing it (the correct answer), they'll get it but it is tough because classes are so big." She also said that when students were in a group situation, "lots of times their partners steer them in the right directions."

Helen was asked how the information gathered when assessing students' preconceptions might be used:

Teacher:	You can say what somebody thought out loud, you can say "This is what she thought." And sometimes I'll explain where the confusion came from and I'll say this is where the confusion is and then I'll explain why I think it is and why I think it's not. You can use them (misconceptions) as examples in class.
Researcher:	Anything else? How might you use the information gathered?
Teacher:	Just as examples in class.

Helen was never observed using a student's idea as an example to other students in this manner during the classroom observations.

The teachers were asked in the interviews if they could think of any common or reoccurring preconceptions that students regularly had on the topics being covered in their class. They were also asked if that knowledge of the generic preconceptions had any affect on the planning they did when teaching the specific topic. Helen responded that she saw reoccurring evidence of preconceptions in students on the topics of " the difference between molecule and compound, atomic number and mass number." She also thought that the difference between families and categories in rocks usually was a problem. The teacher went on to discuss how students always had trouble with graphing and anything involving math. It is possible that she did not use the term preconception to mean an idea or concept but more to mean a difficulty in understanding something. When asked if the knowledge she had of the generic preconceptions affected her planning, she responded:

> Yes, there are some things I start out different now. Like graphing, we start it out with real small steps and with the Periodic Table, I'm trying to but, you try to change, like I don't give the stuff, the notes I give are so different now than they were years ago. I gave a ton. I don't give near as much as I used to; this year has been a lot less...some of it just doesn't work.

Helen was asked to talk about any pros and cons she felt there were for attempting to diagnose students' ideas in the classroom. She said that she thought it was important to do but also that it was very hard to do. When asked why it was hard to do, she replied that it was because "there's a huge difference, it's so broad, there's a ton of variation, it's just enormous."

At the beginning of the stimulated recall interview, the teacher was asked to watch a portion of a lesson she had taught on atoms, elements and the Periodic Table. This segment was part of an introductory lesson for the chapter she taught about elements, rocks, and minerals. In the video segment, the teacher was questioning the students about the Periodic Table, atoms, molecules, and elements. When Helen was asked to describe what she was doing in the clip and why, she responded that she was giving the students information that they needed to know for the chapter. She said she was giving students this information because it was information they had to have to do the rest of the chapter. The teacher was also asked what she thought the students had known about this topic before she started the lesson:

> Teacher: They knew it existed. I know they know the atom existed, I know they knew it had something to do with elements and they knew it had something to do with matter and I'm not sure…uh…I know they know that atoms build up stuff and that it, like, makes matter. But, you know, I knew that they had probably seen the Periodic Table, I wasn't sure that they knew what everything meant on the Periodic Table. I knew they wouldn't know what all the numbers in each box meant. Because, ah, and you know, that's the thing, they knew what was in an atom maybe or if they have an idea, they knew the atom is a tiny speck and I knew they probably had trouble figuring out what were those tiny specks are called and the parts of them…
>
> Researcher: And how did you know that?
>
> Teacher: I kind of gathered that from this group. Two of the students, Tom and Carla, had a good grip on this stuff. A lot of the

> others, they said they knew it but they know some of it. Some of it I've figured out....I kinda have an idea...but you have to ask them.

Helen was also asked to talk about any planning she did before the discussion of the lesson and any changes she may have made in the plans she had for subsequent classes. She said that she had written down some questions prior to the class, but that many of the questions were ones that she had generated a few years before and that she simply pulled out of a file when it was time to introduce this topic. She mentioned that the changes she made to classes following this class were changes she made in the amount of material that she covered in the unit. She had decided to cover less material this year in all of her lessons because she found the students were having a hard time encompassing large amounts of information. The lesson under discussion was one in which she had decided to cover less. This decision was apparently made before she taught the introductory lesson but strengthened after the lesson was taught.

In the first interview, Helen was asked what the terms "conceptual change teaching" and "constructivism" meant. She had never heard of constructivism and responded that maybe conceptual change teaching involved changing the picture a student held in his/her head about a concept. "You have to figure out what the picture is in their head. I guess, I think of a concept, I think of a picture. They kind of see a picture in their head, and you try and have them change their picture in their head."

When asked to describe any science education reforms that had been proposed for secondary science teaching, the teacher discussed the state's implementation of grade 10 testing in science, she said it was good because then "everyone's going to be teaching the same thing." Helen talked about how this reform might affect her teaching because she would be expected to incorporate more physics into Earth Science. She felt that the "reform" would also cause all science teachers to have to cover more material in a shorter period of time.

Helen was asked about her main concerns when planning for a unit or lesson. She said that her main concern was not to overload the students with too much content on a given day, to make the class interesting, and to plan some sort of activity to get the students involved. Also in the first interview, the teacher was asked about the information and resources she used for planning her lessons. She responded that she used the class text and some college texts, also the district curriculum guide and the internet for information.

Summary

Helen was not observed using any formal strategy for identification of students' preconceptions. She was observed using questions as she looked for the students' knowledge of the correct answers rather than their ideas although she maintained in her interview that she thought identification of students' ideas was important. She said that asking students or having a discussion to attempt to elicit students' preconceptions were more effective than a paper-and-pencil form of pre-assessment. She sometimes used a type of poll to get the students to voice their ideas but was never observed to attempt to use the information she gathered in the polls. When asked how she might use information gathered when assessing students' preconceptions, she said she could use it as an example to other students in class. Helen said she would describe the preconception and then explain where the confusion came from to other students in the class. She was never observed doing this type of explanation.

Helen's planning for her lessons did not involve any consideration of students' prior knowledge. When asked what her main concerns were for planning a unit or a lesson, she responded that she was most concerned about overloading the students with information and making the material interesting. She was also asked about how the information she gathered when questioning students was used in planning subsequent lessons. She responded that, in the specific case being discussed, she cut down the information to be covered.

Helen maintained that diagnosing students' ideas was important but her classroom practices were focused on conveying the correct answer to the students rather than eliciting their ideas. Her expressed belief that it is important to find out students' ideas was not in alignment with her everyday classroom practices.

Bob

Description of Teacher, Classroom and Course

Bob received a BS in Biology and teaching certification in science in 1974, 25 years ago; he also has a MS in Education. He has taught grades 7-12 for 24 years, predominantly teaching biology courses. He was the science department head, sat on the site council for the high school and was also a member of the school's Career Advisory Committee

Bob's fifth period General Biology class was observed for data collection. This class was the last of the day for the teacher; he had a sixth hour prep. The students in the class were moderately motivated, there were three freshmen and two seniors and the rest of the students were sophomores and juniors. There was good attendance in the class, all of the 30 students were usually there with only one or two students absent periodically. The classroom was quite large; the students sat at individual desks in the front part of the room, there were eight large tables (with four chairs each) at the back of the room for lab work. The class periods at this high school were all 50 minutes long except when shortened for early release or assemblies. The class was observed from the third week through the twelfth week of school, the teacher covered chapters 2-5 in the text during this time.

Bob typically began each week by asking the students to writ in their day planners all assignments, tests, or labs for that week. He also had a daily schedule up on the board but did not discuss it. Bob most often began the class by going around the room to check each student's homework. He used this time for interactions with the students, often teasing them, asking about their social life, sports activities, or school activities. He stamped their work if done; he gave half a stamp if only half done. Bob used this time to reprimand students that did not have their work done, issuing warnings and threats. After checking the students' work, Bob read the correct answers to the homework and then collected it.

Bob often followed the homework corrections with a presentation of new material. What he termed class discussion consisted of his writing notes on the overhead, often using a videodisc for illustration, and the students copying the new material in their notes. Bob questioned students continually during this time, usually directing these questions to the whole class; typically two or three students responded.

Bob assigned homework three to four times per week; he assigned reading from the text, text worksheets, text questions, crosswords, or lab write-ups. Often there was time in class for the students to work on their assignments, sometimes as much as 25-30 minutes. The work was always stamped and graded the day it was due.

Bob did three demonstrations during the observation period. These demonstrations were fairly simple with little equipment involved. The students were all interested in the demonstrations; they paid close attention, asked questions, and made comments throughout. The teacher always had some type of student participation with each demonstration.

Bob followed the textbook closely; he assigned reading from the text and all the chapter questions. When he assigned reading from the text, Bob usually allowed students time in class to complete it.

Bob gave one or two quizzes for each chapter in the text and one chapter test. He generated the quizzes and tests. The quizzes were usually 10 fill-in-the-blank questions; they took the students about five minutes to complete. The tests were made up of multiple-choice questions, short answer questions, and an essay question. These tests were often difficult for the students; they needed 20-30 minutes to complete the tests.

Bob had the students do labs about once a week, sometimes once every two weeks. The students were required to do a pre-lab write-up the night before the lab, when this was completed to the teacher's satisfaction, he would stamp it and the student was cleared to do the lab. He reviewed the lab questions, conclusions, and error analysis with the whole class after the lab was complete. The students then wrote down the answers that had been generated by the class and turned in the lab.

Bob showed videos in the class five times during the observation period. These were used to highlight a topic being discussed in class such as atoms or acids and bases. The quality of the videos was not high on the average; some were quite old and hard to hear. Students were not asked to take notes or answer questions about the video material. Once the teacher did show a purely entertainment video on Grizzly Bears to take up class time (25 minutes) after the students took a test.

Bob's planning book was reviewed every two weeks. He was typically planned for one week in advance. The entries in his planning book were short, usually a few items. For example for the date, Tuesday, September 29, the entry was: "Discussion pH, start pH lab."

Classroom Observation Forms

Bob's questions to students were primarily on recall of facts or definitions. He also asked a large number of open-ended questions and just as many questions about students' prior knowledge, most of these open-ended and prior knowledge questions were regarding concepts that had been covered earlier in the course and Bob was reviewing with the students. A few questions were posed that asked for students' explanations or clarifications, eight questions about students' prior experiences were observed. Students were not observed to ask many questions of any type in this class; they did however, ask many questions when in the lab. They seemed to continually ask the teacher for help and clarification when attempting lab work.

Bob presented information in a lecture format. He did two demonstrations during the observation period and used scientific concepts to explain phenomena five times. He was not observed to contrast students' preconceptions with scientific concepts, use discrepant events to uncover preconceptions, or to hold class discussion to elicit students' preconceptions. Bob was observed using all written work listed on the observation form except pretests, writing prompts, or concept maps.

Teacher's Strategies for Diagnosis

Bob was not observed to use any formal strategies for diagnosis of students' preconceptions; he was not observed using pretests, concept maps, interviews, writing prompts, or class discussions to elicit students' ideas. Bob volunteered the strategy of oral questioning when asked in an interview how he identified students' preconceptions.

Bob questioned students orally during most class periods. He asked general questions posed to all members of the class and also questions targeted at a specific student, called on by name. When discussing cell theory with the students, he asked a question that revealed a preconception held by a student; no response was made by the teacher to this student:

Teacher:	What might be the exception to the rule of all living things being made of cells?
Student:	An atom?
Teacher:	A virus is the exception to this rule.

Bob was not observed responding to preconceptions exhibited by students except to tell the student that his/her answer was wrong or give the student the right answer. He was primarily concerned with communicating the correct answer.

Bob used a vocabulary exercise to allow individual students a chance to express their understanding of specific terms. This exercise was used during each chapter as the students learned new terms and reviewed old ones. Students worked in pairs; the teacher assigned each group one vocabulary term. They had about 20 minutes to come up with the book definition, their own definition, an example, and a nonexample for the term. The students then put their results on a large piece of paper and presented it orally to the class.

The book definitions and the students' definitions were usually close to the accepted scientific conception of the term but the examples and nonexamples showed that the students might have held preconceptions about the topic. For instance, the nonexample given for the term "adaptation" was "heart, inner organs"; the example for the term "metabolism" was "all living things, plants and humans." Also, a student gave the nonexample "air" for the term "environment." When studying another chapter, an example for the term "digestion" was "defecation" and the nonexample for the same term was "lifting, throwing."

The students were not graded on this project except that they got five points each for doing the presentation. The teacher did not comment on or correct any of the confusing examples or nonexamples expressed. The students had generated these examples and nonexamples from their own experiences and knowledge; they did not use any reference materials.

Teacher's Responses to Interview Questions

Bob was interviewed three times. Two interviews were conducted prior to the classroom observations; the last was held the week after the observations ended.

During the first two interviews, Bob was asked about his background and teaching practices. The last interview was a combination of a stimulated recall interview and an interview about Bob's practices and his identification of students' preconceptions.

Bob was asked if he thought it was important to find out his students' prior knowledge and personal conceptions before teaching a topic. He felt that it was important but said it was very difficult to do.

> Yeah, it is very important to know but it's almost impossible to do. I kinda go on the assumption that they don't know anything. And if you do that, you do one of two things, one you are either reinforcing what they know or you are giving it to them, you're teaching it for the first time. And a lot of the concepts they've had before. They've heard of the word photosynthesis many times but it hasn't sunk in yet. The more you go over it, the more you reinforce it, the more it sinks in.

When asked what some of the ways he might use to find out about students' preconceptions, Bob responded that questioning was important. "That goes back to the reviewing, the questioning and answering things. Asking them specific questions, you can get at a lot of the misconceptions." In his response, this teacher used the term misconception; he seemed familiar with this term and used it when discussing preconceptions and students' personal conceptions. Bob was asked if there were any other ways he could think of to use to find out students' preconceptions, his response was "You could pick up some on tests."

Bob was then asked about using the information gathered when assessing students' preconceptions. His response was: "Well, then you can adjust your teaching accordingly. You can decide what you need to back up and pick up, to get them, you know, what building blocks do you need to get them up to the concept." Bob was observed backing up and rephrasing questions, attempting to reword explanations, and trying to get students to answer his questions correctly by using hints or suggestions.

Bob was asked if he could discuss what he thought were the pros and cons of attempting to diagnose students' ideas. He replied that he thought it was important to try to do and that the negative was that it was very hard to do.

The teacher was asked if he could think of any common or reoccurring preconceptions that students regularly have on any of the topics he covered. He was also asked if his knowledge of these generic preconceptions had any affect on the way he taught that material. Bob said he usually saw a lot of preconceptions on the topic of plant photosynthesis. He described how his students confused cellular respiration and breathing and how year after year he had students that had preconceptions about cell walls and cell membranes and how they could not sort out the concept. When asked about any specific strategies he used to handle these preconceptions since he knew they reoccurred, he responded:

> No, just in the typical teaching. Just, you know, making a point of, okay, plants also have a cell membrane, what is just the function of the cell walls: just support. Well, but the function of the cell membrane is regulating, what's going to regulate what goes in and out of plant cells also? You know, you make a point to hit, to make sure you cover those points that they have misconceptions on.

For the purpose of the stimulated recall interview, Bob was asked to watch a short clip of his teaching a lesson on enzymes. During the lesson, Bob questioned the students both individually and as a whole class. When asked what he was doing and why, Bob responded that he was reviewing because he knew some students had heard all of this before but he was also trying to check for understanding. He said that he thought that most of the students knew the information he was covering and that their responses showed him what they knew. The main point that Bob discussed in conjunction with the portion of the lesson being discussed was involvement of students. He said one of his main objectives for this question and answer session was to get more students to respond to his questions in class. When asked about planning for this session, he said he had planned to do two things, to find out what the students knew and to try to involve as many students as possible in the question and answer session.

When asked about "conceptual change teaching" and "constructivism" in the first interview, Bob said he had never heard of conceptual change teaching and thought that constructivism meant "building on an idea."

Bob was asked if he could describe any reforms that were being proposed for secondary science education. He responded that performance assessment was one that he was being told to incorporate into his teaching; he said he did not feel that using performance assessment would be a benefit. He felt that using it would mean that he would not be able to cover as many topics in the school year. He felt that, especially in his AP biology classes, he had trouble getting through the required material and with "presentations and portfolios, and things like that" he would never be able to cover what was necessary.

Bob was asked about his main concerns when planning for a unit or lesson. He responded that for a unit he was mainly concerned with the sequencing of the material, for a lesson his concerns were for the objectives of that lesson. He felt it most important to establish a goal for the lesson and then check to make sure the goal was accomplished. When asked about the information or resources he used when planning lessons, he responded that he used other biology teachers, the teacher's guide, his own prior knowledge, and the administrative guidelines.

Summary

Bob was not observed using any strategies to identify his students' preconceptions; he did not use pretests, interviews, concept maps, class discussion to elicit students' ideas, or writing prompts. Bob maintained that asking students specific questions was a way to get at their preconceptions. He was observed asking his students questions in class in order to determine their knowledge of the accepted scientific answer. Bob's questions to students were primarily for conveying the correct answer, involving students, or reviewing material. Bob said he used information from diagnosing students' ideas to re-teach what was necessary or to determine what building blocks the students needed. Bob also used a vocabulary exercise that did provide a situation where students' ideas were expressed, he did not mention this strategy in his interviews nor did he use the students' preconceptions that were uncovered in the exercise.

Bob discussed a few generic preconceptions that he had seen in students over the years. He said he made a point of explaining these concepts carefully whenever he taught them.

When describing his objectives during a question and answer session, Bob said he had wanted to find out what the students knew by questioning them but he also had wanted to increase student involvement. His interview response was that he did believe that diagnosing students' ideas was important but Bob's classroom practices did not show evidence of this belief. His questioning was done to see if the students knew the correct answer and to get the students involved in the class.

Steve

Description of Teacher, Classroom and Course

Steve had taught for 15 years and had a BS in Biology, BA in Education, and MA in Science Education. He had taught many science, math and computer science courses over the years but AP Biology and General Biology were the courses he taught the longest. Steve was the co-department chair for the science department, a member of the school Learning Improvement Team, advisor for the science fair and ecology club, and a member of the school's Faculty Council. He also was active in the summer working with other science teachers at the nearby national research laboratory.

The teacher's second class of the day, General Biology, was the class observed for data collection. The majority of the students were sophomores and juniors with a few freshmen. The students seemed to be highly motivated, their attendance rate was good; it was rare for more than one student to be absent on a given day, many days the full class of 28 students was present. The students sat at individual desks in the center of the room; there were lab tables on the edges of the room where groups of four students sat to do lab work. The class period was 50 minutes long except when the school was on an early release schedule; they were then 90 minutes long. The observations of this class were made for nine weeks, from the third week of the school year through the twelfth week. During this time, the teacher covered chapters 1, 3, and 4 in the textbook.

Steve started out each class period by pointing out to the students that day's schedule up on the board. This schedule included homework due, new assignments, any notes to be given, lab work, and any other activity for the day. The teacher began the class with a presentation of new material using the overhead; the students copied the information in their notebooks. This presentation of new material did not occur every day; on the days when no new notes were given, the teacher presented lab information or reviewed class material on the overhead.

Steve typically gave students a homework assignment every day. These assignments were made up of questions from the text, review sheets, worksheets, crossword puzzles, or lab work. The students were given as much as 10 minutes in class to work on their assignment but usually were expected to complete it outside class time. The homework was graded in class the day it was due after being checked and stamped. The teacher stamped any homework that was completed, right or wrong answers. If a student had not completed the homework, then no stamp was given. They could still do the work later but would not receive full credit. The teacher read out the answers to the questions and had students correct their own work or had students exchange papers and correct another student's work. Steve also required the students to do two reports per quarter, either written or oral, on some biological topic that interested them. They were required to do all research and writing of these reports outside class.

Steve did demonstrations two or three times each week in his class. These demonstrations were usually detailed and required a lot of equipment and time to complete. He questioned students thoroughly as he did the demonstrations; the students asked a lot of questions and paid close attention to the demonstrations.

Steve used the class textbook each class period: asking students questions and directing them to a specific page for the answer, using transparencies of text charts and diagrams on the overhead to emphasize material, or using the text's chapter goals as general questions for a class discussion. He also regularly reminded the students to reread their text reading assignments two to three times in order to get the complete meaning.

Steve gave the students an exam at the end of each chapter and a quiz halfway through coverage of the chapter. The tests were multiple-choice with one or two essay questions. Steve generated his own tests. The students were given a review before the test and told exactly what content would be on the test. The tests took the students about 20 minutes to complete. The quizzes were short, usually 10 multiple-choice or matching questions. These quizzes took the students only a few minutes to do. The teacher reviewed the tests and quizzes in class and asked students to correct their answers.

Labs were a regular occurrence in this classroom; Steve had the students do a lab once or sometimes twice a week. The labs often took more than one class period due to the 50-minute classes. No pre-lab write-up was required; Steve reviewed the directions the day before the lab or even the day of the lab. The students answered the lab worksheet questions and turned that in for their lab grade. The worksheets were from the lab book corresponding to the class text. The students worked in groups of two in the lab; there were two more groups than lab stations. These groups were placed at tables in the back of the room. Most students had to be helped and encouraged during the labs; many continually asked Steve for assistance.

Steve rarely showed videos in his class; during the nine-week observation period, the students were shown two videos, both quite short, about 10 – 12 minutes long, of good quality, and of recent production.

Steve did not have a specific planning book but wrote his plans on paper and then stapled them together. These pages were reviewed every three weeks during the observation period; he was typically planned one week ahead. On the page Steve wrote out for a lesson, he would include the notes he planned to put on the overhead for students, a few major questions to ask the students, any demonstration or lab notes, reminders to return specific work, and any homework assignment.

Classroom Observation Forms

Steve asked a large number of questions throughout all his classes. He most commonly asked questions on the recall of facts or definitions but he also asked a large number of open-ended questions and questions about the students' prior instruction. Steve asked a preponderance of questions about the students' everyday experiences and knowledge about common daily events. The students in this classroom asked a large number of questions. Not only during their lab work, but also during the teacher's lectures, students asked questions about the material, asked for explanations and clarifications, and offered input.

The teacher presented information in lecture form and often illustrated his lectures with detailed, showy demonstrations. One of these demonstrations was a discrepant event that could have been developed to uncover students' preconceptions. Steve was observed to use scientific concepts to explain phenomena but was not observed contrasting students' preconceptions with scientific concepts or using class discussion to elicit students' ideas. Steve used all the types of written work listed on the observation form except pretests, writing prompts, or concept maps.

Teacher's Strategies for Diagnosis

Steve was not observed using any diagnostic strategies such as pretests, interviews, concept maps, class discussions, or writing prompts to elicit students' preconceptions. In his interview with the researcher, Steve mentioned that questioning students was one strategy he used to assess his students' understanding. He also mentioned in his interview that using an open-ended, discrepant-event type of lab or telling stories to the students would be ways to identify students' preconceptions on specific topics. He was not observed using either of these methods in his teaching. Steve asked numerous questions throughout the observation period on students' prior knowledge and experiences.

Steve continually asked the students questions as he presented new material and reviewed old material. Most often these questions were recall of facts or definitions; he did ask open-ended questions about half as often as recall questions. Steve used questioning as a strategy to try to identify students' knowledge on science concepts being presented. In a lesson on the particles in solids, liquids, and gases, employing a diagram on the overhead of the three states of matter, Steve asked the following questions:

Teacher:	The particles (solid) are arranged in order, and these particles (liquid), Phil, what would you say about these?
Phil:	They are farther apart.
Teacher:	The distance between them is a little more and they are…?
Phil:	Moving.
Teacher:	Moving. Now here's a catch, are these (solid) moving?
Chorus of students:	No

Teacher:	You know, it turns out they are. Even particles in matter move but the catch in their moving, they just kinda move back and forth, they don't move from this corner. Not like liquids, they are free to move about. Everything moves, what's that energy thing you have cause everything moves?
Chorus of Students:	Kinetic.
Teacher:	Yeah, kinetic.

Steve seemed to listen carefully to the answers students gave and then explained the accepted scientific concept. He did not spend time discussing the students' preconceptions that surfaced during questioning or contrasting them to the accepted view. Steve did not always respond to the preconceptions that he uncovered while asking students questions:

Teacher:	What are protons, neutrons, and electrons made of?
Student 1:	Cells.
Student 2:	Atoms.
Student 3:	Molecules.
Teacher:	Quarks......

Steve was looking for the correct answer in his exchanges with students. If he did not get the students to provide the answer he was looking for, he provided it himself.

Steve asked many questions to students about the prior knowledge they had or about experiences they had involving specific concepts. These questions allowed him to get an idea of whether the students had ever heard of the concepts before beginning to discuss them and also to relate the material to the students' daily experiences.

Teacher:	A volunteer out there.... Carla, do you know what DNA is? Carla?
Carla:	Deoxyribonucleic Acid

Teacher:	Yes, she said deoxyribonucleic acid. That's right, do you know what it is?
Carla:	No.....
Teacher:	In the molecule, it carries the codes of....?
Student:	Genes
Teacher:	Oh, genes. I wanted codes of life. But genes is the code of life too so genes is real good. Now, go over to Shawn, what is RNA? That's hard. If anyone else wants to volunteer go ahead.... If he knows he'd be real smart. I can't imagine anyone just knowing. That's hard, you may never have seen it before, very few people have.
Student:	Ribonucleic Acid
Teacher:	Ribonucleic Acid, what's it do?
Student:	Don't know
Teacher:	That's good, knowing the name is half the battle.

In a presentation of new material on lipids, Steve had a can of shortening and a bottle of oil in front of the room to show the students. He held these up for all students to see and began a discussion to get the students thinking about these everyday items.

Teacher:	What's the difference between these two?
Student 1:	A liquid and a ......
Teacher:	A liquid and a...?
Student 1:	A solid, kinda
Teacher:	What do you mean it's kinda solid?
Student 2:	Nothing, there's no difference.
Student 3:	They're both lipids.
Teacher:	So it's (lard) not as solid as a table?
Student 4:	You couldn't form it.
Student 5:	It doesn't flow as free as a liquid.
Teacher:	It doesn't what?
Student 5:	It doesn't drip, it's thin.
Teacher:	The oil flows, spills, pours, lard doesn't.
Student 6:	It doesn't dissolve in water.
Teacher:	So this one (oil) doesn't dissolve in water and this one (lard) doesn't dissolve in?
Student 6:	Water.
Student 7:	Doesn't dissolve in water.
Teacher:	Oh. So this is a solid (lard) and this (oil) is a liquid. This one (lard) comes from?

Student 8:	Pigs.
Teacher:	Yeah, pigs, cows.
Student 8:	It's called lard.
Student 9:	It's called fat.
Teacher:	This one (lard) comes from?
Student 10:	Animals.
Teacher:	This one (oil) comes from?
Student 10:	Humans.
Teacher:	Plants! Vegetable oil. You can get sunflower oil, corn oil, all kinds. Plants make oils, animals typically fats. They are very different, which is better for you?
Student 11:	The vegetable stuff.
Teacher:	The vegetable stuff, yeah. This (lard) is bad, bad, bad.

Steve was not observed to attempt to change the preconceptions that he uncovered during his questioning of students. His usual response was to provide the students with the accepted scientific answer and move on. When questioning the students about their experiences, he never commented on these answers but accepted all students' responses and used the relevant ones to illustrate his discussion.

Teacher's Responses to Interview Questions

Steve was interviewed three times during this study. The first two interviews involved questions about his background and teaching experiences, the last interview was conducted after classroom observations had been completed and included a stimulated recall interview and questions about identification of students' preconceptions.

Steve was asked if he thought it was important to know what his students' prior knowledge or personal conceptions were before he started teaching a new topic. He responded that he thought it was important but that it was hard to know what they were, he said the only way to know would be to talk to the teachers who had taught the students the year before. Steve was asked if he ever attempted to find out what ideas students had on a topic before he began teaching that concept. His reply was: "Yeah, that would be typically the first day. Like the entry task, anticipatory set. From ITIP, bringing that out, I've asked a question and then we just kind of let things grow. We try to get 7 or 8 kids involved and then lead them into what we're doing. So, so, yeah." This teacher's motivation for asking questions seemed to be getting students involved and also to find out if they knew anything about the topic being introduced.

Steve talked about how he assessed students' understanding using question and answer sessions. He said he tried to start by asking basic knowledge questions and then would ask an application question.

> I try to use the higher thinking skills. We may, I may have to ask, four or five kids a series of questions so that we analyze, and then we're synthesizing and taking that concept and twisting it around, and then, applying it. And it might take several kids around the room. And we just kind of build and grow and finally, we, you know, we can answer a question, because we have organized the information. I'm spreading it around so they don't, you now, I'm just kind of spreading it around, and we're just kind of growing and growing and growing, and then finally, you know, somebody gets the final question that will connect all the ideas.

Steve was asked about any other strategies or approaches that could be used to get an idea of the students' preconceptions. He responded that labs were a good way, he described a photosynthesis lab that he had used in the past that helped students overcome a preconception about plant respiration. Steve claimed that after this lab many students understood the concept of plant respiration but "there's still probably 10% of the kids will say plants don't respire." This lab may have been used to change students' conceptions on plant respiration but the teacher did not describe how he might identify students' ideas prior to the lab. The teacher was not observed using this type of lab during the observation period.

Steve also volunteered the idea of using stories as a strategy to identify students' preconceptions. His description of this strategy showed that he may have again been thinking about how to change students' preconceptions rather than identify them:

> Of course, you can use, you can use stories. I can't think of any that I've used, but I'm sure you could devise stories to have them come to their own conclusion and see a wider breadth of information and then, maybe discredit an old idea. I don't know, it seems like I've had teachers do that but I can't remember… But I don't have any examples, so… That's a weak example.

When asked about using the information about students' ideas that might be found using these strategies, Steve thought that going back to re-teach the concept would be one way to use the information. He discussed the idea that the students may be resistant to change, that their ideas or preconceptions would not be that simple to change.

> You can go back and re-teach. I guess some of my experience has been that you're much, you're almost better off leaving the subject area for a period of time and then coming back and re-teaching… allow digestion time. And then you're going to have to come into it the second time with a different, you know you have to have the same concept, but a different approach. Somehow, you'll make that different, so they don't know that you're bringing 'em into the same area. Create an experience-base… That they

> might, after two or three experiences, might change their mind. Some people are pretty locked, younger, of course, younger people are not as locked...

Steve was asked if he could talk about any pros or cons of attempting to identify students' preconceptions. He replied that he thought it was important to direct students in the right direction and that he did not see any negative aspects. At another place in the interview, he did mention that it was a hard thing to try to do. "I guess the positive is that you're directing them with an accurate account of the scientific knowledge that we have. I don't see any negative to it. And, I don't, you know... that's the things we want to look for."

Steve was asked if he could think of any common or reoccurring preconceptions that his students regularly had on the topics he was teaching. He mentioned photosynthesis, saying that students always had the idea that animals respired but plants did not. This teacher also thought that "controls and the scientific method" were areas where students always had preconceptions. He said that inheritance, especially sex-linked inheritance, was a concept that students often had preconceptions about. When asked if the knowledge he had about these reoccurring preconceptions affected his planning for teaching the topics, he replied that it did not specifically, but he usually had to be sure to spend more time explaining these concepts carefully to the students.

For the stimulated recall interview, Steve was asked to watch a short video segment on his introduction of a biochemistry unit. Steve was asking students questions about their prior knowledge of biochemistry, he asked for definitions of terms such as DNA and RNA. Students were also asked if they could give the functions of DNA and RNA. When he was asked what he was doing in this segment and why, Steve replied that he was preparing the students for the coming chapter; he said that the students would need to know how to pronounce these terms and also what they were. Steve was asked what he thought the students had known about DNA and RNA before he began this discussion. He replied:

> DNA, they'll know about, but RNA... RNA is like maybe 5% will know about it. Actually probably 10% know about it, but only they don't consciously... They've read about it; 10% have read about it. But, they're a little nervous, they've read about so little that they really didn't, wouldn't... To my knowledge, no one, nobody teaches the function of, actually, probably the DNA function or RNA function at this school before me. That's biology, this is the first time for... many of the concepts, it's the first time.

Steve was then asked if he could describe any planning he did prior to the teaching covered in the video segment. He said he had not done any specific planning for that session, he did say his strategy of quizzing students on their prior knowledge was specific and intentional. He did not write it down in his planning but he had remembered that the students would need the information in a few days so he made a point to bring up the terms and talk about them. When asked if the information he gathered about the students' prior knowledge of these terms would affect his teaching of the material at a later date, he replied that he had been surprised that so many of the students had known the names of DNA and RNA and that one or two students had even known their functions but he did not change his plans for teaching the material in any way.

When Steve was asked about the terms "conceptual change teaching" and "constructivism", he replied that he had never heard of either but thought that constructivism was the process of constructing or building a foundation.

Steve was asked about current science education reforms. He mentioned that using different forms of assessment such as portfolio assessment was something he was being asked to do. He said that he liked the idea of alternative assessments but found it hard to use many because he was so busy. When he was asked if the reforms had affected his teaching in any way, he replied that he tried to implement some type of alternative assessment in his classes. He also mentioned that he had read the "standards" and that he tried to use them when he taught.

> I have read the standards and the processes that…our district has process goals. And the state, and the nation has more content goals. So they still can mesh. That's what I think about. I think I… And so, the reforms have affected me by, I try to use them. If I don't use them, I try to think of how I'm going to use them tomorrow, the next day after that, you know! They're always on my mind.

Steve was asked about his main concerns when planning a unit and also a single lesson. He replied that the objectives were the most important thing when planning for both a unit and a lesson. He was also concerned about making the lessons "active-based" for the students, getting the students involved in labs and activities as much as possible. Another concern of Steve's was the time frame for the unit. He said he usually tried to keep all units to a two-week time frame. When asked about the information or resources he used when planning his lessons, he replied that he mainly used the laboratory manual, textbook, study guide, and any handouts available. He also mentioned employing the internet to find information to use when planning a lesson.

Summary

Steve was not observed using any formal strategies for identification of his students' preconceptions. He did not employ pretests, interviews, concept maps, or writing prompts. Steve did say he questioned his students to determine their understanding and prior knowledge of a concept. He was observed questioning students in the classroom. Even though he said it was important and that he would use questioning to diagnose students' preconceptions, the questions Steve was observed using in his class were not probing questions to elicit students' ideas. His questions were predominantly asked to find out if the students knew the correct answer, to focus students' attention, or to involve students. In an interview, Steve responded that discrepant-event labs or stories would be a good way to determine students' preconceptions in the classroom. He was not observed employing either of these strategies.

Steve talked about coming back to re-teach a concept to students if he found they had preconceptions. He thought that leaving the subject for a time, then returning to it and creating some experiences for the students that might change their minds would be a way to use the information he may have gathered on students' preconceptions.

Steve's planning did not involve identification of students' preconceptions. He said he thought about finding out students' prior knowledge of terms and concepts but he did not specifically plan to use this strategy.

Bill

Description of Teacher, Classroom and Course

Bill taught for 34 years, had two BS degrees, math and physical science, and a MAT in physical science. He taught a number of sciences over the years but mostly physics and chemistry; he taught both these courses at the college level as well as the secondary level. He concentrated on general and Advanced Placement (AP) physics for the past 10 years.

The class observed was a third period AP physics class; two of the students had had a previous physics course but the rest of the class had not. The students were motivated as the course was obviously a college-prep course. Bill's classroom was not large, the students sat two to a table, used for both the lab and lecture portions of the class. The class period was 50 minutes long. The researcher was in the class every day for six weeks. The original proposal was to observe this teacher for nine weeks as with the other three teachers, but Bill's student teacher took over teaching the class three weeks earlier than was planned. During the six weeks of observation, Bill covered chapters 4-7 in the text.

Bill began each week by asking the students if they have observed any unusual phenomena. The topics students brought up were then discussed as a class for five to ten minutes. Bill also carefully reviewed the upcoming week's schedule and reminded students of tests, labs, or quizzes. Each class period began with Bill asking for any questions from the homework or lab problems. If students asked questions about specific problems, he did the problems on the overhead or asked a student to come up to the overhead to do a problem. When students asked more general questions on the class material, Bill spent five to ten minutes holding a discussion with students. Students' ideas were solicited and their questions answered. If there were no questions, Bill began the day's notes. He usually gave notes and worked problems on the overhead for about 20 minutes and then gave students the rest of the time to work on homework problems at their desks; they worked with partners or individually.

Bill continually did little demonstrations for the students as he was explaining the material. He often used a book, ruler, or desk. His demonstrations required the students to use their imaginations to visualize some physical phenomenon.

Students in this class were required to read their text material on their own; no class time was used for this activity. Bill used the text as a resource for problems to work in class; students were assigned the problems at the end of the chapter to do on their own and to ask questions about if they had trouble. The text was a college text and Bill had used it for two years.

Bill gave take-home tests for chapter exams; students had one week to complete the tests, which were made up of three or more AP Physics exam problems. He gave quizzes rarely, about once every three weeks. These quizzes were also made up of an AP Physics exam question and were completed in class. Bill graded the tests or quizzes and then reviewed the correct answers with the students in class when the tests or quizzes were returned.

The labs in this class were done every two to three weeks or whenever there was a 90- minute period (when the school had an early release day). Bill discussed the lab with the students the day prior to the lab and assigned the lab to be read as homework. Both labs observed were from the lab book. The students did the lab in class and then were required to complete the lab questions as homework, due a week after the lab occurred. The students worked independently in the lab; Bill spent time during the labs interacting with the students individually.

Bill showed videos in class about once every two weeks. All videos observed were good ones, demonstrating and discussing physics principles that were impossible to show in the classroom.

Bill's planning book was reviewed once during the observation period. He had his plan book laid out by nine week quarters, he had planned the complete quarter and did not write up specific daily plans. Every day for the quarter had an entry, usually one to two words such as: "Lab, Chapter 5" or "Chapter 4 Questions."

Classroom Observation Forms

Bill asked a large number of questions in his class; an equal number of recall questions, open-ended questions, and questions about students' prior knowledge and experiences were observed. Bill also asked a large number of questions that required students to make predictions and questions to specifically elicit the students' preconceptions. Students in this class asked questions whenever they were confused and needed an explanation or clarification.

Bill did not lecture as he presented new material. He worked problems on the overhead and embedded explanations of new material into these problems. He did continual demonstrations and used scientific concepts to explain phenomena consistently. Bill was observed to contrast students' preconceptions with scientific concepts but did not use discrepant events to uncover preconceptions. All types of written work on the observation form were observed except pretests, writing prompts, concept maps, and worksheets.

Teacher's Strategies for Diagnosis

Bill did not use strategies such as pretests, interviews, concept maps, or writing prompts to identify students' preconceptions. He was observed using questions when diagnosing students' ideas. He used class discussions to elicit students' preconceptions and asked students to make predictions to help him identify their ideas. Bill also was observed using questions about students' prior knowledge and experiences to help him form an idea of their conceptions.

Bill often asked the class a question and persisted with questions until a number of students had volunteered their ideas:

Teacher:	You all know what a sunspot is?
Student 1:	I don't know what it is.
Teacher:	Okay, who does know what it is so they can answer? The rest of you must fit in that category right?........Mr. Evans, what's a sunspot?
Student 2:	Ahhhh, ummmm
Teacher:	You are asking me to ask my questions and answer my questions? No way.
Student 3:	A burst of energy.
Teacher:	A burst of energy. From what?
Student 3:	The sun.
Teacher:	The sun. Why?
Student 3:	Because it has gas explosions.
Teacher:	Oh...Nope.
Student 4:	Different gases, a bunch of different gases burn.
Teacher:	What are some of these different gases?
Student 4:	Helium.
Teacher:	Helium burns real well doesn't it? Pretty soon you are going to think of the sun as a gas ball and it's on fire and we get the heat off that fire. Not likely!......Stan?
Student 5:	I have two...One is that it is a stretch of energy in the sense that the radioactive waves are coming together and it's like exploding or it is a matter of fluctuations of energy, the sun has so much energy it is creating we're gonna have fluctuations.
Teacher:	Neither one comes close. Sunspots. Does that imply singular?
Student 6:	Particle flares?
Teacher:	Particle flares, solar flares. Sunspots occur in pairs, any hint now?
Student 7:	Is it polar?
Teacher:	The flares are polar, very definitely. One is a different pole than the other one. They are not located at poles on the sun; they're magnetic poles!

Bill asked questions about the background knowledge of the students. Since this class was an AP physics class, most of the students had had previous courses in science, either biology or chemistry. Bill spent time questioning them about and explaining terms he expected them to know.

Teacher:	Solar flares bathe the earth in a lot of plasma. Now what is plasma, Carrie?
Student 1:	Ahhh...ummmm
Teacher:	Help her out Josh, what's plasma?
Student 2:	High energy
Teacher:	All right, it is the fourth state of matter, give me one word that describes the fourth state of matter. I know this isn't in your assignment but it should be part of your general background.
Student 3:	Energy of particles
Teacher:	One word and it starts with "I".......
Student 3:	Ion.
Teacher:	An ion! Do you remember what an ion was from Chemistry? Biology?
Student 4:	Charged particle.
Teacher:	Charged particle, any charged particle.

This teacher tied his explanations of physical phenomena to experiences he thought it likely the students would have had. The questions he asked about these experiences helped him identify their ideas:

Teacher:	Have you ever gone around a corner in a car and had a cup or glass of water in your hand?
Students:	Yes.
Teacher:	What happens to the liquid?
Students:	It comes out, spills.
Teacher:	It comes out unless it is real low in the container. Why?
Student 1:	Because it is too hot.
Student 2:	Car's moving.
Student 3:	Inertia
Teacher:	It has its own inertial frame of reference. It is still going straight, the container doesn't apply the centrifical force in a proper fashion. So it continues on while you make the curve. What happens if you start or stop real fast holding a cup of coffee?
Student 4:	When you stop, the coffee still has velocity.
Teacher:	It is inertia again.

Bill did not always spend time addressing or even acknowledging the preconceptions that were uncovered as he questioned the students, he persisted with questions until he got the right answer but did not attempt to change the incorrect ideas that surfaced. If he did not get the right answer from the students, Bill provided it himself. Bill also asked the students to make predictions about physical phenomena in order to identify their preconceptions. In a presentation on gravity, the following discussion involving students' predictions took place:

Teacher:	Do you think it's going to be the same, larger or smaller, the effects of the moon on the earth versus the effects of the sun on the earth? I'm standing right here and the moon's right overhead, does the moon reduce gravity on me more or less or no effect at all versus the sun?
Student 1:	More.
Student 2:	More.
Teacher:	It (the moon) is a lot smaller.
Student 3:	It's a lot closer.
Teacher:	It's a lot closer. The effects are... 3.4. Smaller! The mass makes up for the difference...Thank goodness. What if this was a bigger number? What would the outcome be?
Student 4:	The gravitation....
Student 5:	Don't know.
Teacher:	Tell them, Lisa, what would the effect be? Let's say the sun and the moon's values were reversed.
Student 6:	Change gravity on earth.
Teacher:	In what way?
Student 7:	Your mass on the earth would be a lot less?
Teacher:	These are very small values compared to 10 but you would weigh less.
Student 8:	You'd have solar eclipses more often.
Teacher:	No you wouldn't! It'd have no effect on them. Come on!!!....See you're all land lubbers aren't you?
Student 9:	Tides.
Teacher:	Tides! What about tides?
Student 9:	They'd be bigger.
Teacher:	They'd be much more pronounced! A hundred times what they are now. Tidal effects would be tremendous, not only on oceans but on land.

Bill questioned students about their ideas vigorously. He tried hard to get them to come up with the preferred answer on their own; he often gave hints until the students reached a point where they could provide the answer he was looking for. The students in this class expressed their ideas in the discussions the teacher held, although the teacher often had to ask many questions before the students would open up. The teacher expected the students to express their ideas about the topics discussed; he berated them if they provided no input, saying he would rather have wrong ideas than none at all.

Teacher's Responses to Interview Questions

Bill was interviewed three times, twice before the classroom observations and once after the observation period. The last interview combined a stimulated recall interview with a short interview about the teacher's strategies for identifying students' preconceptions.

The teacher was asked if he thought it was important to know his students' personal conceptions or prior knowledge before teaching a topic. He responded that he thought it was "pretty important." He described how he used to try to get to the counselor's office before a class started for the year to go through all his students' files to try to get an idea of the students' potential and also their background. He said he is unable to do that now. When asked what he does in his classroom to get an idea of students' prior knowledge or personal conceptions, he replied:

> I get a feeler on my first quiz—I ask them what they would like to see discovered in science, or… any area of science. And it sort of gives me a feeler as to some of their thoughts; whether they're really into fiction, or whether they're into saving the world, or saving humankind, or if they're just plain interested in the down-to-earth simple thing. And, you know, we try to weave some of the class around that.

Bill also discussed how he questioned his students to try to identify their ideas. He was observed using many types of questions in his classroom and continually asking students for their ideas, predictions, or answers. He talked about how his strong subject matter background and his many years of teaching physics helped him assess his students' understanding. When questioning students in class, he said he could usually tell what the students' "understanding or misconceptions" were from their answers. He felt strongly that all students needed to be held accountable for answering questions in class; he talked about how difficult it is for the teacher to question students in large classes.

> I will question every, every, youngster. I'm just about to the point where, all 160, I can put their name and face and location together. And every one will be questioned many times during the year. Just, there's no quiet spots, or hiding spots; because I remember that game from high school. There's always a spot you can hide, and nobody will call on you. But, that's not the case… One to one contact with them….You know, one to one contact gives you, without question, the best feeling as to what they know, and when you have large groups that's very difficult. My most frustrating years is when I have as many as 46 AP kids in here at one shot. You know, it's 3 or 4 kids at a table and it, you just, you can't even take time to go to them. And, I don't operate that way. I like to be, I can handle 35, 36 without any problem. When it gets down to, I have one this year that's 22, phew! It's like, we're all sitting together and boom, boom, boom, boom, back and forth. And they respond, you know.

Bill talked about how he used tests and also reading his students' facial expressions to get an idea of their understanding of concepts. He was observed dealing with his students on a personal level in his class; he talked about how his background and teaching experience allowed him to excel at this.

Teacher: You know that on certain kinds of questions if they react positive, they're in pretty good shape. And if they give you that stare-look, like, if you repeat that again… well, it doesn't mean that they're not going to get it, but it means they've no real experience with it. And so you better start slow and work your way up. Don't hit 'em hard with it.

Researcher: So, it's your one on one, your reading of their expressions that's a major part of it.

Teacher: It is a major part. And I think that only comes with background experience and teaching experience. You gotta have a background. I don't know how somebody would walk into a physics class and try to get a feeling as to whether they (students) were getting it or not.

Bill was asked in the interview whether he used the information he gathered when assessing student ideas. He responded that he might change the depth that he goes into a concept or determine which students are interested in a specific topic.

> Sometimes I'll back off as to the depth I'm going to go with the material. There will be some groups where… Then again, it's never everybody, so you know you're never going to work it just right. But if there are 25 kids in class, and there are about 10 or 15 who are really into dimensional terminologies I can run a little bit deeper for them. If they're 2 or 3, we can get together in the split sessions and talk, rather than hit the whole class because then they'll just sit there and, "uhhh…"

In the final interview, Bill was asked about the pros and cons of attempting to diagnose students' preconceptions. He replied that he thought it was important to know where the students were before trying to teach them something; he felt one problem with trying to diagnose students' ideas was that a teacher would need to have a lot of experience and strong subject matter knowledge to do it well.

Bill was asked whether he could think of any common or reoccurring preconceptions that students might have on the topics he taught. He was also asked if the knowledge he had of these reoccurring preconceptions had any affect on the planning he did to teach that concept. Bill's response was that he had seen many areas where people have preconceptions in physics. He talked about gravity and how many students he had taught from high school to college "get it stuck in their mind that the bigger object has to fall faster than a smaller object and an object going horizontal falls at a different rate than something just straight down." He also discussed how electricity and circuitry always were an area where students had preconceptions. The teacher was asked if he used this knowledge of the reoccurring common preconceptions when he taught these concepts. He replied that he did try to describe the common preconceptions and explain the correct concepts.

> I try to point out to them, some of this, you know, it'll pop in… some misconceptions here are this, this, or this, or… "Light," I say, "remember all you ever see is reflective light." And they look at me like, "I know that." I say, "all right, if it rains, and you're driving on the highway with your headlights, how come you can't see anything." And somebody who's had the experience will pop up and say, "I don't know, why?" I say, "Well, what happened to the dust particles in the air with the rain?" "Oh."

Prior to answering the stimulated recall interview questions, the teacher was asked to watch a short clip of his teaching a lesson on energy and sunspots. During the video segment he was questioning the students trying to get them to tell him what they knew about sunspots. When asked what he was doing in the video segment and why, the teacher answered that he was "looking for background material to see what they know in regards to this energy source." When asked why he was doing this, he replied that he had to know where the students were before he went ahead:

> I didn't want to jump and not have anybody have a clue why I'm jumping there, so I looked for a background. And some years, boy the class will explode! They know it. Other years, this is one of them, in terms of AP groups, well, this is a real low year. Real low. On a scale of 1 to 10, this is about a 3. Cause they'll give me lectures on it, and they'll pull it in, and I'll just sit and prod a little bit. Because there's always somebody who doesn't know in class, but it's not usually as large a percentage of the group as it has been.

When asked about the planning that occurred prior to this session, the teacher replied that he did what he usually does before teaching a new topic: he looked over his old notes from previous years and also tried to add something new that might be relevant to the students. The teacher was asked if the information he gathered when questioning students in this lesson had affected his planning for subsequent lessons. He said that information gathered had not affected his planning specifically in this lesson but he would change the way he presented a topic by rewording explanations or using different examples if he found that students had gaps in their prior knowledge or had preconceptions.

Bill was asked what the terms "conceptual change teaching" and "constructivism" meant. He replied that he had never heard of either of these terms.

When asked about any science education reforms for secondary science, Bill replied that he had heard things about having students write more in their subject area but he really did not get the feeling that anything was very different than it had been in the past:

> But, as far as doing something different, I don't really see anything happening at all. And, again, it may be simply because I might slave away in my room, at my subject matter, and so I can't follow somebody else's that close. But I don't get any feeling that it's happening. I don't get any revelations from kids saying, "Gee, suddenly we're doing this," and "We never, ever, ever did this before."

Bill was asked about his main concerns when planning for a unit of instruction. He replied that his main concern was that the students have a good experience, that the material is covered in such a way that it is not boring. When planning for a single lesson, Bill said that his main concern was to make sure the lesson had continuity with the lessons preceding it and the lessons that followed. When asked about the information or resources that he used when planning a unit, he replied that he tried to use information in which the students were interested.

> I try to tie the unit to popular things going on. And then, where they're showing an interest. The first quiz I give, the last question is, "What would you like to see discovered in science?" And it gives me a feeling as to—to them what seems sort of interesting. Most the time it's astronomy, and medicine, and energy… they're fairly predictable areas. But you're always surprised, somebody will come up with something that just seems so far off. For the first time I had four or five kids talk about being hard-wired. Where the computer chip is inserted in … they're very interested what's going on, so I try to tie some of the things we're doing into that.

<u>Summary</u>

Bill was not observed using formal strategies such as pretests, interviews, concept maps or writing prompts to identify his students' preconceptions. He was observed asking continual, probing questions in an attempt to assess his students' prior knowledge and understanding. He employed class discussions in order to elicit students' preconceptions on specific topics. In an interview, he talked about how he used questioning to find out what his students knew. He claimed that his strong background and years of experience made this possible. During the interview, Bill mentioned that he used students' responses on the first quiz of the year to try to form an idea of the students' thoughts, interests and ideas. Bill also mentioned using tests and evaluating students' facial expressions to determine their understanding.

Bill talked at great length about the numerous preconceptions people have about physic concepts. He said he tried to explain these topics and their preconceptions whenever he taught that specific material. He was observed using this type of explanation in the classroom.

Bill mentioned that he specifically planned to probe students for their ideas prior to teaching a new topic and then changed his lesson according to the depth of understanding he found. He was observed questioning students in this manner during a class discussion.

Bill's avowed belief is that diagnosing students' ideas is important. His demonstration of that belief in his classroom practices showed that his beliefs fit his practice in this instance.

Comparison of Teachers

The four teachers studied in this research project are compared in a number of ways. First their experience, background, and classrooms are briefly compared with their differences and commonalties defined. Second, the teachers' strategies for identifying students' preconceptions are compared, and lastly, the ways that teachers use the information gathered in the identification process are compared.

The teachers in this study were all defined as experienced due to the fact that they had all been teaching at least five years. The number of years of experience of each teacher varied from 5 to 33. Helen was relatively new to teaching with only five years of experience and Bill was in his 34^{th} year of teaching. The other two teachers had been teaching a significant number of years: Steve for 15 years and Bob had 24 years of experience. These differences in experience level were evident in the way each teacher responded to the observation and interview process. Helen was often hesitant and unclear when describing her teaching; she said she felt as if she were being evaluated. She seemed nervous when first being observed and videotaped but she relaxed noticeably as the observation period progressed. Both Steve and Bob mentioned that it was a strain on them to be videotaped but neither was noticeably nervous. Bill was always relaxed in his manner; he was confident about his interview responses, easy-going in the classroom, and said that he never paid attention to the video camera.

The four teachers all had Masters degrees in education and undergraduate degrees in science. All the teachers seemed to be competent in their subject areas.

While being observed, their content knowledge was informally assessed, none of them showed any sign of inadequate content knowledge. Helen did have some areas of content that seemed difficult for her to explain to the students. This difficulty may have been due to her lack of experience. Bill was obviously strong in his content knowledge; he knew many ways to explain concepts and always had a variety of examples to employ in his explanations. Bob and Steve were strong in their content knowledge of biology; they were both less so in their knowledge of chemistry.

The classrooms of the four teachers spanned a range from lower-level, unmotivated students to top-level, college bound students. Helen was observed teaching a class that had some discipline problems. The students were not always focused and many were not interested in the course. Bill's classroom was an AP physics class with a majority of students that were college bound, motivated and interested in the material. The other classrooms observed, Bob's and Steve's, were standard classrooms with a few motivated students, some that were not at all motivated, and the majority of the students were average achievers. The number of students in each of the classrooms varied but not widely: Helen's and Steve's classes both had 28 students; Bob's had 30 and Bill's had 22 students. It was rare for more than one or two of the students to be absent on a given day so these teachers were dealing with a consistent class number daily. The lower number of students in Bill's class may have made it easier for him to conduct classroom discussions. When comparing how teachers questioned students when attempting to identify their preconceptions and how the students responded, all of these classroom factors must be taken into account.

None of the four teachers observed used any type of instrument to identify students' preconceptions. No evidence of pre-testing, interviewing, concept mapping or using writing prompts was seen in the classroom observations. Helen mentioned that she had been required to use a paper-and-pencil test to pre-assess students during her student teaching. She did not feel it was an effective measure and did not use it after that time.

When asked if it is important to know students' prior knowledge and personal conceptions before teaching a new concept, all of the teachers maintained that it was important. Helen, Bob, and Steve mentioned in their interviews that they thought it important to diagnose students' ideas but they were not observed doing so in their classroom practices. In their classroom practices, they questioned students for the correct, accepted scientific answer rather than probed students for their ideas. Bill, on the other hand, also mentioned the importance of diagnosing students' ideas; but, he was observed spending more time probing students for their ideas and involving the class in discussions in which the students' ideas were solicited.

The teachers were also asked if they had ever attempted to find out what their students' personal conceptions or prior knowledge might be on a topic before teaching it. All the teachers answered that they found out students' ideas through questioning or talking to students. The way that these questions were posed to students varied in each classroom.

In Helen's classroom, the questions were recall questions, aimed at getting the students to answer with the correct answer if they knew it. Bob and Steve also were seen to use this type of questioning although these two teachers both asked more open-ended questions than Helen. In Bill's classroom, the questions were of a more probing type; he elicited students' ideas and used these ideas to create a discussion.

Helen, Bob, and Steve all tended to react in the same way if a student answered a question with the incorrect answer. They might rephrase the question for the same student; they might move on to another student; or they might simply give the student the correct answer. None of these three teachers spent time in the classroom attempting to question their students in depth; their questions were predominantly recall questions. Bill, on the other hand, often kept posing and probing with his questions until students started to provide ideas. He seemed to want to hear what all students had to say, right or wrong. Due to class size and the type of student, Bill's classroom may have been more conducive to this type of questioning than any of the other classrooms.

Bill's demeanor when questioning students was more relaxed than any of the other teachers. He always assumed a non-threatening pose in front of the class when he asked students questions or initiated a discussion. He usually sat on a lab demonstration table at the front of the room, often leaning back with his feet up on the table; he did not hold a book or notebook when questioning. The feeling in the class was relaxed; he communicated to the students that he had all the time in the world. The other teachers, in contrast, always stood at the front of the room and walked back and forth, usually holding a book or papers that they consulted when needed. The feeling communicated by these teachers was that they were in a hurry to get the answers to the questions being asked and to move on to the next activity.

All the teachers except Steve mentioned using tests as a strategy to identify students' preconceptions. They said that short answers and essay answers provided by the students might give a clue of students' ideas. Use of this strategy would be hard to document, as it would involve getting a record of the teachers' thought processes as they corrected tests outside the classroom. Steve said that using a type of discrepant-event lab to uncover students' preconceptions was a possible strategy. He was never observed using this strategy.

When the teachers were asked how they thought that the information about students' ideas could be used, three of the teachers responded that they would use that information to re-teach the concept. Bob, Steve, and Bill all thought that when they found that a student had a preconception about a concept, they would like to go back over that concept and either explain it in a different way or provide experiences of a kind to help the student reach understanding. Helen responded that she would use the information as an example to other students in class. She said she would use it to point out to others where the confusion occurred and try to clear up that confusion. She was never observed using this strategy.

All the teachers said that they had run across reoccurring preconceptions on certain topics throughout the years they had been teaching. These ideas, that seemed common to many students, cropped up repeatedly in a number of science concepts. Helen, Bob, and Steve each had one or two examples to discuss but Bill, as a long-time physics teacher, had many. He talked about how these preconceptions came from students' experiences and also from elementary school teaching. All the teachers discussed how they dealt with these common preconceptions: they took care to explain the concepts carefully and made sure they spent adequate time on the topic.

None of the four teachers studied had a clear idea of the terms conceptual change teaching or constructivism. They had not heard the terms used and could only guess at possible meanings.

The four teachers answered the questions about science education reforms in a variety of ways. Steve was the only one who mentioned the standards in any fashion; he knew about the national and state content standards. Helen and Bob were more localized in their thinking, focusing on state testing or performance assessment. Bill had not heard of any reforms and did not think that any thing was changing.

All of the teachers' planning was analyzed for evidence of any mention of assessment of student' ideas. The teachers all wrote down abbreviated plans for their lessons; no mention was made of attempting to diagnose students' preconceptions.

Summary

None of the four teachers studied used a formal assessment of students' preconceptions. They did not seem to be knowledgeable about strategies that might be used to diagnose students' preconceptions in the classroom such as pre-tests, concept maps, writing prompts, interviews, or journals. All the teachers maintained that it was important to diagnose students' preconceptions in the classroom, they all said they used questioning to identify students' ideas; only one teacher was observed to attempt to do this type of questioning in his classroom. The discrepancy between the teachers' avowed beliefs about the importance of this diagnosis and their actual classroom practice is an important issue, it is discussed in-depth in the following chapter.

The four teachers all used questioning in their classrooms to involve students, to determine their students' knowledge of the correct answers, and to convey the accepted scientific answer to their students. The least experienced teacher depended on this type of questioning to a greater extent than the more experienced teachers; the most experienced teacher used the most probing type of questions of the four teachers. He was also the only teacher to attempt to elicit student ideas in a class discussion.

Three of the teachers expressed the idea that they would use the information gathered in an assessment of students' preconceptions to re-teach the material. They were not observed re-teaching material in their classrooms; this inconsistency between their belief of the importance and use of the information gathered and what they actually did in class is discussed in the next chapter.

Knowledge of common, generic preconceptions seen in students is a valuable indicator of a teacher's understanding of the importance of students' preconceptions. The least experienced of the teachers in this study had little knowledge of the common preconceptions in her content area, the most experienced teacher had a thorough knowledge of the many preconceptions students bring to a physics class.

Chapter V

Discussion and Implications

Introduction

According to constructivist theory, all knowledge must be individually and socially constructed and based on the learner's existing knowledge and experiences. When undergoing this construction of meaning, what the student already knows is of central importance (Treagust, Duit, & Fraser, 1996). Therefore, science teachers must elicit their students' ideas before attempting to restructure their concepts.

A review of the research supports the conclusion that students do hold preconceptions about their physical world. These studies (Abraham, Williamson, & Westbrook, 1994; Brooks, Briggs, & Driver, 1984; Novick & Nussbaum, 1981; Osborne & Cosgrove, 1983; Stavy, 1990) have shown that there are common preconceptions that students hold about science concepts that are not in line with the accepted scientific beliefs.

In this study, the strategies teachers used to identify their students' preconceptions in the classroom were analyzed. The way that teachers used any information they gathered about students' preconceptions was also investigated. These strategies and the motivation behind their use are discussed in this chapter as is the use teachers make of information gathered. The teachers' beliefs and their understanding of students' preconceptions and the diagnostic process are examined.

The reasons for a lack of diagnosis of students' preconceptions by teachers are also discussed. Following these discussions, the implications that these results have for science teacher education are examined and the limitations of this study outlined. Lastly, recommendations for future research on this subject are made.

Teachers' Strategies for Diagnosing Preconceptions

Over the past 20 years, reams of research have been produced (Wandersee, Mintzes, & Novak, 1994) verifying that students enter their science classrooms with ideas about science concepts that have been influenced by their prior experiences, textbooks, teacher's explanations, or everyday language. Researchers have used interviews (Erickson, 1979; Novick & Nussbaum, 1978; Stavy, 1990) in their attempt to identify students' preconceptions. Other methods of diagnosis of students' preconceptions seen in the literature have been concept mapping (Wandersee, 1990; Novak & Gowin, 1984), classroom discussion (Driver & Oldham, 1986), small-group work (Basili & Sanford, 1991), journal writing (Fellows, 1994), and pencil-and-paper pre-tests (Hewson, 1996). All of these methods have been shown to successfully allow diagnosis of students' preconceptions in a research situation. These diagnoses of students' preconceptions are seen as the essential first step in the process of teacher-facilitated conceptual change. The focus of this study has been on the strategies that are used by teachers in secondary science classrooms to diagnose their students' preconceptions.

Four secondary science teachers were observed and interviewed in this study, three of these four were not seen to use any type of formal diagnosis of their students' preconceptions. One teacher was observed employing probing questions and class discussions to elicit students' ideas. All of the teachers maintained that they thought the diagnosis of students' preconceptions was important and they said they did so in their classes by questioning students.

Teachers' Questioning of Students

When the teachers were asked in the interviews if they had ever attempted to diagnose or find out their students' preconceptions or personal conceptions on a topic, they all answered that they had and the method they all mentioned was questioning students. They unanimously said that by talking to and questioning students, they were able to find out the students' ideas. Helen mentioned that talking to and questioning students was important because if she heard someone say something in class that was "way off" she could try to correct it. Bob said that by asking specific questions, he could "get at a lot of the misconceptions." Steve's response was that he tried to assess students' understanding before beginning a topic by having question and answer sessions. Bill talked about how he was experienced in assessing students' understanding through questions, he felt years of experience and strong subject matter knowledge allowed him to do this type of assessment.

All the teachers were observed questioning their students in class. The questions used by Helen, Bob, and Steve were not as probing as those used by Bill; their questions did not seem to be used to elicit students' preconceptions or explore students' ideas as much as those of Bill. His questions, and the discussions, with which he wove his questions together, had the objective of uncovering students' ideas. For example, in the questioning Bill carried out on sunspots (quote, page 128), he asked students for their ideas about what sunspots are, allowing as many students as possible to volunteer an idea. Bill asked questions about the ideas the students hazarded even when their answer was not the one he was looking for. When they did not come close to the answer, Bill gave them a hint and tried to get them to elaborate on the concept. The other three teachers' questions seemed much shallower in nature; they usually involved a general question to the class, a response from one or more students, and the teacher proclaiming the accepted scientific answer. For example, when Bob asked a student what is the exception to the rule of all living things being made of cells and the student answered "an atom", Bob simply stated "a virus is the exception to this rule" and moved on. Lemke (1993) describes this type of teacher questioning as a way that the teacher may transpose the thematic context of a lecture or monologue into dialogue form. As the students or the teacher provide the correct answers, the teacher is able to control the development of the topic being discussed. By keeping close control of the questions and the answers provided, the teacher does not allow the context of the dialogue to veer away from the topic being presented.

The questions used by the three teachers were seen by the researcher to uncover students' preconceptions. For example, when Steve asked his class, "What are protons, neutrons, and electrons made of?" he received the answers "cells," "atoms," and "molecules." These answers from the students are an example of a common preconception in students about the size of particles and the relationships among particles and subatomic particles (Driver, Squires, Rushworth, and Wood-Robinson, 1994). This question from Steve to his class may not have been meant to elicit students' ideas. The teacher was looking for the answer "quarks" and when he did not receive that answer from the students, he supplied it himself. He was not observed to use the information he gathered about the students' ideas in any way. When the teacher was asked about this episode, he replied that the students had given the wrong answer and he was moving on to get through the material he needed to cover on atomic structure. Therefore, this teacher may not have recognized the answers given by the students as problematic preconceptions.

The teachers all mentioned in the interviews that they held class discussions. The term discussion when used by the teachers did not mean students talking to students or students sharing their ideas with the class. These discussions seemed to involve the students answering the teachers' questions. Bill was the only teacher who held discussions in his class where the students did more than provide answers to the teacher's questions. The students in his class did talk among themselves and ask questions of the teacher during the discussion. When asked about their motivation for questioning the students during these discussions, the teachers said they were checking the students' understanding or presenting new material. The teachers did not mention that they were attempting to find out the students' ideas. Bob said one of his motivations for holding the discussion was to increase student involvement in the class.

The questions that the teachers asked were used to solicit the correct scientific answer. They often called this questioning "checking for students' understanding" but they seemed only concerned about students providing them with the correct answer. When the teachers received the wrong answer, they did one of three things: they moved on to another student, rephrased the question to the same student or provided the answer themselves. They were never observed explaining a wrong answer, using it to elicit other students ideas, or using it as an example in an attempt to explain away confusion. This process, called the 'right answer' syndrome (Driver, Guesne, & Tiberghein, 1985), does not allow students to generate a range of conceptual schemes. Both the teacher and the students were involved in the process of getting the right answer with no encouragement given to students to consider possible interpretations or evaluation of events.

The conclusion is that the three teachers, who mentioned in their interviews that they would use questioning as a method to identify students' preconceptions but were not observed doing this in the classroom, had an inadequate understanding about questioning to identify students' preconceptions. It is also possible that they may have had an incomplete understanding about what was meant by the term preconception. They may not have understood the importance of a probing, in-depth type of questioning for eliciting students' ideas; they did not question students on a one-to-one, individual basis. They were ultimately concerned with getting the right answer vocalized. Bill was observed using a more probing type of questioning and did mention in his interview that he questioned students to find out their prior knowledge, understanding, and preconceptions in order to teach them successfully. He seemed to understand, and use correctly, the terms preconception and misconception.

Other Strategies

Three of the teachers, Helen, Bob, and Bill, all stated that they used test answers to attempt to identify students' preconceptions. Steve made no mention of this strategy. The teachers talked about how a student's wrong answer on a test could be a sign of a preconception; they said they would mark it wrong but would try to remember that it was a trouble spot. Helen mentioned that she would like to put down what she thought the student meant on the test paper when she corrected it but did not have time. She said that by going over the correct answers in class, the students would be given the right idea or correct answer.

Using test answers to attempt to identify students' preconceptions may be an overwhelming task in the secondary classroom. With over 150 students and fairly lengthy chapter tests, the teacher would never have the time or capabilities to remember the students' wrong answers that potentially point to preconceptions. A short quiz or a quick writing assignment, on the other hand, might be an instrument that a teacher could use solely for the purpose of assessing students' ideas. These pretests would need to be designated as such by the teacher and kept short and easy to correct. The teachers observed did use quizzes frequently in their classrooms. They may have used the answers that students provided as information about the students' preconceptions but they did not mention that they used test information to diagnose students' preconceptions when interviewed.

Steve mentioned in his interview that he might use a discrepant event lab to uncover students' preconceptions. He was never observed doing this; he used labs that had a definite and predictable outcome. The lab he described would have provided results that the students would not have expected; it would have confused them. Steve talked about how this lab allowed him to talk about their ideas and hopefully change their preconceptions. He said he had done a similar lab in the past that involved plant respiration. Without being observed employing this type of lab, it is questionable whether he would have used it to actually identify and change students' preconceptions.

Both Helen and Bill mentioned in their interviews that they would watch students' facial expressions in order to determine their understanding. They thought it possible to get an idea of students' confusion on a topic by watching their body language. This type of identification may be possible in a small class but seems to be an overwhelming and not very valid strategy for a teacher faced with 30 or more individual high school students. Students expressing confusion through body language could be demonstrating their momentary lack of knowledge about the right answer rather than dissatisfaction with an inveterate preconception.

Teachers' Beliefs on Diagnosis of Preconceptions

Three of the teachers studied expressed a belief that diagnosing students' preconceptions was important but were not observed to do so in their classroom practices. The fourth teacher also expressed the belief that diagnosis was important, he was observed using an informal assessment strategy to get an idea of his students' preconceptions. The three teachers who said that they thought it was important to identify students' preconceptions but did not do so, may have simply not had the knowledge of useful strategies necessary to carry out a diagnosis. Smith, Blakeslee, & Anderson (1993) have shown how these teaching strategies are essential when involved in identifying and changing students' preconceptions but that teachers may not be able to instinctively use them; they may need to have direction and education on their use. It has also been recommended (Hewson, 1996; Hewson & Hewson, 1983; Trumper & Gorsky, 1993) that teachers have knowledge about generating and using materials that specifically address students' preconceptions. Without this knowledge, the teachers' beliefs on the importance of students' preconceptions would not be observable in their classroom practices.

A lack of teacher knowledge about diagnosis of students' preconceptions was seen in the fact that the teachers thought they were carrying out a diagnosis through questioning students. They said in their interviews that the strategy they used was asking students what they thought. Only Bill was successfully able to carry out this type of probing diagnosis; the others all thought that by asking students for the correct answer, they were assessing their ideas.

It was seen, from the absence of the teachers' diagnosis of students' preconceptions in classroom practice when they expressed a belief in its importance, that their belief did not transfer into practice. The translation of teachers' beliefs into their classroom practice may not always be straightforward and direct. Gess-Newsome and Lederman (1995) showed that the relationship between teachers' perceptions of subject matter structure and classroom practice was complex and varied. Lederman and Ziedler (1987) found no evidence that teachers' beliefs on the nature of science directly affected their classroom practices. In their discussion on teachers' thought processes, Clark and Peterson (1986) mentioned that the relationship between teachers' espoused beliefs and their classroom practice was not always high and that it may be moderated by circumstances beyond the teachers' control. It is therefore important not to think of teachers' beliefs as being a simple system with a predictive bearing on the teachers' actions.

It is possible that the teachers studied held views that impeded the expression of their espoused view of the importance of diagnosing students' preconceptions. These views of teaching and learning would act as barriers to their diagnosis of students' ideas. Prawat (1992) discussed the beliefs held by teachers that act as impediments to constuctivist teaching. The teachers observed in this study focused on delivery of the content rather than construction of knowledge; they also provided students with constant lab or hands-on activities with little consideration for the learning involved. The teachers observed concentrated on the curriculum, seeming to consider it as a fixed agenda that needed to be mastered by the students. All of these views, according to Prawat (1992), are barriers to the teacher's adoption of a constructivist way of teaching. Gallagher (1996) also discussed the common belief held by teachers that can be described as "covering the content," the view that presenting the science content prescribed in a syllabus or completing the text is believed to be the central task of teaching.

The teachers in this study may have been constrained from acting upon their beliefs about diagnosing students' preconceptions by obstacles they perceived as being overwhelming. Tobin, Tippins, & Gallard (1994) discuss how perceived constraints, such as time, scarce resources, control, or social expectations, may suppress any change in teachers' practices even if the teacher is strongly committed to personal change. The four teachers studied all said that it was hard to diagnose students' preconceptions, this feeling was possibly enough of a constraint to keep them from actively pursuing some sort of formal diagnosis.

The discrepancy between the teachers' espoused beliefs about diagnosis of students' ideas and their lack of doing so in the classroom may also be due to an inaccurate expression of their views. When the researcher asked the teachers if they thought it important to diagnose students' preconceptions, they all answered that it was. This would be a hard question for them to answer with a negative. It is possible that the only answer they could give, whether they truly believed the statement or not, would be "Yes." By saying "No," they might think they would be labeling themselves as uncaring, insensitive teachers. Tobin, Tippins, & Gallard (1994) mention that many teachers' beliefs are implicit and tacitly held; they may not always be ascertained by asking the teachers about their beliefs in relation to given situations. It is also possible that these teachers had not previously thought about whether they valued diagnosing students' ideas. Without any previous consideration of the question, their first reaction may simply have been to answer "Yes, it is important."

Teacher Experience and Subject Matter Knowledge

Bill was the only teacher who was observed using some type of strategy to elicit students' ideas and also talked about his practice of doing so in the interviews. Bill's responses in the interviews showed that he felt strongly about knowing students' ideas before teaching a topic; he said he needed to know where students were before he could jump to new concepts. His extensive experience as a physics teacher and his strong subject matter background were conducive to this practice. Bill often asked many probing questions in his class and he expected the students to participate in class discussions. In their description of exemplary teaching research, Tobin, Tippins, and Gallard (1994) maintained that exemplary teachers used verbal interactions that enabled them to monitor their students' understanding of science concepts. These exemplary teachers also asked questions to stimulate thinking, probed the students' responses for clarification and elaboration, and offered explanations to provide further information. These characteristics were all seen in Bill's teaching; he often asked his students to make predictions about events or ideas; he told them he would rather hear wrong ideas than none at all.

The other three teachers, on the other hand, did not use as many probing questions or questions to stimulate thinking; they were ultimately concerned with communicating information to the students. This difference was seen in Berliner's (1987) research on novice and expert teachers. The novice teachers focused more on providing students with feedback than with eliciting information from them before beginning a unit of instruction. The expert teachers focussed on assessing student knowledge of the subject matter and having students provide information on what they knew or could do. Since the teachers in this study had all been teaching for at least five years, they could be termed experts (Berliner, 1987) but Bill, as the most experienced teacher, used these questioning strategies much more often than the other teachers.

Bill's strong subject matter knowledge may have allowed him to successfully employ strategies to diagnose his students' ideas. His content knowledge in physics and mathematics was strong; he had an undergraduate degree in each of these subjects and he had taught both subjects at the college level. Research has shown (Tobin & Fraser, 1990) that teachers with strong subject matter expertise and the ability to represent the subject matter to students engage in skillfully leading flexible class discussions of content. Gess-Newsome & Ledeman (1995) showed that strong content knowledge about a specific subject allowed a teacher to extend, expand and connect the content material and also to present more examples than were provided in the text. Bill was observed using these strategies in his class discussions.

Students

What the students already know when they enter the classroom or begin a new topic is of utmost importance to their consequent learning. The research reviewed (BouJaoude & Giuliano, 1994; Chandran, Treagust, & Tobin, 1987; Osman & Hannafin, 1994) supports the idea that students higher in prior knowledge (students with a large amount of content knowledge) have more success when learning science concepts and that prior knowledge is a significant predictor of students' achievement. Students with low prior knowledge (students with a small amount of content knowledge) may be different types of learners than students with high prior knowledge (Lambiotte & Dansereau, 1992; Osman & Hannafin, 1994); they may be unable to ask meaningful questions or relate new information to prior conceptions. Teachers, therefore, need to become aware of the prior knowledge that students hold and use this knowledge to teach new science concepts.

The students in the classes observed covered a wide variety of academic levels. The students in Bill's classroom were college-bound, motivated and a majority were the top students in the school. In contrast, the students in Helen's class were low-achievers and most were not motivated academically. Research (de Berg, 1992; Griffiths & Preston, 1992; Trumper & Gorsky, 1993) has shown that the academic or cognitive level of the students has no effect on the number or type of preconceptions that they may hold. Therefore, the higher level students in Bill's class possibly had as many, or more, preconceptions than the students in Helen's class.

The size of the classes observed varied from 22 students in Bill's class to 28 or 30 students in the other three classrooms. The small size of Bill's class allowed him to deal with his students on a personal level; he maintained that he had to be able to do this to get an idea of their preconceptions.

Teachers' Use of Information

The review of research on conceptual change strategies has shown that conceptual change materials designed with students' preconceptions as the focus (Basili & Sanford, 1991; Fetherstonhaugh and Treagust, 1992; Smith et al., 1993; Thijs, 1992) have been successful in moving students' conceptions closer to the accepted scientific view. Using catalogued or collected preconceptions about certain topics to build teaching materials has been a successful strategy to force students to confront their own or their peer's ideas, discuss these ideas, and ultimately resolve any conflicts as they move closer to the accepted scientific view. Using this strategy in small groups has been shown to be effective (Basili &

Sanford, 1991) and having students face common preconceptions in a text format has also had success (Hynd et al., 1994). None of the teachers observed in this study used information about students' preconceptions to design curricular materials, set up small group work, or confront students with preconceptions in a text format.

The teachers in this study were asked how they might use information they gathered when diagnosing students' preconceptions. Three of the teachers, Bob, Steve, and Bill, all said that they would use the information to adjust their teaching. They said it would be important to go back and re-teach the material on which there were preconceptions and to possibly change the details they covered in that material. These teachers were observed rephrasing questions to students who had trouble providing a correct answer but were not observed re-teaching the material. It is possible that the teachers meant that reviewing the material on a subsequent day would be a way to use the information but they did not state so. All the teachers did regularly review material that had been taught at an earlier date but this reviewing strategy is not evidence of their re-teaching material due to information gathered on preconceptions. The teachers may have used information they had gathered in the past to adjust present lessons and may adjust future lessons because of information gathered during their current teaching of the material. There was no way in this study to document this use of information. The teachers' knowledge of common, reoccurring preconceptions and the effects this knowledge has on teachers' planning are discussed in the following section.

Bill said that he used the information gathered on students' ideas to change the depth he went into the material and also to identify students' interests. He mentioned in his stimulated recall interview that he needed to know where the students were before he began a new concept; he looked for their background. This teacher was observed probing for students' ideas in class; his use of the information was not as easy to document.

Helen stated that she would use the information gathered as an example in class. She discussed how she would repeat what a student's preconception was out loud and explain to the whole class where the confusion originated. She said she would then explain why she thought it was right or wrong. Helen was never observed doing this type of explanation during the observation period.

Common Preconceptions

Research (Basili & Sanford, 1991; Fetherstonhaugh and Treagust, 1992; Thijs, 1992) has shown that conceptual change materials designed using common, cataloged preconceptions have been successful in helping students move closer to the accepted scientific view. Therefore, a catalog of preconceptions that students commonly hold is an important resource for teachers. As Wandersee, Mintzes, and Novak (1994) proclaim "a working knowledge of discipline-specific alternative conceptions research findings might well be considered basic to the professional preparation of master science teachers" (p. 186).

The four teachers studied in this research were asked in the last interview whether they knew of any common or reoccurring preconceptions that students had on the topics they taught. They all volunteered a few examples and then discussed how they have taught that material to alleviate the preconceptions.

Helen said when asked about common preconceptions that she thought her students always had preconceptions about the difference between molecules and compounds and the difference between atomic number and atomic mass. It is possible that she did not provide an example of a preconception but of an area of confusion of terms. Her response is discussed in a following section: evidence of teachers' incomplete understanding about preconceptions.

The other three teachers gave examples of areas where they have seen reoccurring student preconceptions and told how they would teach to help decrease the students' preconceptions in these areas. Bob and Steve both mentioned photosynthesis as an area of common preconceptions; this reference to photosynthesis is supported by the discussion in Driver, Squires, Rushworth, and Wood-Robinson (1994) about how students often think of photosynthesis as a substance rather than a process or as the plant's kind of respiration. Both of these teachers talked about how they would make a point of explaining this concept carefully and cover the points in detail to help decrease the students' preconceptions. They were not observed using this type of explanation in their classrooms.

Bill described in detail a number of preconceptions that he had seen during his years as a physics teacher. He said he had seen students from college age to high school age "get it stuck in their mind that the bigger object has to fall faster than a smaller object and an object going horizontal falls at a different rate than something just straight down." He also discussed how electricity and circuitry always were an area where students had preconceptions. These examples of preconceptions are supported by many years of research that show people of all ages have trouble grasping Newtonian laws of motion and the path of electrons in a circuit. Bill mentioned how he would describe the common misconceptions to his students when they were studying these topics and try to give examples of them. He was observed describing common preconceptions in his classroom.

Evidence of Teachers' Incomplete Understanding

The four teachers involved in this study varied in their understanding of students' preconceptions and assessing these preconceptions in the classroom. They ranged in understanding from the strong understanding seen in Bill to the incomplete understanding observed in Helen.

Bill supplied suggestions for strategies that were viable for assessing students' preconceptions; he was observed using one of these strategies in classroom observations, and he discussed common preconceptions seen in many areas of physics. He tended to use the term misconception when he talked about preconceptions; this term was his choice and he seemed most comfortable with the term "misconception." During the observations of his classroom, there were no instances of students' preconceptions that were identified by the researcher but not recognized by the teacher. Bill did not mention that he used student ideas when planning for a unit or lesson; he did mention that he tried to identify the students' prior ideas before moving ahead to new concepts.

The other three teachers had a less complete understanding than Bill. They all suggested possible strategies to use when assessing students' ideas but were not observed using these strategies in the classroom. Their questioning and discussions did not focus on eliciting students' ideas; rather they focused on the teacher supplying the correct answer to the students or correcting students' errors. The three teachers, Helen, Bob, and Steve, did not respond to students' ideas when they were expressed except to tell the student that they were incorrect and provide the correct answer. In Bob's vocabulary exercises, the students provided definitions and examples of terms that were problematic and possibly evidence of preconceptions but the teacher did not respond to the students in this situation except to say "That's good," or "Okay."

None of the teachers expressed the notion of using students' ideas when planning for a unit or lesson. None of them said that they would try to find out where their students were in respect to the concepts being introduced before teaching those concepts. Bill talked about identifying the students' ideas before moving ahead but none of the teachers mentioned students when they talked about planning.

Helen had used a pre-assessment tool when she was a student teacher to attempt to identify students' ideas. She said that this tool was not as effective as the discussions she said she would hold in class to pre-assess students. It is questionable whether Helen's understanding of the use of the pretest was complete. She may have found it ineffective for a number of reasons; her conclusion was that it was not as effective as a discussion. Since she did not show evidence of using the discussion to elicit students' ideas, it is doubtful that she knew how to properly use the pretest.

Helen's understanding of the term "preconception" may not have been complete. This term was explained to the teachers as both "a misconception" and "a student's personal conception" before the interview process. Helen may have confused students' preconceptions on a concept with students' prior exposure to a concept. When she responded to a question about the importance of knowing students' preconceptions, she said that if students have had the material introduced to them before then she could go deeper into it, but if not, she needed to take it in small steps (quote, p. 96).

It is probable that all the teachers except Bill had an incomplete understanding of the term preconception and of the idea of identifying students' preconceptions in the classroom. Bob and Steve seemed to understand the major concept but may not have had complete understanding of all aspects. Helen was incomplete in her understanding and did not seem to understand the term misconception when used to describe preconception.

Reasons for Lack of Diagnosis

The four teachers involved in this study were not observed using strategies such as pretests, interviews, concept maps, or writing prompts to diagnose their students' preconceptions. Bill was observed employing class discussions that had the objective of eliciting students' ideas. The teachers all expressed the idea that identifying students' ideas was important to them, they all suggested viable strategies but they were not observed using these strategies to diagnose students' preconceptions.

There are certainly a number of reasons why all the teachers did not diagnose students' ideas. One of the reasons may be that the teachers did not understand and have the knowledge necessary to deal with students' preconceptions. They mentioned that they thought this type of diagnosis was important but they did not have full understanding of the depth and breadth of students' preconceptions on the topics they were teaching. As Prawat (1992) mentioned, there may be impediments to the teachers' acceptance of a constructivist way of teaching. They may have such strong beliefs from their own prior learning about covering content and conveying the correct answer, they do not consider diagnosing students' ideas in any formal manner. When teachers do not consider the complexity of their job, they are unlikely to employ teaching and learning tasks that result in students' understanding, application, and development of the attitudes and habits of mind that are the intended outcome of science teaching (Gallagher, 1996). Bill demonstrated both by his teaching practices and interview responses that he had a better knowledge and understanding of diagnosing students' preconceptions than the other three teachers.

None of the teachers seemed to have knowledge of strategies that might be used to diagnose students' ideas other than questioning students or evaluating their answers on tests. This lack of familiarity or even awareness of strategies other than questioning points to the fact that these teachers had little or no introduction to diagnosing students' ideas. Helen had used a pre-assessment tool in her student teaching; she did not feel that this had been an effective tool. Judging by her lack of understanding of students' preconceptions, she may not have understood the reasons for this pre-assessment tool.

The teachers had little or no experience or knowledge with using strategies other than questioning but possibly more important, they did not show an appreciation for the value of knowing students' ideas before teaching a concept. Bill was the only one who mentioned that he wanted to know students' ideas before teaching a topic. The others did not mention the need to relate students' preconceptions or prior knowledge to their planning or teaching of their material. The teachers were asked about the inherent problems of attempting to identify students' ideas. They were asked about the pros and cons of diagnosing students' preconceptions. Helen responded that she thought it was hard to do because of the huge difference among students' conceptions; she thought there was too much variation. Bob said he thought it was almost impossible to do. Steve said he did not think there were any negative aspects to it although in other discussion, he mentioned it was hard to do. Bill responded that a teacher would need lots of experience and subject matter knowledge in order to diagnose successfully. The teachers all thought it difficult to carry out diagnosis but did not really identify why; Bill was the only one to say specifically that diagnosis depended upon teacher experience and subject matter knowledge. The teachers did not say that they thought finding ways or finding time to diagnose student ideas was a concern; their view was that they already did use some strategies to accomplish diagnosis and felt they were successful.

Not having enough time may certainly be a reason for teachers to not carry out a diagnosis of students' preconceptions. Helen mentioned this lack of time when she talked about correcting and evaluating students' ideas on tests. She said she did not have time to evaluate answers on every student's test. None of the other teachers mentioned time as a constraint or as a reason for a lack of diagnosis. As far as time in class, the classroom observations in each of the four classrooms showed that every teacher would have had time to do a more formal form of diagnosis. They all seemed to have ample time to pretest students with a short quiz, assign writing prompts or concept maps. The time that it would take the teacher out of class to deal with the information generated would be a consideration; it would increase the time the teacher regularly spent evaluating students' work.

Class size was possibly a factor in whether the teachers carried out diagnosis of their students' preconceptions. Bill's small class size, 22 students, may have allowed him to question his students in a more probing manner than the other teachers were able to do with larger classes. He mentioned in his interview that when he had larger classes, he found it very difficult to question students in a probing manner or to deal with the students on a one-to-one basis. Without additional teachers with small classes to compare to Bill and his small class strategies, it is difficult to reach a definite conclusion about class size and its effect on diagnosis of students' preconceptions.

The main reason that the teachers observed did not diagnose their students' preconceptions in the classroom was that they did not have the knowledge and understanding of the importance of knowing students' ideas or the strategies to use; they also thought that they were identifying their students' ideas successfully. They discussed the strategies they used to identify students' ideas; they were under the impression that these strategies were successful but no evidence was seen that the teachers used any information they said was collected. One of the teachers, Bill, did successfully question his students about their ideas and was aware of the value of doing so. The teachers all would have had time in their classes to use strategies that have been shown to successfully identify students' preconceptions. Classroom time would not have been a factor; dealing with the information gathered by these strategies would have taken more teacher time.

Summary

The purpose of this study was to investigate teachers' understanding and identification of students' preconceptions. The four teachers involved with this study were observed and interviewed to determine the strategies they used to identify students' ideas. Three of the four secondary science teachers did not use any of the strategies suggested by past research to identify students' preconceptions. One of the teachers was observed using classroom discussion to elicit students' ideas.

The teachers' use of the information gathered in the diagnostic process was also analyzed. The teacher who was observed using probing questions to identify students' ideas used the information gathered to determine how deeply he went into the material he was teaching, he also said he needed to know the students' background before starting new material. The other three teachers were not observed using the information that surfaced in their class; they said in their interviews they would use it to re-teach or as examples in class.

The reasons for lack of diagnosis of students' preconceptions were analyzed. The reasons that the three teachers studied did not use this process were because they did not fully understand the value or the strategies involved. The teacher that did use informal diagnosis had a much better understanding and used one strategy effectively. None of the teachers had ever heard of the terms conceptual change or constructivism. They did not have any awareness of the theoretical justification of basing current teaching on students' prior ideas. Another reason that the three teachers did not use any recommended strategies was that they were under the impression that they were successfully diagnosing students' ideas, they said that they did diagnose preconceptions in their classrooms by questioning students. It is possible that due to lack of understanding about the term preconception, the teachers' claim that they were carrying out diagnosis has little value.

Teachers with experience may have an intuitive feeling that they need to know students' ideas before teaching a concept. All the teachers in this study vehemently stressed the importance of diagnosing students' preconceptions. They all said that it was important and essential to know the prior ideas a student brings into the classroom. Expressing their appreciation of its importance is not the same as actively using the strategies in the classroom. These teachers had the appreciation of the importance but did not all have the strategies to diagnose students' ideas. This discrepancy between the teacher's beliefs and their classroom practice may be due to their holding contrasting beliefs that did not support constructivist teaching (Prawat, 1992). Also, their beliefs may be so complicated that it is not possible to have a clear translation into their classroom practice (Gess-Newsome and Lederamn, 1995), or it may be that the teachers did not accurately express their true beliefs (Tobin, Tippins, & Gallard, 1994).

All the teachers studied seemed to be caught up in the "right answer" syndrome, they were ultimately concerned with conveying the correct answer to the students and with correcting any student errors. Rather than probing for students' ideas and preconceptions, the teachers moved as quickly as possible through the content, communicating the accepted scientific answer to the students and accepting the repetition of the correct answer as evidence of understanding.

Bill was observed using the strategy of class discussion to elicit students' ideas. He also talked about using the information he gathered to adjust his teaching, his knowledge of and experiences with common preconceptions, and his awareness of the importance of knowing students' ideas. Bill had been teaching for 34 years and he had a strong background in physics. The class he was observed teaching was an AP physics class with 22 motivated, bright students. All of these factors contributed to the success of Bill's identification of students' preconceptions.

None of the other three teachers were observed using strategies for the diagnosis of students' preconceptions. They did not have a complete understanding of the value of knowing students' ideas before teaching a concept. The other three teachers had not been teaching as long as Bill; Helen had only been teaching for 5 years. The students in the classes that these three teachers were assigned were of a lower level than the AP physics students of Bill. These teachers had larger classes and more discipline problems to deal with than did Bill. It is possible that these factors all contributed to their lack of diagnosing students' preconceptions.

In conclusion, the teachers studied did not diagnose students' preconceptions except in one case using class discussions. They did not have a complete understanding of the need to identify students' ideas although they expressed its importance in an interview. One of the teachers, the most experienced and having the strongest understanding of students' preconceptions, did attempt to elicit his students' ideas before teaching a concept.

Implications for Teacher Education

Implications for the education of teachers, both inservice and preservice, may be drawn from the results of this study. The current science education reforms call for science teachers who are able to design and adapt curricula that relate to the past experiences and current understanding of their students (AAAS, 1990; NRC, 1996). To teach in a constructivist manner, teachers must identify their students' prior knowledge of the concepts to be taught. By then building upon this preinstructional knowledge, teachers may be able to help students bring their conceptions closer to the accepted scientific view (Champagne, Gunstone, & Klopfer, 1986; Driver & Scott, 1996; Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982).

One of the findings of this study was that the teachers had no repertoire of strategies to use in diagnosing students' ideas. Questioning was the only strategy the teachers mentioned as a strategy they said they used to identify students' ideas in the classroom. It is important that teachers have an understanding of all the possible strategies that can be used to diagnose students' preconceptions. They need to be educated about employing pre-tests, interviews, writing prompts, discussions, or concept maps. Careful evaluation of students' ideas and knowledge claims help teachers to design instructional experiences that force students to sort out their beliefs (Dushl, 1991). Teachers may not be able to use these strategies instinctively (Smith et al., 1993); in addition to being educated about these strategies, teachers also need to be taught how to use them to effectively assess students' preinstructional knowledge. Experience with the strategies and experience with the use of the information gathered to adjust their teaching should be a part of all teacher education programs.

The teachers involved in this study had an imperfect understanding of the importance of diagnosing students' preconceptions. They all expressed the idea that it was important but none completely understood why. The discrepancy between the teachers' beliefs and their actual classroom practice may point to a need for teachers to reflect on and identify the strengths of their beliefs about diagnosis of students' preconceptions. To create a classroom that is a center of intellectual inquiry where both teachers and students engage in the in-depth exploration of important ideas, teachers will need to attend to their own conceptual change at least as much as they attend to this process in their students (Prawat, 1992). Teaching for conceptual change, according to Hewson (1996), requires that the teacher's conceptions of the nature of learning, of teaching, and of science are supportive of the constructivist nature of teaching for conceptual change.

Preservice teachers may also need to have their beliefs about how students learn challenged in their teacher preparation classes. If preservice teachers could be involved in situations where they were required to attempt to elicit students' ideas, such as a one-to-one interview, the teachers may gain an understanding of how difficult it is to find out what students really understand and how difficult it is to change students' ideas. Preservice teachers need to be placed in situations where they are able to hear students talk or write about their ideas on a concept. The preservice teachers must be confronted with how instruction affects students' ideas, how students' ideas are often tenacious and impervious to instruction. This could be done by employing small groups where students discussed their ideas with peers after a lesson or in a situation where the preservice teacher interviewed students immediately after a lesson taught by the cooperating teacher.

None of the teachers had heard of the terms conceptual change teaching or constructivism. In these days of proposed science education reform, it is essential that teachers in secondary science classrooms have an understanding of the theories that are driving the reform. Constructivist approaches to learning require that teachers have a broad view of their subject and they must emphasize individual construction of contextualized knowledge rather than the transmission of decontextualized content knowledge (Prawat, 1993). If classroom teachers can be made aware of the justification of methods such as identification of students' preconceptions, they will then have an increased appreciation and understanding of the strategies. Both inservice and preservice teachers need to be provided with as much information as possible about the science education reforms, the theories on which they are based, and the teaching practices necessary to implement these reforms.

If teachers use materials that specifically address known preconceptions when presenting new concepts, students have a better chance of learning the new material (Hewson & Hewson, 1983; Trumper & Gorsky, 1993). Other studies (Basili & Sanford, 1991; Fetherstonaugh and Treagust, 1992; Smith et al., 1993; Thijs, 1992) have also shown that materials designed with students' preconceptions as the focus have been successful in moving the students' conceptions closer to the accepted scientific view. The most experienced teacher in this study, Bill, had a thorough knowledge of the common, reoccurring preconceptions students may have in the field of physics. He had seen people of all ages that held these ideas and was aware of how the preconceptions affected their learning the concepts. This knowledge was gained through 34 years of teaching; it helped him identify preconceptions when he employed his strategy of eliciting students' ideas through class discussion.

If knowledge of the principle, supraordinate preconceptions on specific science topics could be provided to beginning teachers, teachers would be able to better assess their students' ideas. Knowledge of these general preconceptions would allow teachers to understand students' explanations of their ideas. In addition, teachers would be able to design curricular materials using both their students' preconceptions and the documented common preconceptions. Teachers must understand the prevalent preconceptions students hold on a particular science topic if they are to tailor their lessons to fit the students they serve (Wandersee, Mintzes, & Novak, 1996). It is not feasible to expect teachers to know a long list or catalog of common, reoccurring student preconceptions. The most valuable tool they could be given would be an understanding of a few of the most general preconceptions that may be seen in students.

It is not conceivable that beginning teachers could easily acquire the knowledge gained from 34 years of teaching but to have an understanding of these common preconceptions in their field would arm them in the battle against students' preconceptions. Preservice teachers should begin teaching with a general knowledge of the broad preconceptions that they might encounter in their specific content area and also an introduction to the concept that student ideas may differ from accepted scientific concepts.

It is important to look at the strategy used to diagnose students' preconceptions identified in this study. Bill regularly involved his whole class in a discussion to attempt to elicit the students' ideas. This strategy required the teacher to force the students to express their thoughts about a topic. Bill talked about how he had to train his students to participate in class discussions at the beginning of each year. He often refused to answer the questions he posed himself, a habit none of the other teachers had mastered. This strategy took time to complete; he had to wait until the students provided answers. In a classroom where a teacher is ultimately concerned with covering a specific amount of material in a set time, this strategy would be difficult to employ. If a teacher were willing to take the time to hold such a discussion, the students would eventually learn to express their ideas. The implication of this need for discussion is that science classes may need to be organized so that there is more time available for students and teachers to become involved in discussions. Also, the pressure of covering a certain amount of material in a set time may need to be relaxed to allow the teachers the freedom to indulge in such discussions.

The teachers in this study had difficulty recognizing the difference between eliciting students' ideas and asking students for the correct answer. They seemed to think that by asking the students for the correct answer, they were diagnosing students' ideas. This focus on the right answer, the right answer syndrome (Driver, Guesne, & Tiberghein, 1985), forces students into the role of suppliers of the correct answer regardless of their understanding of the concepts. This questioning mode undermines students' construction of meanings for themselves; they are not forced to actively reflect on their own thinking. Rather than simply asking for the correct answer, teachers concerned with the conceptual change of their students need to elicit students' ideas and then help students think about their ideas in relationship to the ideas they are trying to understand (Beeth, 1998).

Limitations of the Study

The research study discussed in this paper necessarily had certain limitations. These limitations arose due to the design of the study.

Due to time constraints, only four classrooms and four teachers were studied in depth. The length of the observation period and the geographical situation of the schools where the observations occurred determined that only four teachers could be involved in the study; a larger sample size would have decreased the depth to which the teachers were studied. The small sample size allowed the researcher to observe each teacher every day; every teacher and student interaction pertinent to the study was observed and recorded. The results of this study are confined to the four classrooms and four teachers involved, they may not be generalizable to a larger population. It was not the goal of this research to generalize the results to a larger population but to provide an in-depth view of the four participants, their teaching practices, beliefs, and opinions. Generalizations in qualitative studies are made from clusters of studies as opposed to the qualitative approach where generalizations are made from single studies based on sampling theory.

Another limitation in this study was the lack of data about the teachers' daily planning for lessons. The teachers supplied written plans for their units of instruction but did not write in any detail about their daily lessons. To compensate for this lack of information on daily planning, it would have been possible for the researcher to informally interview each teacher daily about their plans for that day's lesson. This would have supplied data about the teachers' unwritten plans for the lessons and allowed the researcher to analyze any planning teachers may have done for the assessment of students' understanding. This daily interview with teachers about their lesson plans would also have allowed the researcher to assess any changes that the teachers made from their planning to the actual implementation of the lessons.

Only one stimulated recall interview was held with the teachers in this study. The stimulated recall interview was done with the teachers after the observation of classes was complete. Due to never having done an interview such as this before, the teachers seemed to have a hard time focusing on and talking about their own teaching. They reacted with embarrassment when watching themselves on the video player. Their reactions included exclamations like: "That's how I look?", "Do I really sound like that?" or "I really don't want to watch myself at all!" They also focused on the students in the video clips, trying to see what they were doing or saying. This focus on external events detracted from the teachers' concentration on their own teaching. The teachers did not show any inclination to stop the VCR in order to make a comment or review a segment. If they had been involved in a series of stimulated recall interviews throughout the nine weeks of data collection, they may have felt more at ease watching themselves and been better able to answer the researcher's questions about their teaching. This lack of focus on their own teaching did not affect the conclusions made about the teachers' strategies or understanding; it only limited the depth of the teachers' responses.

A possible limitation in this study was that the specific details about the teacher training programs that each of the participants had been involved in were not analyzed in relation to the teachers' practices. It is possible that the teachers' preservice training, specifically training about how students learn, had an impact on their diagnosis of students' preconceptions. It would be an important addition to this type of study to question the teachers about their ideas of how students learn science. The teachers' training may also have influenced their views about the importance of questioning in the classroom. It would have added to this study to know if the teachers studied had ever learned how to use data gathered through questioning students.

The researcher was also a limitation in this study. The researcher's presence in the classroom for the nine-week observation period may have had an effect on the teachers' classroom practices. The teachers said that they did not change their way of teaching due to the researcher's presence in their classrooms. Also, the researcher's opinions and philosophies about diagnosing students' preconceptions had an impact on the analysis of the data and the focus of the conclusions drawn. The researcher's strong belief that it is essential to diagnose students' ideas before teaching a concept has affected the direction of this study. By examining and documenting all comments and conclusions, by remaining open and truthful about all biases, the effect of the researcher on this study was kept to a minimum.

Recommendations for Future Research

Research stemming from the results of the current study will need to focus on two aspects of secondary science teaching. The first area of further research should be how teachers employ strategies for diagnosis of students' preconceptions when they are provided with the means and the justification for use of the means.

Smith et al. (1993) have shown that teachers may not be able to use conceptual change materials instinctively; they need to be educated on the use of such materials. If teachers are supplied with materials for diagnosing preconceptions and educated on the use of these materials, how will their teaching change? How will an increased knowledge and understanding of diagnosis of students' preconceptions affect teachers' classroom practices? If teachers are to teach in a constructivist manner, they must be given the opportunity to participate in a learning community with other teachers and educators similar to the one they are trying to provide for their students (Prawat, 1992). If teachers are given this opportunity, how will their teaching change? If teachers' understanding of constructivism and constructivist teaching is increased, how will they identify their students' preinstructional ideas? How will teachers use the information they gather in diagnosis if they have strategies to employ and an increased understanding of its importance? Another branch to this research would be to study teachers who already have in place the knowledge, appreciation, and strategies for conducting diagnosis of students' preconceptions in order to see how teachers translate this knowledge into their classroom practices. Also, what is the effect on student understanding when a teacher is able to diagnose preconceptions?

Future research could be done to study the effects of a specific intervention involving an experienced teacher's diagnosis of students' preconceptions. This intervention could be done with the teacher in the present study that was identified as having a basic understanding of diagnosis of preconceptions. The study would involve a specific agenda of building the teacher's knowledge of strategies for diagnosis, his understanding of the justifications for diagnosis, and his understanding of student learning. After an intervention involving this focus, the teacher's resultant diagnosis of students' preconceptions in the classroom would be analyzed.

The second aspect of future research might be whether a teacher's length of experience and strong subject matter knowledge are prerequisites for a diagnosis of students' preconceptions. Are beginning teachers, with an understanding of students' preconceptions and strategies to identify them, able to diagnose students' ideas in the classroom? Also, is it possible for a thorough knowledge of the common preconceptions cataloged on science topics to be understood by beginning teachers or does it take years of experience to understand and appreciate this information?

Another aspect of this topic would be an investigation of the importance of subject matter knowledge in teachers' diagnosis of students' preconceptions. Studies have shown that preservice teachers with higher subject matter knowledge may know of more ways to identify students' preconceptions than preservice teachers with lower subject matter knowledge (Morrison, 1996) and that teachers are able to discover students' preconceptions only in areas in which the teachers themselves are experts (Hashweh, 1987). The importance of the role of subject matter knowledge in teachers' diagnosis of students' preconceptions should be researched in future studies.

Future research should also be focused on the outcome of teachers' diagnoses of students' preconceptions. How do expert teachers employing diagnosis use the information they gather? What effect does the diagnosis process have on students' understanding of the material? As an integral part of the conceptual change process, diagnosis of students' preconceptions needs to be researched in more depth.

References

Abraham, M.R., Williamson, V.M., & Westbrook, S.L. (1994). A cross-age study of the understanding of five chemical concepts. *Journal of Research in Science Teaching,* 31(2), 147-165.

American Association for the Advancement of Science (1993). *Benchmarks for Science Literacy.* New York: Oxford University Press.

American Association for the Advancement of Science (1990). *Science for All Americans.* New York: Oxford University Press.

Bar, V., & Travis, A. S. (1991). Children's views concerning phase changes. Journal of Research in Science Teaching, 28(4), 363-382.

Basili, P.A., & Sanford, J.P. (1991). Conceptual change strategies and cooperative group work in chemistry. *Journal of Research in Science Teaching,* 28 (4), 293-304.

Beeth, M. E. (1998). Facilitating conceptual change learning: The need for teachers to support metacognition. *Journal of Science Teacher Education,* 9(1), 49-61.

Bell, B., Osborne, R., & Tasker, R. (1985). Finding out what children think. In R. Osborne & P. Freyburg (Eds.) *Learning in science: The implications of children's science.* (pp.151-165). Auckland, NZ: Heiemann.

Benson, D.L., Wittrock, M.C., & Baur, M.E. (1993). Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching,* 30(6), 587-597.

Berliner, D.C. (1987). Ways of thinking about students and classrooms by more and less experienced teachers. In J. Calderhead (Ed.), *Exploring Teachers' Thinking* (pp.60-83). Great Britain: Cassell.

Bogdan, R. C., & Biklen, S. N. (1992). *Qualitative research for education: An introduction to theory and methods.* Needham Heights, MA: Allyn and Bacon.

Bogdan, R. C., & Taylor, S. (1975). *Introduction to qualitative research methods.* New York: Wiley.

BouJaoude, S.B., & Giuliano, F. J. (1994). Relationships between achievement and selective variables in a chemistry course for nonmajors. *School Science and Mathematics,* 94 (6), 296-302.

Brooks, A., Briggs, H., & Driver, R. (1984). Aspects of secondary students' understanding of the particulate nature of matter. The University of Leeds, Centre for Studies in Science and Mathematics Education.

Carey, S. (1986). Cognitive science and science education. *American Psychologist*, 41(10), 1123-1130.

Champagne, A., Gunstone, R., & Klopfer, L. (1985). Effecting changes in cognitive structures among physics students. In L.H.T. West & A.L. Pines (Eds.), *Cognitive structure and conceptual change* (pp.163-187). New York: Academic Press.

Chandran, S., Treagust, D.F., & Tobin, K. (1987). The role of cognitive factors in chemistry achievement. *Journal of Research in Science Teaching*, 24(2), 145-160.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M.C. Wittrock (Ed), *Handbook of Research on Teaching* (pp. 255-293). New York: MacMillan.

de Berg, K.C. (1992). Student's thinking in relation to pressure-volume changes of a fixed amount of air: the semi-quantitative context. *International Journal of Science Education,* 14(3), 295-303.

Driver, R., Guesne, E., & Tiberghein, A. (1985). Children's Ideas in Science._Philadelphia, PA: Open University Press.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education*, 13, 105-122.

Driver, R., & Scott, P.H. (1996). Curriculum development as research: A constructivist approach to science curriculum development and teaching. In D. F. Treagust, R .Duit, & B.J. Fraser (Eds), *Improving Teaching and Learning in Science and Mathematics* (pp.94-108). New York: Teachers College Press.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. New York: Routledge.

Duit, R., Treagust, D.F., & Mansfield, H. (1996). Investigating student understanding as a prerequisite to improving teaching and learning in science and mathematics. In D. F. Treagust, R .Duit, & B.J. Fraser (Eds), *Improving Teaching and Learning in Science and Mathematics* (pp.17-31). New York: Teachers College Press.

Duschl, R.A., & Gitomer, D.H. (1991). Epistemological perspectives on conceptual change: Implications for educational practice. *Journal of Research in Science Teaching,* 28(9), 839-858.

Erickson, G.L. (1979). Children's conceptions of heat and temperature. *Science Education*, 63(2), 221-230.

Fellows, N. J. (1994). A window into thinking: Using student writing to understand conceptual change in science learning. *Journal of Research in Science Teaching,* 31(9), 985-1001.

Fetherstonhaugh, T., & Treagust, D. F. (1992). Students' understanding of light and its properties: Teaching to engender conceptual change. *Science Education*, 76(6), 653-672.

Gallagher, J.J. (1996). Implementing teacher change at the school level. In D. F. Treagust, R. Duit, & B.J. Fraser (Eds), Improving Teaching and Learning in Science and Mathematics (pp. 222-231). New York: Teachers College Press.

Gess-Newsome, J., & Lederman, N. (1995). Biology teachers' perceptions of subject matter structure and its relationship to classroom practice. *Journal of Research in Science Teaching*, 32(3), 301-325.

Gilbert, J., Watts, D., & Osborne, R. (1985). Eliciting students views using an interview-about-instances technique. In L.H.T. West & A.L. Pines (Eds.), *Cognitive structure and conceptual change* (pp.11-27). New York: Academic Press.

Good, R. (1991). Editorial. *Journal of Research in Science Teaching*, 28 (5), 387.

Griffiths, A.K., & Preston, K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching,* 29(6), 611-628.

Gunstone, R. (1989). A comment on 'the problem of terminology in the study of student conceptions in science.' *Science Education*, 73, 643-646.

Hashweh, M. Z. (1987). Effects of subject matter knowledge in the teaching of biology and physics. *Teaching and Teacher Education*, 3, 109-120.

Hesse, J.J., & Anderson, C.W. (1992). Student's conceptions of chemical change. *Journal of Research in Science Teaching*, 29(3), 277-299.

Hewson, P. W. (1996). Teaching for conceptual change. In D. F. Treagust, R. Duit & B.J. Fraser (Eds), *Improving Teaching and Learning in Science and Mathematics* (pp.131-140). New York: Teachers College Press.

Hewson, M. G., & Hewson, P.W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. *Journal of Research in Science Teaching,* 20 (8), 731-743.

Hynd, C. R., McWhorter, J. Y., Phares, V. L., & Suttles, C. W. (1994). The role of instructional variables in conceptual change in high school physics topics. *Journal of Research in Science Teaching*, 31 (9), 933-946.

Lederman, N. G., & Zeidler, D. L. (1987). Science teachers' conceptions of the nature of science: Do they really influence teaching behavior? *Science Education*, 71, 721-734.

Lemke, J. L. (1993). *Talking science: Language, Learning, and Values.* Ablex: New Jersey.

Lambiotte, J.G., & Dansereau, D. F. (1992). Effects of knowledge maps and prior knowledge on recall of science lecture content. *Journal of Experimental Education*, 60 (3), 189-201.

Morrison, J. A. (1996, January). *The development of preservice teachers' ability to assess students' understanding.* Paper presented at the annual meeting of the Association for Education of Teachers in Science, Seattle, WA.

National Research Council (1996). *National science education standards.* Washington, D.C.: National Academy Press.

Novak, J.D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching*, 27(10), 937-949.

Novak, J.D., & Gowin, D.B. (1984). *Learning How to Learn.* New York: Cambridge University Press.

Novick, S., & Nussbaum, J. (1978). Junior high school pupils' understanding of the particulate nature of matter: An interview study. *Science Education*, 62(3), 273-281.

Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education*, 65(2), 187-196.

Osborne, R.J., & Cosgrove, M.C. (1983). Children's conceptions of the changes of the state of water. *Journal of Research in Science Teaching*, 20(9), 825-838.

Osborne, R.J. & Freyburg, P. (1985). *Learning in science: The implications of children's science*. (pp.151-165). Auckland, NZ: Heiemann.

Osborne, R.J. & Wittrock, M.C. (1983). Learning science: A generative process. *Science Education*, 67(4), 489-508.

Osman, M.E., & Hannafin, M.J. (1994). Effects of advance questioning and prior knowledge on science learning. *Journal of Educational Research*, 88 (1), 5-13.

Prawat, R. S. (1992). Teachers' beliefs about teaching and learning: A constructivist perspective. *American Journal of Education*, 100, 354-395.

Prawat, R. S. (1993). The value of ideas: Problem versus possibilities in learning. *Educational Researcher*, 22, 5-16.

Posner,G., Srike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66, 211-227.

Renstrom, L., Andersson, B., & Marton, F. (1990). Students' conceptions of matter. *Journal of Educational Psychology*, 82(3), 555-569.

Smith, E.L., Blakeslee, T.D., & Anderson, C.W. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching*, 30 (2), 111-126.

Stavy, R. (1990). Children's conception of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research in Science Teaching*, 27(3), 247-266.

Taylor, S. J., & Bogdan, R. C., (1984). *Introduction to qualitative research and methods: The search for meaning.* New York: Wiley.

Thijs, G. D. (1992). Evaluation of an introductory course on "force" considering students' preconceptions. *Science Education*, 76(2), 155-174.

Tobin, K., & Fraser, B. (1990). What does it mean to be an exemplary science teacher? *Journal of Research in Science Teaching*, 27(1), 3-25.

Tobin, K., Tippins, D. L., & Gallard, A. J. (1994). Research on instructional strategies for teaching science. In D. L. Gabel (Ed.) *Handbook of research in science teaching and learning* (pp. 45- 93). New York: Macmillan.

Treagust, D. F., Duit, R., & Fraser, B.J. (1996). Overview: Research on students' preinstructional conceptions- The driving force for improving teaching and learning in science and mathematics. In D. F. Treagust, R. Duit, & B.J. Fraser (Eds*), Improving Teaching and Learning in Science and Mathematics* (pp. 1-14). New York: Teachers College Press.

Trumper, R., & Gorsky, P. (1993). Learning about energy: The influence of alternative frameworks, cognitive levels, and closed-mindedness. *Journal of Research in Science Teaching,* 30(7), 637-648.

von Glaserfeld, E. (1993). Questions and answers about radical constructivism. In K. Tobin (Ed.) *The practice of constructivism in science education.* AAAS.

Wandersee, J.H. (1986). Can the history of science help science educators anticipate students' misconceptions? *Journal of Research in Science Teaching*, 23, 581-597.

Wandersee, J.H. (1990). Concept mapping and the cartography of cognition. *Journal of Research in Science Teaching*, 27(10), 923-936.

Wandersee, J.H., Mintzes, J.J., & Novak, J.D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed*.) Handbook of research in science teaching and learning* (pp. 177-210). New York: Macmillan.

White, R., & Gunstone, R. (1992). *Probing Understanding*. New York: Falmer.

APPENDICES

Appendix A

Dear ____________,

I am writing to invite you to participate in a science education doctoral dissertation research project through Oregon State University. This project will focus on secondary school science teachers' lesson planning, interactions with students in the classroom, and assessment of students' understanding.

If you volunteer to become involved in this study, you will be asked to participate in three informal interviews with the researcher (myself) and also to allow the researcher to observe and videotape some of your science classes. It will also be necessary for the researcher to view some of your lesson plans and a variety of students' work. The time period for this project will depend on the material you will be covering but it will most likely encompass 8-9 weeks of your teaching during Fall term, 1998.

All information gathered in this study will be held strictly confidential. The anonymity of all participants will be of utmost importance and no one except the researcher will view the classroom videotapes, these will be destroyed after the project is finalized. The data collected during interviews and classroom observations will be coded to protect participants, pseudonyms will be used so that participants will not be identifiable in any publication of the results of the study. If at any time you feel the need to drop out of this research project, you will certainly have the freedom to do so

Your participation in this project would be greatly appreciated; teachers have little spare time for extra projects such as this but I believe you will benefit from your involvement. You will have access to all information gathered and may view classroom videos at any time. Hopefully, this chance to have nonpartisan information on your teaching will appeal to you.

If you are interested in participating in this study, please sign the form below and return in the self-addressed envelope enclosed. Your prompt reply will be greatly appreciated. If you would like to have more information about the study before signing, please do not hesitate to call me at: (509) 627-7232.

Thank you very much for your time. I hope to meet you in person soon,
Sincerely yours,

Judy Morrison Dr. Norm Lederman (Major professor) (541) 737-1819

Name_________________________________
School________________________________

Phone number ________________(school)__________________(home-optional)

Yes, I would be interested in participating in this study. I will be available for three interviews and agree to have classroom observations conducted in my class.

Appendix B

To Parents/Guardians and Students:

Your child's science teacher at ___________ High School will soon be involved in a doctoral dissertation research project. This project is through Oregon State University where I am a doctoral student in Science Education. The focus of my research will be the teacher's assessment of students' understanding of science concepts. The students in the classroom will not be involved in the study as subjects; the focus of this research is the teacher.

During the course of my investigation, which will last 8-9 weeks, I will be videotaping the classroom and the teacher's interactions with students. It is possible that your child may be videotaped at sometime during this project. When the videotapes are transcribed, pseudonyms for all students, their teacher, their school, and their community will be used. Anonymity of all participants in this study will be preserved at all times. Once the videotapes have been analyzed, they will be destroyed; no one but my major professor and myself will have access to these tapes during their analysis.

If you have any questions or concerns regarding this research project, please contact me at (509) 627-7232 or feel free to contact my major professor, Dr. Norm Lederman, at (541) 737-1819.

Please sign and date the form supplied below and ask your child to sign also and return it to their teacher as soon as possible. I greatly appreciate your permission to allow me to videotape students in the classroom.

Sincerely yours,

Judy Morrison

I agree to allow my child to be videotaped during the course of this research project and realize that all information will be kept confidential and pseudonyms will be used for all names.

Signed____(parent/guardian)

Date____________________

Signed____(student)

Date____________________

Appendix C

<u>Classroom Observation Form</u>

Date____________Class Observed__________________Teacher________________

Questioning Strategies:

a. T asks for explanation (EXPLANATION) Occurrences__________ Notes:

b. T asks for clarification (PROBE) Occurrences__________ Notes:

c. T asks for predictions that may show preconceptions (PREDICT) Occurrences________ Notes:

d. T asks Qs to directly elicit Ss preconceptions (PRECONCEPTIONS) Occurrences_____ Notes:

e. T asks for recall of facts or definitions (RECALL) Occurrences_________ Notes:

f. T asks open-ended Qs w/many correct answers (OPEN-ENDED) Occurrences________ Notes:

g. T asks about Ss prior experiences (EXPERIENCES) Occurrences_________ Notes:

h. T asks about prior knowledge (PRIOR KNOWLEDGE) Occurrences_________ Notes:

i. Ss preconception not recognized by teacher (NONRECOGNITION) Occurrences______Notes:

j. Other (MISC) Description:

Student to Teacher Questioning:

a. Ss asks a Q (STUDENT Q) Occurrences_________ Notes:

b. Ss asks a Q that shows a preconception (STUDENT Q w/precon) Occurrences_________Notes:

c. Ss asks for explanation (MISUNDERSTANDING) Occurrences__________ Notes:

d. Ss asks for clarification (CLARIFICATION) Occurrences_________ Notes:

e. Ss asks for individual help (INDIVIDUAL) Occurrences__________ Notes:

f. Other (MISC) Description:

Teacher Presenting Information:

a. Straight lecture (LECTURE) Occurrences_________ Notes:

b. Demonstration (DEMO) Occurrences__________ Notes:

c. Text work (TEXT) Occurrences_________ Notes:

d. T uses scientific concepts to explain phenomena (SCI CONCEPTS) Occurrences_______Notes:

e. T contrasts Ss preconceptions w/scientific concepts (CONTRAST) Occurrences_______Notes:

f. T uses discrepant event to uncover preconceptions (DISCREPANT E.) Occurrences__________ Notes:

g. Class discussion in which Ss ideas are elicited (DISCUSSION) Occurrences_________Notes:

h. Other (MISC) Description:

Written Work

a. Pretest (PRETEST) Occurrences__________ Notes:

b. Writing Prompts (PROMPTS) Occurrences_________ Notes:

c. Concept maps (MAPS) Occurrences__________ Notes:

d. Worksheet (WORKSHEET) Occurrences________ Notes:

e. Quiz (QUIZ) Occurrences_________ Notes:

f. Lab Write-up (LAB REPORT) Occurrences________ Notes:

g. Exam (EXAM) Occurrences_________ Notes:

h. Other (MISC) Occurrences_________ Notes: