1990

Student understanding of selected science concepts related to water

Linda Hagelin
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**Student understanding of selected science concepts related to
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Hagelin, Linda B., M.A.

San Jose State University, 1990

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**STUDENT UNDERSTANDING OF SELECTED SCIENCE
CONCEPTS RELATED TO WATER**

A Thesis

Presented to

The Faculty of the Division of Teacher Education
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

By

Linda Hagelin

August, 1990

APPROVED FOR THE DIVISION OF TEACHER EDUCATION

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ABSTRACT
STUDENT UNDERSTANDING OF SELECTED SCIENCE
CONCEPTS RELATED TO WATER

by Linda Hagelin

Recent findings regarding the understanding of how students learn concepts in science have revealed a high occurrence and persistence of misconceptions that students bring into the science classroom. The purpose of this study was to explore and document patterns of student understanding of science concepts dealing with water, particularly in predicting behavior and interpreting observations of two water solutions of different density. Students from the fourth, sixth and eighth grades were given a paper and pencil assessment test accompanied by a video taped demonstration. The test asked for explanations of the students' ideas in their own words. The results of this test indicate differences in student ideas, which characterized each grade level studied, about the behavior of two water solutions of different weight or density.

Classroom implications are presented that indicate the importance of teacher recognition of the ideas students bring into the classroom. Pretests that probe student understandings in science appear to be an aid in effective lesson planning by providing the teacher with insight into student views of a topic.

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CHAPTER I

INTRODUCTION

Recent findings regarding the understanding of how students learn concepts in science have revealed a high occurrence and persistence of misconceptions that students bring into the science classroom. The origin of these misconceptions, also known as naive theories, alternate conceptions and alternate understandings, apparently lies in understandings built by personal experiences with the natural world:

The work of Jean Piaget and others on the development of children's thinking, has indicated that . . . pupils bring to their school learning in science ideas, expectations, and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. These alternate frameworks, in some cases strongly held and resistant to change, . . . have their influence on the effectiveness of formal science programmes. (Driver, 1981, p. 93)

Numerous interviews with students at all levels and in many countries have shown that pupils do not come to science class with a "blank slate" representing their understanding of science concepts (Champagne & Klopfer, 1983; Driver, 1989; Eaton, 1983; Smith & Anderson, 1984; Viennot, 1979). To the contrary, even the youngest student has formulated explanations for natural phenomena according to his or her own experiences. These personal explanations have real meaning for the child and are not easily changed or "corrected" by classroom instruction. "The evidence that students' prior

knowledge is an important aspect of their learning of science is overwhelming, resulting in the consensus that science teachers will have to confront this aspect of learning in their instruction to bring about the elusive goal of meaningful learning in their classrooms" (Zietsman & Hewson, 1986, p. 28).

The prior knowledge that a student brings to the science class sometimes leads to unknowing misinterpretation of what is taught, a process that ensures that the new information presented by the teacher will not be in conflict with earlier ideas held by the student. Thus, the student retains an alternate conception that makes sense to him or her, even though the alternate conception might not agree with the accepted scientific theory. "Because they are based on pupils' intuitions about everyday experiences, these alternate frameworks may be held persistently and be resistant to change through teaching" (Driver, 1982, p. 74).

Alternate understandings of concepts might go unrecognized and unchallenged by educators (Smith & Anderson, 1984). It is possible, for instance, that students might be taught a series of lessons on "How We See" and still fail to demonstrate an understanding of the role of reflected light in that process (Eaton, 1983).

Background

As of January 1990, there had been no survey or assessment of science concept understanding among students in the Saratoga Union School District below the 8th grade. No investigation of science misconceptions had been done with any of the district's students. The administration was interested in the results of this kind of study and agreed to district participation.

Since the researcher has a particular interest in marine science topics, an examination of student understanding of science concepts dealing with water was undertaken for this study. It focused on assessing the characteristics of fourth, sixth, and eighth grade student understanding of a demonstration involving the interaction of two water solutions of different densities. A total of 274 students were tested using a combination of a written instrument and a video taped demonstration, both developed by the researcher.

Problem Statement

Evidence shows that children's misconceptions or alternate understandings of specific science concepts can interfere with their assimilation of related knowledge presented during classroom instruction and, as a result, there are many concepts in the biological and physical sciences that are misunderstood by students. Some studies have further demonstrated that student understanding increases dramatically when the teacher is aware of common misconceptions that pupils might have about the subject (Smith & Anderson, 1984).

Purpose Statement

The purpose of this research was to assess and describe patterns of understanding of certain science concepts dealing with water held by a sample of students in the fourth, sixth, and eighth grades in the Saratoga Union School District. In particular, student ideas about the relative density and

interaction of water-based solutions were examined for implications that might be useful to teachers when planning lessons on science concepts dealing with water.

Hypotheses

The hypotheses addressed in this study are summarized below. See Chapter III for a complete statement of each hypothesis.

1. Among fourth, sixth and eighth graders, the percentage of scientifically accurate predictions increases with student age.
2. Students in these grade levels demonstrate characteristic differences in their patterns of responses when asked to give predictions regarding the interaction of water solutions having different densities.
3. Students in the fourth, sixth, and eighth grades demonstrate characteristic differences in the explanations of their predictions regarding the interaction of water solutions having different densities.
4. More than two-thirds of the students at each grade level can accurately observe and report a situation demonstrated on video tape.
5. Fourth, sixth and eighth graders demonstrate characteristic differences in the reasons they give for observations regarding different water solutions.
6. Less than one-fourth of the sample populations will demonstrate prediction bias in their responses.
7. Frequency distribution of correct responses will not differ significantly between males and females at any one grade level.

Research Questions

Research questions addressed by this study include:

1. What are the key characteristics and patterns of understanding across the three grade levels of the interactive behavior of fresh water and a water-based solution (such as salt water) due to their densities?
2. Do eighth graders exhibit an understanding of this concept that is closer to the scientific view than do fourth and sixth grade students?

Operational Definitions

For the purposes of this study, the researcher defines the following terms:

1. Misconceptions, Alternate Conceptions, Alternate Understandings, or Naive Theories: Ideas that are in variance with the generally accepted scientific explanation of a particular science concept. These ideas are developed from a child's own experience with the natural world.
2. Key Characteristics: The common characteristics of understanding noted at each level from the administration of the assessment instrument.
3. Prediction Bias: The tendency to confirm predictions, even if those predictions turn out to be incorrect: "I saw what I thought I would see."
4. Scientifically Accurate or Correct Responses: The responses that reflect the most likely scenario within a short period of time using simple observation with the unaided eye. In the case of the video demonstration with fresh and salt water, many of the responses could be considered correct if observed under great magnification, or over a period of hours or days.

Assumptions

During the course of this study, the researcher assumed the following:

1. Students answered specific concept questions honestly, and when asked for an explanation of their ideas regarding the concept, responded fully and sincerely.
2. Students who took the test could read and write in English well enough to understand and respond to the questions.

Limitations

The researcher recognizes the following limitations pertaining to this study:

1. The sample population is limited to students in the Saratoga Union School District, Saratoga, California.
2. Student personality factors, such as disinterest in an ungraded test, might affect results.
3. The topic tested is limited to selected physical science concepts dealing with water:
 - a. Water has weight.
 - b. Water solutions of equal volume can vary in weight.
 - c. "Heavier," more dense water tends to sink in a container of water.
 - d. "Lighter," less dense water tends to rise in a container of water.

Statement of Significance

With the information provided by this study on certain misconceptions held by Saratoga Union School District students in science, the teachers can direct instructional attention to the areas of need. There are specific examples available to the teachers that describe fourth, sixth and eighth grade student alternate conceptions related to the relative density of water solutions. This information can be used by teachers to focus instruction and enhance student understanding in these specific areas. The result will be an increased likelihood that student ideas regarding these concepts will more closely parallel the prevailing scientific view.

Documentation of student ideas about the relative density of water solutions can be particularly useful in marine science lessons. Currents caused by temperature and salinity differences in adjacent water masses are part of the explanation for circulation in the world's oceans, affecting the climate and biology of many areas.

In a broader sense, this study contributes to the growing body of research that documents the prevalence, and gives specific examples, of student alternate understandings of science concepts. Teacher awareness of naive theories has been shown to be a useful tool in improving student understanding of specific concepts (Smith & Anderson, 1984). This study contributes to the improvement of science teaching methods by enhancing teacher awareness of some of the ways students make sense of the natural world.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

Numerous studies have investigated student understanding of biological and physical science concepts. These studies reinforce a view of learning set forth by Piaget: the learner's previous experiences and ideas have a significant influence on how new information, e.g. from a classroom lesson, is understood and accepted by the student. Many students, because of naive theories based on experience or intuition, fail to grasp the "new" concept presented by the teacher in a science class (Champagne & Klopfer, 1980). Currently accepted views in learning theory can provide insight into the role of student preconceptions in the educational process.

One school of thought that recognizes the role that experience plays in the learning process is Constructivism. Constructivists emphasize the influence of student ideas built from these experiences. They also suggest that some of these ideas might hinder learning of accepted scientific theory by interfering with the students' assimilation of new information (Driver, 1981). Constructivists believe that designing the learning environment to encourage exploration and articulation of student ideas can facilitate the restructuring of those ideas when students are given the opportunity to contrast them with prevailing scientific theory. Investigations into student alternate conceptions on a wide range of science topics have provided educators with clues to understanding the learning process.

Influence of Previous Experiences on Learning

It has become widely accepted among educators that a child's learning is a result of the interaction of what the child brings to the classroom, or already knows, and what the teacher presents during the course of the lesson. ". . . the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel, 1978, p. 64). According to Piaget, the child searches for a state of "equilibrium," or balance, between what he or she already has learned and the questions brought to mind by a new situation or idea. The image of learning is one of constant change, building on previous experience, and searching for coherence: ". . . the equilibria achieved always open onto new problems and potential operations that it is possible to construct starting from preceding operations. Thus the most elaborated science remains in continual becoming, and in every area disequilibrium plays a functional role of first importance because it necessitates reequilibrations" (Piaget, 1975/1985, p. 139).

Piaget's works, according to Posner, Strike, Hewson, and Gertzog (1982), ". . . have perhaps had the greatest impact on the study of the interpretive frameworks students bring to learning situations" (p. 211). Piaget and Inhelder (1958) sought to find a parallel between childrens' explanation of a natural phenomena and their age. They were looking for patterns of cognitive development common to all children. Piaget's image of a child as ". . . a young scientist building successively more sophisticated models of the world . . ." (Case, 1985, p. 22) has provided a framework for widespread research into student misconceptions or alternate conceptions in science.

Learning as Conceptual Change

Piaget's image of the learning process as a constant searching for equilibrium, or answers to the questions posed by new situations, emphasizes the importance of the learner's mental framework. Learning involves changing that framework to make sense of new information. Posner (1982) called this mental rearrangement "conceptual change."

The view of learning as conceptual change has two main elements, according to Posner et al. (1982). In one, a student uses existing ideas or concepts to understand and deal with new experiences. This mechanism is termed "assimilation." For example, some children who have had experience with floating toys in a bathtub might not be puzzled by ships floating in the sea. However, sometimes the existing concepts are not adequate to handle the new phenomenon successfully. In this case, children who say "all metal things sink because they are heavy," might find it puzzling when they realize that steel-hulled cargo ships float. That realization could initiate a re-evaluation of concepts about "floating and sinking" in the child's mind. "Then the student must replace or reorganize his central concepts. This more radical form of conceptual change we call accommodation" (Posner et al., 1982, p. 212). The student brings previous experiences to bear on new situations, and if they are inadequate to answer the questions raised, he or she then changes or replaces those previous concepts to accommodate the new information. This change in conceptual framework is the essence of the learning process.

Posner and his colleagues were interested in the conditions under which accommodation, or conceptual change, took place in student thinking. Under what conditions do students find it necessary to either replace or reorganize

their currently held concepts? This is an extremely important question for science educators. "Teaching science involves providing [the students with] a rational basis for a conceptual change" (Posner et al., 1982, p. 223).

One of the primary conditions necessary for conceptual change is for the student to be dissatisfied with his or her existing framework of ideas. The child in the "All metal things sink because they are heavy" example, above, is dissatisfied when the mental rule that facilitates his understanding of sinking and floating is clearly inadequate. Piaget (1975/1985) emphasized the importance of this conflict as a factor in acquiring new knowledge. The teacher plays a key role in providing situations that encourage students to re-think their ideas about a topic. In order for conceptual change to take place, Posner (1982) suggests: (a) there must be dissatisfaction with existing conceptions, (b) a new conception must be intelligible, and (c) a new conception must appear initially plausible (p. 214). Conceptual change, or accommodation, generally is a gradual process, a bit by bit, piece by piece, change in concepts. "Accommodation, particularly for the novice, is best thought of as a gradual adjustment in one's conception, each new adjustment laying the groundwork for further adjustments but where the end result is a substantial reorganization or change in one's central concepts" (Posner et al., 1982, p. 223).

The Constructivist View

An idea that is being adapted for science education is that of the constructivists (Driver, 1982, p. 69). The constructivist view recognizes that learning depends upon the mind set, or "conceptual framework," of the learner. They understand the importance of prior experience for making the student

"ready" to learn, and assert that: ". . . children actively construct meaning from what they experience, using their existing ideas to make sense of events in the classroom" (Wightman, Green, & Scott, 1986, p. 1). In recognizing already existing ideas that the students possess, constructivists also realize that some of these ideas students have in science might be other than accepted scientific theory. These alternate frameworks are based on pupils' intuitions about everyday experiences. This viewpoint recognizes the possibility that instead of each experience building on previous experiences in a steady progression toward greater understanding, it is possible that student preconceptions might actually interfere with learning and block the assimilation of scientific concepts. "These existing ideas may colour the meaning that children construct to such an extent, that the learning outcomes expected by the teachers do not materialise" (Wightman et al., 1986, p. 1). Recent studies of student naive theories have sought to assess their frequency and to describe any characteristics and common patterns found across grade levels.

The Studies

A number of research studies have documented student alternate conceptions or naive theories in science (Anderson, 1986; Arnaudin & Mintzes, 1985; Brook, Driver & Hind, 1989; Champagne & Klopfer, 1980; DiSessa, 1982; Driver, 1987; Eaton, 1983; Giese, 1987; Osborne & Cosgrove, 1983; Smith & Anderson, 1984; Wandersee, 1986; Westbrook & Marek, 1988; Wightman et al., 1986). "Such studies indicate that although individual children will bring unique perspective to learning there are enough common trends in their thinking to make a study of more common alternate frameworks worthwhile" (Driver, 1981,

p. 98). The overviews of selected studies that follow are organized by science topic.

Biology

Arnaudin and Mintzes (1985) examined students' alternative conceptions of the human circulatory system across the grades. Two data gathering methods were used for the construction of a test instrument: concept mapping and clinical interviews. The student-constructed concept maps were used as a point of departure for the interviews which probed student understanding of the circulatory system.

Twenty-five students each from the fourth grade and college freshman levels participated in this phase of the study. Responses from the interviews of all fifty of the students were categorized to determine scientific and alternate conceptions. The set of alternate conceptions collected provided the basis for development of a test instrument.

The test instrument consisted of eleven multiple choice and four open-ended questions which addressed student understandings of the cardiovascular concepts. This test was administered to a total of 495 students at the 5th, 8th, 10th grades and the college freshman level. "In a number of instances, the relative frequencies of alternative conceptions common to elementary school students remained stable at the secondary and college levels" (Arnaudin & Mintzes, 1985, p. 729). This finding supports the idea that student preconceptions are tenacious and resistant to change (Ausubel, 1978). In other cases the frequency of scientifically acceptable responses rose steadily across the age groups. These variations appear to be unpredictable, and represent what Posner et al. (1982) described as conceptual change which

involves "much fumbling about, many false starts, mistakes, and frequent reversals of direction" (p. 223).

Junior high school through college students were evaluated for their understanding or misconception of four biology concepts by Westbrook and Marek (1988). One hundred students each from the 7th, 10th grades and college level were tested to evaluate their understanding of the following concepts: the cell, diffusion, homeostasis, and gene function. The results of the tests showed that students at the college level did not always demonstrate a greater degree of understanding of these concepts. Misconceptions here frequently arose from the misapplication of science terminology.

There was an increase in understanding with increased student age for the concepts of the cell and homeostasis, but there were no differences in understanding across the grades for diffusion. This study found that, contrary to expectations, the developmental level of the student did not seem to predict the number of alternate conceptions that students were likely to hold. Older (formal) students might have as many misconceptions as the youngest (concrete).

Light

Eaton (1983) studied misconceptions about light held by two classes of fifth grade students. The elementary teachers who participated in the study taught science regularly. The researchers studied in detail six students, three from each class, to determine the way these children "make sense of their textbook and class instruction on light and seeing" (Eaton, 1983, p.3).

Thirteen lessons were observed with the researchers making detailed notes on the classroom setting, what was said by the teachers and students, activities and locations of the teacher and students. The pretest and posttest

given were identical. These multiple choice and short answer tests were the source of information about the students' conceptions of light and seeing before, as well as after, the unit was taught.

Pretest data showed that all six of the study students held a common misconception that an object is seen because light shines on it and illuminates it. Among the total group of 102 students in the two classes, only three of the students who took the pretest mentioned the role of "reflection" or "bouncing" light in vision. Eaton and her colleagues believed understanding that we see by reflected light was essential to student comprehension of other parts of the science text unit on light and how the eye works.

After the unit of instruction on light, five of the six students studied showed little change in their understanding of how we see. In the classes as a whole, about 30% of the 113 students who took the posttest mentioned bouncing or reflected light.

It seems, then, that most of the students had difficulty understanding and believing that opaque objects reflect light to our eyes. The misconceptions that opaque objects do no more to light than stop it, and that we see such objects simply because light shines on them, rendered meaningless much of the material the students were taught from unit four. (Eaton, 1983, p. 8)

Simply stating the scientific conception (as is often the case in textbooks) is not enough to alter student understandings. "The scientific conception must be carefully explained and contrasted with common misconceptions. In a sense, it must be proven to the students' satisfaction" (Eaton, 1983, p. 23). The conclusion was that conceptual change had not occurred because the student misconceptions were not addressed at any time during instruction.

Smith and Anderson (1984) assessed student misconceptions about light and about plants at the fifth grade level. Fourteen classes of 5th graders were followed for two years as units on light and plants were taught. Each class was administered pre and posttests. The researchers made detailed observations of the lessons taught, interviewed the teachers and observed lesson planning during the first year. The results of the first year's study were used to design instructional modifications in the units on light and plants to be implemented during the second year.

At the end of the first year, "There was not a single classroom in which even half of the students came to understand the key concepts taught" (Smith & Anderson, 1984, p. 9). The researchers blamed part of this failure of instruction on misconceptions held by both students *and teachers*. They believed these pre-existing ideas had negative effects on the way information was processed in the classroom (p. 9). Common student misconceptions about light are similar to those found by Eaton (1983): (a) Light shines on or brightens objects so that people's eyes can see them directly and (b) Objects have colors. Light helps people to see those colors.

During the second year of this study, curriculum materials were developed that helped teachers become aware of and respond to the student misconceptions. Supplemental transparencies were prepared to accompany the textbook. "Each transparency presented a situation and asked a question that could be answered using either the students' misconceptions or a scientific conception of light" (Smith & Anderson, 1984, p. 13). These new materials and the awareness of likely student misconceptions were found to affect teacher behavior in the classroom. Teachers were more likely to focus on key concepts and to ask for clarification of student ideas about light and seeing. The

successful instruction posed questions designed to draw out anticipated misconceptions and to contrast those with scientific alternatives.

The results of the revised teaching methods showed that at least three times as many students understood the scientific conceptions of light compared to the previous year. "Research examining students' misconceptions and experience of instruction on a particular topic can be used to develop strategies and materials that are much more successful in bringing about student learning of scientific conceptions" (Smith & Anderson, 1984, p. 19).

Water

Children ranging in age from eight to seventeen years were interviewed about their ideas of what happens when water boils, evaporates and condenses, and when ice melts. Osborne and Cosgrove (1983) found that the 43 children tested have personal explanations of these commonly observed phenomena. These views were not necessarily scientifically acceptable, and older student ideas were often similar to those of the younger. In fact, some misconceptions were more popular with the older children than with the younger (more 15 year olds said water changed into hydrogen and oxygen when it boiled). "Implications for teaching are clear. Unless teachers identify childrens' views and design their teaching accordingly, some children's ideas will not change, or will change in unanticipated ways, as a result of science teaching" (Osborne & Cosgrove, 1983, p. 836).

Giese (1987) studied eighth grade student understanding of water pressure among 13 students in a program for the gifted. Student discussions of pretest questions reflected their direct experience with water pressure, such as garden hoses and watching coffee drip from a filter coffee maker. None

recalled specific instruction on the topic, but they also mentioned sources of information such as television documentaries about the ocean. These students brought their experiences to bear on the test questions. "Each student seemed to have incorporated, prior to this study, parts of ideas from other sources without consciously examining any idea for consistency with his/her other beliefs" (Giese, 1987, p. 145). For example, when comparing water pressure on a fish's back with the pressure on its mouth, a student wrote: "More water pressure is exerted on the striped fish downward than from the side. If the pressure was from the side, it would not 'stand' still" (p. 147).

The test Giese administered to the students consisted of 20 questions that required a written explanation for each answer. The two generalizations focused on regarding water pressure were: (a) pressure increases with depth and (b) pressure at a given depth is equal in all directions. After the pretest, demonstrations and discussion of water pressure were provided for the next four class sessions. At the end of the fourth session, a posttest identical to the pretest was administered.

The students understood (a) pressure increases with depth better than (b) pressure at a given depth is equal in all directions, as shown on the test results. A common misconception of pressure being equal in all directions at a given depth was that ". . . horizontal pressure at a point on an object is directly proportional to the horizontal distance from that point to the nearest boundary of the water" (Giese, 1987, p.146). In other words, fish have more pressure exerted on one side of them than on the other, unless it happens to be exactly in the middle of a body of water. Giese attributes this idea to an incorrect extension of the concept of increasing pressure with depth. The instructor urged the students to think that scenario through to a "real world" situation. It

means that a fish would have unequal sideways pressure on it, pushing it toward the shoreline with increasing force. Significant speed could be reached in bodies of water as large as an ocean! "No student thought of the logical consequences of this misconception until the consequences were presented by the researcher by demonstrations, hands-on activities, and discussion" (Giese, 1987, p. 147). The posttest results showed that some, but not all of the students adopted the scientific view on this topic, while others accepted parts of ideas without accepting the whole. This finding concurs with Posner's (1982) image of conceptual change as a gradual, bit by bit adjustment of concepts. Giese concluded teacher knowledge of student understandings of a topic to be a valuable guide to effective lesson planning.

Motion

Naive theories' resistance to change was demonstrated by Champagne and Klopfer (1990) with a group of students on the college level. Even after many years in school, college students come to physics class with a poor grasp of basic concepts. In a study of 110 non-science majors, students were assessed with a demonstration-observation-explanation (DOE) test. This method requires the students to observe and explain what they see demonstrated by the researcher. Answers to the DOE test were viewed as probes of student understanding of the concept of motion. The surprise to researchers was that a good score on the DOE test was not a strong predictor of success in learning physics. Even though grasp of basic concepts was poor, ". . . students do not start the introductory physics course with any lack of ideas about the motion of objects. These common-sense intuitive ideas, based on years of experience with moving objects, serve the student satisfactorily when

describing the world" (Champagne & Klopfer, 1990, p. 1077). It is these ideas that the researchers believe might interfere with student interpretation of classroom instruction. Champagne suggests that to improve instruction the pre-existing ideas of the students must be recognized. These student ideas must then be compared and contrasted to the "scientific" model, using experiments with apparatus and demonstrations. Students need the opportunity to test their own ideas against the accepted view in order to change their mental models.

Density

High school student understandings about states of matter and density changes were investigated by Shepherd & Renner (1982) using a paper and pencil assessment test. Students in grades 10 and 12 ($n = 135$) were shown an illustration of a lake in summer and the same lake in winter, noting that the temperature at the bottom of the lake was cooler than the rest of the lake in summer, but warmer (39 degrees F) in winter. The students were also provided with the information that "A gallon of water at 39 degrees F weighs more than a gallon of water at 37 degrees F" (Shepherd & Renner, 1982, p. 656). They were asked to write a paragraph to explain what happens in the lake to make the bottom the coldest in summer and warmest in winter. The written responses were coded according to key characteristics and rated as one of the following:

1. Sound Understanding: includes all components of a complete explanation.
2. Partial Understanding: includes at least one component of a complete explanation.
3. Specific Misunderstanding: an alternate conception used to explain the lake problem.

4. No Response

None of the students exhibited what the researchers considered to be a complete understanding of the lake problem. Some of the specific misunderstandings (23% of the responses) included (a) heat rises in summer and falls in winter and (b) bottom water is affected by the earth's temperature. Partial understanding was demonstrated by 58% of the students. Typical of the partial answers were (a) weather was the only factor affecting lake temperatures winter and summer, (b) sun's rays cannot penetrate deep enough to affect the bottom water temperature, and (c) ice insulates water below in winter, and summer sun heats only the top layers of the lake. The researchers found that "Tenth graders demonstrated more partial understanding . . . than did the 12th graders. The older students demonstrated more specific misunderstandings on the same question than did 10th graders. The only conclusion that can be drawn from those data is that understandings of the two concepts investigated here are not enhanced . . . with schooling" (Shepherd & Renner, 1982, p. 662). Even though these students had been taught the concepts from the junior high school level, the researchers conclude: "The concepts which schools think they are teaching are not being learned" (p. 664).

Floating

Rodrigues (1980) investigated childrens' ideas about floating in water and in air by showing them cartoon drawings of possible and impossible situations and asking them for their explanations. The youngest children (7 years) would have had little formal science training on these topics, so their responses reflected the conclusions drawn from everyday experiences.

Fifteen children between the ages of 7 and 13 years were tested. Each child was interviewed individually for 20 minutes, and the session was tape recorded. The child was shown the cartoon and asked for a description of what was going on in the story. The researcher asked some specific questions about the reasons for the phenomena observed in the cartoons. The student answers were categorized according to scientific accuracy. For example, the children were asked if they saw anything in common between the cartoon showing a ball floating on water and another showing a balloon floating in the air. Answers ranged, with increasing age, from "It's not the same thing, because this one has gas and this one has air in it" (age 8), to "Sort of, because this is lighter than air, and this is lighter than water" (age 11.7) (Rodrigues, 1980, p. 67).

Rodrigues noted that ". . . the explanations children give about floating and falling in water and in air evolve gradually with age toward the adult explanations" (p. 71). The explanations for phenomena became less specific and more general with increasing age. "This fact points not to a sudden realizing of Archimedes' principle and gravity, but rather to a gradual organization of thoughts about their several applications and aspects . . ." (p. 69). In other words, the children are constructing their own theories and ideas based on previous experience or intuition.

Particle Theory

As noted in an earlier study by Champagne and Klopfer (1980), the gradual growth in scientific understanding with increasing age does not hold true for all topics in science. Novick and Nussbaum (1981) studied students from all levels to determine their understanding of the particulate nature of matter. The subjects ($n = 576$) ranged from the 5th to the 12th grades and

included non-science majors at the university level. Teaching About Particles in a Gas (TAP) was a paper and pencil test showing simple experiments. Each experiment asked for a written explanation or a choice among a number of given explanations. The questions explored student understanding of particles in a gas. The written responses were categorized according to key characteristics and the frequency distribution calculated.

The number of students who indicated that gas has a uniform distribution of particles increased steadily from the elementary to the high school level. However, 30% of the junior high and 10% of the senior high and university sample seemed to retain a misconception of motionless particles in a gas. Although there was a steady increase in "scientific" understanding that could be traced through the grades, ". . . even at the senior high and university levels, the figure [correct response] does not reach 50 percent" (Novick & Nussbaum, 1981, p. 191). These researchers recognize the persistence of alternate conceptions even at the university level, and suggest teacher use of diagnostic testing such as TAP as an aid in curriculum development.

Nature of Matter

Similar naive theories about physics were found in classes of the same age groups by Driver and her colleagues (1987). The Children's Learning in Science Project concluded that "In other words, there is evidence that there is commonality in the learning path followed by different classes of students. If this is the case then such information can be shared with other science teachers" (Driver, 1987, p. 105). Following is an examination of two of the studies in this project from the University of Leeds, England.

The first study concerned ideas about matter held by 13 and 15 year olds (Wightman, Green & Scott 1986). After instruction on the nature of matter, student responses still reflected alternate conceptions to the scientific view. The five teachers who volunteered to be part of this study kept a diary of the six lessons taught, with comments on their own and pupils' activities. The lessons were also audio taped by the researchers, and teachers and pupils were interviewed by the researcher outside of lesson time. From the data gathered, constructivist teaching strategies were to be developed and used the following year by the teachers. The lessons taught during the study were provided to the teachers by the researcher to insure uniformity of topic coverage among all five classes.

Classroom atmosphere and teacher expectations were found to be factors in learning. Characteristic responses of students in the classes were to look for quick "right" answers to the hands-on activities. They tended to short-cut processes and exploration. This concern for right answers, the researchers found, made the students highly dependent upon the teacher at a time when they should be learning independence at the secondary level. The students were given ample hands-on experiences and were encouraged to make their own observations and explanations. For example, students were looking for evidence of particles in the structure of water. A razor blade was rested on a pool of water in a petri dish, then a drop of detergent was added, and the razor sank. Discussions of what happened showed the difficulty students had of relating particle theory to what they saw. Pupils readily discussed observations, but when explanations were requested, responses were few. The researchers suggested that the classroom situation was a factor. The classroom atmosphere must be one which encourages risk-taking: "In the gym, we give

pupils confidence by providing a soft landing mat. In the classroom and laboratory too, we need to provide an intellectual landing pad so that more of our pupils will make the mental leap forward" (Wightman, Green & Scott, 1986, p.4).

Student alternate conceptions were apparent after small group work answering questions about solids, liquids and gasses. For example, density was described as being (a) related to the quantity of a substance, (b) dependent only on the number of atoms, and (c) a changeable property of a substance. Implications were that these naive theories must be recognized and addressed if conceptual change is to take place:

Pupils often have perfectly viable explanations of scientific phenomena according to their own view of the world, and without the opportunity for a thorough exploration of these ideas may not succeed in constructing the scientific view because of the conflict with their own beliefs. Alternatively, they may add scientific ideas to their own, to be used only in special 'scientific' circumstances, given suitable cueing, but reverting to their own in more 'normal' situations. Or they may integrate the science view with their own, resulting in a sort of hybrid version. Thus, what we as science teachers see as simple and non-controversial may be anything but to our pupils, and teacher telling does not necessarily mean pupil learning. (Wightman, Green & Scott, 1986, p. 2)

Air

The second Children's Learning in Science Project study investigated pupil understanding of the physical characteristics of air across the age range of 5-16 years. Brook, Driver and Hind (1989) interviewed 100 pupils in an

informal setting. The older students were interviewed in pairs, younger ones individually. Interviews were recorded on audio tape for later analysis. There was an informal, exploratory time at the beginning of each interview when the students could manipulate and "Find out anything interesting" or "Think of interesting questions" about the materials. The materials were used in the second part of the interview to explore student ideas about air. Materials included jars, funnels, balloons, straws, sink plungers. The older students did not spontaneously explore with the materials. They were more concerned with exactly what was expected of them. The younger ones eagerly used the materials. The interviewer asked the child to then tell what he/she already knew about air. Then the equipment was used to set up simple situations and pose questions for student response. For example, a jar inverted in a pan of water was used to elicit thoughts about why the water doesn't fill the jar.

The results showed the younger children explaining events in terms of human actions. After pushing on a sink plunger and noticing it stick to the surface, the young child answered a "why" question with "because I pushed it down" (Brook, Driver & Hind, 1989, p. 53). They were more likely to make observations based on what they expected to happen. As children get older, the use of ideas such as "lightness" and "vacuum" appear in their explanations. Older children also tested their hypotheses in a way to confirm, rather than in a critical or objective manner.

Some characteristics of student understanding of air are: (a) the youngest (5-7 years) understand that air is all around us, (b) middle elementary (7-11 years) realize air has weight., (c) older (11-14 years) students grasp the notion of atmospheric pressure and that pressure differences tend to equalize.

The researchers conclude that lessons should include ". . . activities

which take account of children's prior ideas and encourage the development of the intended scientific concepts. Knowledge of the children's understandings is important in making selections of learning experiences" (Brook, Driver & Hind, 1989, p. 57).

Other Physical Science Concepts

The importance of student opportunities to experience and test ideas was emphasized by the findings of Renner, Abraham, Grzybowski and Marek (1990). Textbooks were found inadequate for science teaching. These researchers studied student understandings of selected concepts in physics found in junior high school textbooks. The four concepts used in this study were:

1. Expansion concept: the process in which the volume of a substance increases.
2. Doppler Effect concept: change in wave frequency caused by motion of the wave source.
3. Floating concept: when mass of displaced liquid is equal to mass of the object, the object floats.
4. Kinetic Energy concept: kinetic energy is the energy of motion and can be changed to heat energy.

A written test requiring short explanations of simple experiments or situations was given to 257 students in the eighth grade. The answers were evaluated on a scale of levels of understanding similar to that of Shepherd and Renner (1982), above: Sound Understanding, Partial Understanding, Specific Misconception, No Understanding, No Response. The researchers were looking for the percentages of eighth graders that fell into each category after

instruction on the concepts. They found that many older children have the same misconceptions of the world held by younger children, even after years of exposure to science teaching. Well over half (60.8%) of the eighth grade responses were in the Specific Misconception or No Understanding categories. Their conclusion was that students were "... reading about science and not experiencing it" (Renner et al., 1990, p. 51).

Parallels with the History of Science

Some scholars have been intrigued by what seems to be a parallel between the development of scientific ideas through history, and the developing ideas of students through the grades. This is especially true in physics. McCloskey (1983) found that some physics students at the university level seemed to have ideas of motion that were reminiscent of the medieval "impetus" theory. This was true even after instruction in some cases. Students at the college level would have been exposed to the current scientific view of physical laws many times during their educational career. "In particular, information presented in the classroom may frequently be misinterpreted or distorted [by the student] to fit the naive impetus view, with the result that many students emerge from physics courses with their impetus theories largely intact" (p. 318). The persistence of these alternate conceptions is well documented by studies such as this one.

Clement (1982) pointed to Galileo's explanation of the impetus theory as "... supporting evidence for the strong, intuitive attraction of the 'motion implies force' belief. The students' errors appear not to be simply capricious; the belief appears to be 'plausible theory' that has been constructed by students on the

basis of experience" (p. 69). Educators, according to Clement, should not be surprised by the frequency of this misconception among students, and should respect these naive theories that students have constructed on their own from experience with the natural world. Clement further suggests that if students are given the opportunity to make predictions, and take an active part in following through on their ideas based on these naive theories, that the current scientific viewpoint can then be more readily assimilated by the pupils. In other words, the students are more likely to adopt the scientific view if they have had a chance to test their own ideas and find inconsistencies.

Wiser and Carey (1983) refer to the history of science as having only limited application when trying to understand naive theories. "It is extremely unlikely, although not impossible, that today's novice begins with a conceptual framework like Aristotle's. . ." (p. 296). They argue that the whole picture of scientific and social thought of the time was at work in Aristotle's thinking, and that today's novice does not bring the same repertoire to a physics problem. This researcher would agree, however, with Clement that the history of science points out to the science teacher an interesting coincidence that many students share similar ideas about the natural world with thinkers of earlier times. Even though many of today's students may not have the intellect of Aristotle, some of these ancient theories have reappeared in studies of student understanding of physical science concepts.

Wandersee (1986) suggests that the history of science can be useful to educators in predicting student misconceptions about photosynthesis. He found that the younger (elementary and junior high age) students were more likely to hold concepts found in the history of science that have been discarded

by modern views. Alternate conceptions at all grade levels were found to be similar to those documented in the history of science.

DiSessa (1982) noted the persistence of preconceptions when he observed sixth grade students of varying abilities at work in a computer lab. The students were using a Logo program with a graphics entity called "dynaturtle." The students were provided with games to play using the turtle. The students were responding to the turtle in non-Newtonian ways that were continually challenged by the behavior of the turtle. The turtle moving up the screen did not change direction at a right angle instantly. The result of a sideways "kick" is a compromise 45 degree angle. The students were very perturbed at this response, and thought the machine was broken. It took weeks for students to understand this "problem." DiSessa uses the example of kicking a soccer ball. Experienced players have learned to stop the ball before kicking it in another direction, which would conform to Newtonian physics. Students tried to "kick" the moving turtle in the direction of intended motion, with a compromise result in the change of direction. Students "tenaciously" tried to make the turtle behavior conform to their preconceptions about motion, or perhaps they were simply recalling earlier experience with computer games. Most played about twenty games on the computer before concluding there might be another explanation. Previously held conceptions die hard even in the face of evidence that challenges these theories.

Summary

Research into the conditions for student learning at all grade levels has shown that children come to science class with ideas about the natural world

constructed from their own experience and intuition. Sometimes these student ideas, or alternate conceptions, are at variance with accepted scientific thought, and might actually interfere with student acceptance of classroom instruction (Wightman, Green & Scott, 1986).

According to the literature, there appear to be at least two classroom factors that affect student understanding of science concepts:

1. Teacher awareness of alternate conceptions that students hold, which facilitates lesson planning to address those naive theories and contrast them with the scientific view.
2. A classroom atmosphere that encourages exploration, discussion, testing of ideas, and risk-taking by the students.

Two widely-used ways of assessing student understanding of a scientific concept are: (a) clinical interview with student observation and explanation of an event posed by the interviewer, and (b) paper and pencil tests that require short written explanations of situations or simple experiments. The number of years a child has spent in school does not seem to guarantee greater scientific understanding. On the contrary, these tenacious naive theories are resistant to change by traditional classroom methods, and sometimes common patterns can be seen through the grades (Arnaudin & Mintzes, 1985; Novick & Nussbaum, 1981; Osborne & Cosgrove, 1983).

Evidence shows that when students are given opportunities to express, test, and evaluate their ideas and to compare them with the scientific view, greater understanding of scientific concepts results (Driver, 1987; Geise, 1987; Smith & Anderson, 1984). In order for teachers to provide experiences for students to test their preconceptions about a topic, teachers must know what those ideas are likely to be. Widespread research has documented many of

these naive theories at all levels on a number of science topics. Some researchers recommend teacher testing of classes prior to starting a unit of instruction (Novick & Nussbaum, 1981). Models of written test questions which probe student conceptions are readily available in the literature (Brook, Driver & Hind, 1989; Eaton, 1983; Novick & Nussbaum, 1981; Renner et al., 1990; Shepherd & Renner, 1982; Smith & Anderson, 1984; Wightman, Green & Scott, 1986). When teachers are aware of possible specific misconceptions students might have about a topic, the children's scientifically acceptable understanding of the topic increases significantly (Smith & Anderson, 1984).

CHAPTER III

METHOD

Research Design

This descriptive study identified and compared understandings held by fourth, sixth, and eighth grade students about selected science concepts related to water. Specifically, this study investigated student understanding of a demonstration involving the interaction of two water solutions of different densities. Students from the fourth, sixth and eighth grades in the Saratoga Union School District (CA) were shown a video taped demonstration and tested with a paper and pencil assessment instrument (see appendix) that asked for a prediction and an observation, giving an explanation for each. The results were analyzed across grade levels to identify patterns of understanding and specific misconceptions.

The video taped demonstration began with two beakers, each with the same volume of two different water solutions (fresh and salt), on a balance scale. The students were asked to:

1. Choose a prediction from a multiple choice list about what would happen when one solution was released into the other.
2. Write a reason for that prediction.
3. Report their observations of what occurred when one solution was released into the other.
4. Write an explanation for what they saw.

A complete description of the video taped demonstration can be found later in this chapter under "Description of the Assessment Instrument."

Hypotheses

Fourth, sixth, and eighth grade students were presented with a video taped multi-step procedure that demonstrated the separation by density of two water solutions (fresh and salt). Students were asked to make predictions and give explanations for what they saw on the video tape. Thirteen hypotheses in seven categories were tested:

Category 1. Hypotheses related to accuracy of predictions:

- a. Fourth graders choose scientifically accurate predictions less often than do sixth graders.
- b. Sixth graders choose scientifically accurate predictions less often than do eighth graders.

Category 2. Hypotheses related to frequency distribution of predictions.

- a. Fourth graders, when compared to sixth graders, demonstrate significant differences in their frequency of prediction choices regarding different water solutions.
- b. Sixth graders, when compared to eighth graders, demonstrate significant differences in their frequency of prediction choices regarding different water solutions.
- c. Eighth graders, when compared to fourth graders, demonstrate significant differences in their frequency of prediction choices regarding different water solutions.

Category 3. Hypotheses related to explanations (reasons) for predictions.

a. Fourth graders, when compared to sixth graders, demonstrate characteristic differences in the pattern of reasons they give for predictions regarding different water solutions.

b. Sixth graders, when compared to eighth graders, demonstrate characteristic differences in the pattern of reasons they give for predictions regarding different water solutions.

c. Eighth graders, when compared to fourth graders, demonstrate characteristic differences in the pattern of reasons they give for predictions regarding different water solutions.

Category 4. Hypotheses related to accuracy of student observations:

a. More than two-thirds of the fourth graders tested will accurately observe and report a situation demonstrated on video tape.

b. More than two-thirds of the sixth graders tested will accurately observe and report a situation demonstrated on video tape.

c. More than two-thirds of the eighth graders tested will accurately observe and report a situation demonstrated on video tape.

Category 5. Hypotheses related to explanations of reported observations:

a. Fourth graders, when compared to sixth graders, demonstrate characteristic differences in the reasons they give for observations regarding different water solutions.

b. Sixth graders, when compared to eighth graders, demonstrate characteristic differences in the reasons they give for observations regarding different water solutions.

c. Eighth graders, when compared to fourth graders, demonstrate characteristic differences in the reasons they give for observations regarding different water solutions.

Category 6. Prediction bias:

Less than 1/4 of the sample population will demonstrate prediction bias in their responses.

Category 7. Male vs. female correct responses:

Frequency distribution of correct responses will not differ significantly between males and females at any one grade level.

Additional Considerations

These hypotheses are based on the assumption that student understandings become more sophisticated and more "scientific" with increasing pupil age. Both cognitive development and exposure to science instruction are factors that affect student growth in scientific knowledge. A child in fourth grade would not have had the exposure to science instruction nor the "life experience" of an eighth grader; therefore the younger student probably does not have the understanding of scientific concepts that the older student would have. Likewise, it was expected that the sixth grade understandings would fall somewhere between fourth and eighth grade on a scale of increasing scientific accuracy.

Cognitively, students at the fourth through the eighth grade levels represent "Concrete Operational" (4th), "Transitional" (6th), or the "Formal

Operational" (8th) stages of development, according to Inhelder and Piaget (1958). Thus, students in the fourth grade age range (9-10 years) are less able to make generalizations, or transfer information to new situations. It would be more difficult for this group to apply the information presented at the beginning of the video tape to make an accurate prediction of what will happen when the solutions come together through a hole in the cup. Sixth graders (11-12 years) are in transition from the "Concrete Operational" to the "Formal Operational" stages. It was expected that more of these students could make use of the relative weight information from the video. Likewise, the eighth graders (13-14 years) were expected to demonstrate more "Formal Operational" characteristics. They should see specific events as examples of general principles, facilitating a more "scientific" understanding of the video demonstration.

Research Population

Saratoga Union is a small elementary school district with a total enrollment of 1,590 students. The ethnic mixture is approximately 70% Caucasian, 27% Asian, and 3% Black, Hispanic, American Indian and others. The student population is fairly stable, with approximately 4% growth for the two previous years (1987-88 and 1988-89). Figures at the district office reflected growth in student population only. There were no specific figures on "turnover" or numbers of students who leave the district each year.

The total number of students tested was 274. The sample included four classes each of fourth ($n=89$), sixth ($n=91$), and eighth ($n=94$) grade students from three schools.

Participation was based on random selection of classes and on teachers' cooperation in allowing the use of a class period for administration of the test by the researcher. The classes were representative of academic ability levels that are characteristic of the Saratoga District.

Based on district office records, Saratoga students receive consistently high test scores from the California Assessment Program (CAP). The CAP tests are annual examinations given in grades three, six and eight. The tests include assessment in reading, mathematics, history, and, for eighth grade only, science content areas. Saratoga typically scores in the 96th to 99th percentiles in statewide rankings for all of the content areas. Saratoga's rankings relative to other districts of similar student populations are in the 85th to 95th percentiles. This high ranking correlates with the predominance, according to school records, of engineering, medical, and other science related professions among the parents in the district.

The science component of the CAP test is given only to the eighth graders. During the 1988-89 school year, the Saratoga eighth graders scored in the 94th percentile for science statewide, and 79th percentile in relative ranking. In the subcategory of Physical Science/physical states and changes of matter, the eighth grade students showed a relative strength compared to their scores from the other science categories tested that year. The other science categories included in the CAP test are: Biological, Earth, Physical/energy, Science-Technology-Society, Laboratory Skills, and Science Processes.

Student Science Background

The science program for the fourth and sixth graders consists of a one hour lesson each week taught by the science resource teacher. The students

leave the classroom and meet in the science room at their school. The science rooms are quite well equipped by state standards, with laboratory "glassware" and microscopes. A standard classroom at each school has been converted for use as a science room, and the school district has made a financial commitment to the science program. No specific instruction on the relative density of water solutions had been given to the fourth and sixth grades. A related topic that only the sixth grade was taught was "Properties of Air." This unit of instruction included the Bernoulli Principle, and concentrated mainly on the principles of flight. Relative density of warm and cold air was not taught.

The eighth grade groups consisted of the four physical science classes from the junior high school. These students had just completed the one semester of physical science offered by the school, which is one of three semesters of science required for eighth grade graduation. No specific lessons on the relative density of water solutions had been taught. The topic of density had been discussed in relation to solids, not liquids. The Physics semester had included an introduction to Chemistry and "States of Matter."

Description of the Assessment Instrument

Since the intent of this study was to test a fairly large number of children across several grade levels, a paper and pencil test was used to generate data that would reveal patterns of student understanding. The "Concept Assessment" test and accompanying video taped demonstration were developed by the researcher. Based on a format used by Driver (1987) the written instrument requests the student to write a reason for each of his or her answers.

In constructing questions that investigate children's ideas related to water weight or density, the area of focus has been restricted to the following concepts:

1. Water has weight.
2. Water solutions of equal volume can vary in weight.
3. A heavier (more dense) water solution tends to sink in a container of lighter (less dense) water solution.
4. A lighter (less dense) water solution tends to rise in a container of heavier (more dense) water solution.

The instrument used in this study was reviewed by two science curriculum experts and pilot tested with a group of 29 student teachers in an elementary science methods class at San Jose State University in November, 1989. The student teachers were asked to look for unclear questions and to suggest changes that would make the instrument more appropriate for fourth, sixth and eighth grade children. Revisions were based on these suggestions and those of the science curriculum experts. The assessment test was administered to the sample population during January and February, 1990.

The written instrument used for this study (see appendix) consisted of two questions, which were part of a seven item test. Each question involved a simple experiment or a situation. After viewing the first segment of the video demonstration, students were asked to (a) choose from a number of given predictions and (b) write a reason for that choice. They then observed the video segment showing the two water solutions mixing and were asked to (c) record what they saw happening on the video tape and (d) write an explanation for that observation. Following is a synopsis of the video taped demonstration.

Video Tape

1. A balance scale is shown with two identical beakers filled to the same level with water solutions. The water in one beaker is blue (salt) water, the water in the other beaker is dark green (fresh) water. The beakers do not balance. The dark green (fresh) water is lighter in weight, and therefore that side of the balance scale is elevated above the level of the blue (salt) water. The term "water" was used on the tape when referring to the water solutions.

2. Demonstrator: "Please watch this demonstration carefully. You will use the information to answer a question. Notice that even though these two beakers are filled to exactly the same level with water, they do not balance on the balance scale. I am going to add enough water to the green side so the beakers will be balanced."

3. Water is added with a dropper to the green (fresh) beaker until the scale balances. Now there is more green water than blue water on a balanced scale. Students who can, in Piagetian terms, conserve weight will not be confused by this. Note that the students are not told that the beakers contain fresh and salt water.

4. A new set-up is shown. The same two beakers from the balance scale are in front of a large glass one-liter measuring cup, and a small paper cup with a thick pin stuck into the side of it is nearby.

5. Demonstrator: "Let's see what happens when the blue and green water come together. I am going to pour the blue water into the large glass cup, and [some of] the green water into the paper cup. Then the paper cup goes into the blue water in the glass cup."

6. Closeup now of the glass cup with the paper cup containing [some of] the green fresh water submerged in the blue salt water (figure 1).

7. Demonstrator: "What do you think will happen if I pull out the pin on the side of the paper cup? Please mark your answer to question number one on your answer sheet. Your teacher will turn off the video now."

Figure 1. Video Demonstration Apparatus

8. Question 1: Students take as much time as they need to (a) choose one of the multiple choice predictions and (b) write a brief explanation of why they made that choice.

9. Demonstrator: "Now watch what happens when the pin is pulled from the paper cup. Please describe what you see under number two on your answer sheet."

10. Question 2 on the answer sheet asks for two written explanations: (a) what the student saw on the video tape, and (b) what he or she thinks the reason was.

Administration of the Instrument

The researcher introduced each group to the test with a brief explanation of what to expect and why the research was being conducted. The reason given was: "Tests like this help teachers understand how children learn science." Students were reminded that no letter grades would be given on the test.

The questions for this study were included in a seven item test. There was no time limit. Pupils completed questions 3-7 at their own speed. The students could then read or work on other assignments at their desks until everyone in the class had finished. The entire seven question test took approximately 40 minutes across the grade levels.

Two precautions were taken to help prevent discussion of the test questions among students: (a) the tests for one grade level were given on the same day at any one school, and (b) testing groups after lunch was avoided so that conversation about a previous group's experience might be less likely to be shared. The only exception to this was the eighth grade group. All eighth graders were tested during one school day, which necessitated using two of the classes that met in the afternoon, as well as two morning classes. This "timing" problem has been described by Giese (1987): "Maybe students discussed the pretest at other times; however, adolescents outside of classroom situations usually talk about things more captivating to them than answers to a nongraded test" (Giese, 1987, p. 146).

Data Analysis

For the purpose of this study, only Questions 1 and 2 from the seven item assessment test were coded and analyzed. These are the questions that accompanied the video taped demonstration and probed student understanding of the interaction between two solutions that differ in density.

Responses for Question 1 (Prediction), which required students to choose from a list of predictions in a multiple choice format, were reviewed with a frequency distribution. Students were given a choice of the following predictions for Question 1:

No change.

Green water will rise.

Green water will sink.

Blue water will enter cup.

Blue and green water will mix evenly.

Open-ended Questions 1 (Reason for Prediction), 2 (Observation), and 2 (Reason for Observation), were analyzed for frequency of key characteristics that were coded from written responses. Following is a description of the coding system for the responses given for these open-ended Questions (those requiring written responses in the student's own words) asking students to (a) give a reason for their prediction, (b) report an observation, and (c) give an explanation of their observation.

	Code Number	Student Response
Question 1	0	Behavior of water
(Reason)	1	Water weight/density

	2	Water color
	3	Water volume
	4	Apparatus related
	5	Force/Pressure related
	6	Miscellaneous
	7	No mark
Question 2	1	No change
(Observation)	2	Green water rose
	3	Green water sank
	4	Blue water entered the cup
	5	Blue and green water mixed evenly
	6	"Water came out of the cup
Question 2	0	Behavior of water
(Reason)	1	Water weight or density
	2	Water color
	3	Water volume
	4	Apparatus related
	5	Force or Pressure related
	6	Miscellaneous
	7	No mark

The coding system for Question 1 Reason and Question 2 Reason was devised after reading the actual reasons written by students on their test papers. These reasons were grouped according to common characteristics and assigned the numerals 0-7 (above). Following are typical student responses that were assigned to each code number:

Code	Number	Meaning	Student Response
	0	Behavior of water	Because water and water always mix.
	1	Weight or density	When the scale was measuring, the green water was lighter.
	2	Water color	I think the green water will sink because it is darker
	3	Water volume	The blue water will enter the cup because there is more blue water than green water
	4	Apparatus	The waters will mix becuae there is a hole in the cup
	5	Force/Pressure	There is equal pressure on each side so there will be no change
	6	Miscellaneous	I read a book of science like it
	7	No Mark	

The data was analyzed utilizing the *Stat View*™ statistical program for the Macintosh computer created by BrainPower, Inc. Calabasas CA. Frequency distributions were determined for:

1. Responses to all questions across grade levels.
2. Number of scientifically accurate choices made at each grade level.
3. Number of students at each grade level who accurately observed and reported the situation demonstrated on video tape.

4. Number of students at each grade level who demonstrated "prediction bias" when reporting observations.

5. Number of male and female correct responses.

The differences in frequency of responses between grade levels for numbers 1,2,3, and 5, above, were measured for significance using the chi-square method of statistical analysis. Chi-square analysis was also used for Question 1 Reasons and Question 2 Reasons to determine significant differences in response patterns between grade levels.

CHAPTER IV

RESULTS

Introduction

The hypotheses posed in the previous chapter fall into seven general categories:

1. Accuracy of predictions
2. Frequency distribution of predictions
3. Explanations of predictions
4. Accuracy of observations
5. Explanations of observations
6. Prediction bias
7. Male vs. female correct responses

To facilitate an orderly review of results from this study, each of these categories will be used as a focus for data presentation.

1. Accuracy of Predictions

It was hypothesized that, given five choices in a multiple choice format, fourth graders choose scientifically accurate predictions less often than do sixth graders, and sixth graders choose scientifically accurate predictions less often than do eighth graders.

Table 1 shows the percentage of correct predictions (choice #2) made by students at each grade level tested. Note that the 6th grade students made the

Table 1

Frequency of Question 1 Predictions

"What will happen when the pin is pulled from the side of the cup?"

Prediction	Percentage by Grade		
	4 (<i>n</i> = 88)	6 (<i>n</i> = 91)	8 (<i>n</i> = 93)
1. No change	21.59	18.68	35.48
2. Green water rises*	27.27	43.95	22.58
3. Green water sinks	21.59	10.98	9.67
4. Blue water enters cup	4.54	5.49	7.52
5. Waters mix evenly	25.00	20.87	24.73

*correct

scientifically accurate predictions far more frequently than either the 4th or the 8th grade students. In fact, the 8th graders made the correct choice less often than either of the other groups. The results of this study do not support the hypotheses related to accuracy of predictions: older students do not necessarily choose scientifically accurate predictions more often than younger students. The reasons given by students for each prediction will be addressed in the sections immediately following "Question 1 Predictions."

2. Frequency Distribution of Predictions

It was hypothesized that the frequency of predictions chosen by the fourth, sixth and eighth grades would be significantly different when the assessment test results were analyzed. The results support some of the hypotheses related to prediction frequency. However, statistically significant differences in responses were not found between all grade levels.

Question 1 Prediction Frequency

The students were asked to choose from a list of five written responses in order to predict what they thought would happen when the pin was pulled from the side of the paper cup on the video demonstration. The frequency of responses for these predictions between fourth and sixth, sixth and eighth, and fourth and eighth grades were measured for significance using a two-tailed chi-square test. The results show there is no significant difference between fourth and sixth, and fourth and eighth grade predictions at the .05 level (Table 2). The hypotheses related to Prediction Frequency for fourth-sixth and fourth-eighth grades are not supported by these results. The Prediction Frequency hypothesis for sixth-eighth grades is supported by these results. Note that the response frequency for sixth and eighth grade predictions in Table 2 was found to be significantly different at the .05 level. The most dramatic differences between sixth and eighth grade predictions (Table 1) are the first two: "No change" and the correct prediction that "Green water will rise."

Fourth Grade. The 4th grade predictions in Table 1 demonstrate the fairly even distribution of possible responses made at this level. Almost all of the possibilities are equally represented in these responses. The researcher

noted during the testing period that students at this level finished their tests as fast as did the older students (about 40 minutes).

Sixth Grade. Table 1 indicates that the 6th graders more frequently chose the "correct" (#2) prediction than did either of the other groups. The second most frequent prediction by the 6th graders was that the "blue and green water will mix together evenly."

Eighth grade. The 8th grade predictions (Table 1) reflect an assumption held by more than 1/3 of this group that there will be no change when the pin is pulled from the side of the cup. Note that the "correct" prediction (#2) was the third most frequent choice at this level.

Table 2

Chi-Square Analysis of Question 1 Predictions

Grades	χ^2	df	p
4 & 6	7.19	4	.1264
6 & 8	11.78	4	.0190
8 & 4	8.25	4	.0829

3. Explanations of Predictions

The students were asked to write a brief explanation, or reason, for their predictions made in Question 1. This open-ended answer was written in the students' own words.

Question 1 Reasons

It was hypothesized that fourth, sixth, and eighth graders would demonstrate characteristic differences in the pattern of reasons they give for their predictions related to different water solutions. The results support these hypotheses related to Explanations of Predictions. Chi-square analyses of Question 1 reasons show significant differences at the .05 level for every grade level (Table 3).

Table 3

Chi-Square Analysis of Question 1 Reasons

Grades	χ^2	df	p
4 & 6	38.98	7	.0001
6 & 8	15.85	7	.0264
8 & 4	44.08	7	.0001

Each student was asked to write a reason for the prediction he or she made in question 1. There are definite patterns of responses that become evident when these reasons for student predictions are examined.

Overview: fourth. Table 4 shows the overall frequency of reasons all students gave for their predictions in Question 1. Note the mode for 4th grade is reason number 4, "apparatus." The frequency of this reason drops off dramatically in the 6th and 8th grade responses. The most common "apparatus" related response was simply "because the hole in the cup will leak" or "because there is a hole in the cup."

Table 4

Frequency of Question 1 Reasons

Reason	Percentage by Grade		
	4	6	8
	(<i>n</i> = 89)	(<i>n</i> = 91)	(<i>n</i> = 94)
0. Behavior of water	6.74	12.08	12.76
1. Weight/density	23.59	50.54	30.85
2. Color of water	4.49	2.19	1.06
3. Volume of water	8.98	2.19	8.51
4. Apparatus	39.32	9.89	6.38
5. Force/pressure	10.11	19.78	26.59
6. Miscellaneous	6.74	1.09	3.19
7. No mark	0	2.19	10.63

The 4th graders seemed to focus on the cup and the hole left by the pin: "There have to be two holes in order for change to take place." The youngest group also was more likely to give miscellaneous reasons, or reasons that did not fit into categories 1-5 on Table 2:

"I think it will become very hot and stimy."

". . . because science will make it" [happen that way].

"I tried a book of science like it" [so it will happen as I predicted].

Some reasons did not follow predictions. After predicting "no change," the reason given by one fourth grader was: "I think it will have a hole so the water will leak."

Overview: sixth. Table 4 shows that the sixth graders gave the scientifically accurate reason (#1) more often than the other groups. A common reason for the (second most frequent) prediction that blue and green water will mix evenly was: "two liquids usually mix together." The reference to the beakers on the balance scale was sometimes applied inappropriately to explain why the water would mix evenly: "The green water was weighed the same as the blue water" and "They were balanced to begin with."

Overview: eighth. The "correct" reason (#1, weight/density) was given by 30.85% of the eighth graders, as shown on Table 4. However, 26.59% of this group gave a reason related to force or pressure to explain their predictions. The eighth graders show the greatest frequency of reasons related to force/pressure. The majority of these force/pressure reasons accompanied a prediction of "no change" when the pin was removed from the paper cup. Typical explanations refer to a "lack of air" creating a "pressure" that makes water movement from the cup impossible:

"No air, it is a suction."

"Air trapped in between the area creates a seal making each of the water stay together."

"There isn't enough air for the blue water to come out. There's too much pressure."

"No air, so it is like a suction cup and the green water stays in."

Note that in Table 2 the steady increase of "no mark" frequency reaches more than 10% at the 8th grade level.

Students who predicted "no change." Table 5 shows the reasons given by the students who had chosen this prediction for question 1. Note that reason #5, "force/pressure," was most often given at the 6th and 8th grade levels, and given just as often as "apparatus" at the 4th grade level. Written reasons include:

Fourth: ". . . the pressure would keep the green water in."

"The air pressure is pressing against the water so no water can go in the cup and no water can go out."

Sixth: "The pressure of the water is the same and there is nothing pushing the green water out."

"There is enough air pressure to keep the water from mixing."

Eighth: "Because no air will be able to go into the cup to take the liquids place, and no liquid will go out."

"Cause there's even pressure (same amount)."

Students who predicted "green water will rise." Table 6 indicates that the majority of reasons given for this prediction at all grade levels pertained to the weight or density of the water. Most of the written reasons referred to the balance scale showing that the green water was "lighter" or the blue water was "heavier." Very few (7 total) students used the term "density" in their explanations. Two sixth grade students used the word "thicker" when describing the blue water:

"The green water will rise to the top because the blue water is thicker than the green."

The fourth grade second most frequent choice, "apparatus," included the

Table 5

Reasons Given by Students Who Predicted No Change

Reason	Percentage of this subgroup by Grade		
	4 (<i>n</i> = 19)	6 (<i>n</i> = 17)	8 (<i>n</i> = 33)
0. Behavior of water	0	5.88	3.03
1. Weight/density	5.26	5.88	6.06
2. Color of water	0	0	0
3. Volume of water	21.05	0	6.06
4. Apparatus	31.57	5.88	3.03
5. Force/pressure	31.57	76.47	60.60
6. Miscellaneous	10.52	5.88	6.06
7. No mark	0	0	15.15

following written statements:

"It will come out of the cup" [There is a hole in the cup].

"There is a hole in the cup so the green water will leak out."

Students who predicted "green water will sink." Table 7

indicates that the most popular reason for this prediction across all grade levels was related to weight/density of the water.

Table 6

Reasons Given by Students Who Predicted Green Water Will Rise

Reason	Percentage of this subgroup by Grade		
	4 (<i>n</i> = 24)	6 (<i>n</i> = 40)	8 (<i>n</i> = 21)
0. Behavior of water	0	5	0
1. Weight/density	54.16	80	85.71
2. Color of water	4.16	0	0
3. Volume of water	4.16	2.5	0
4. Apparatus	33.33	7.5	4.76
5. Force/pressure	4.16	2.5	4.76
6. Miscellaneous	0	0	0
7. No mark	0	2.5	4.76

The majority of these reasons again refer to weight, not density, in the explanation. Once again, however, the fourth grade has a greater percentage of alternate answers than do sixth and eighth. Fourth graders refer to the hole in the cup as a reason for the green water to sink.

Students who predicted "blue water will enter the cup." Note that only 17.55% of the total responses (averaging 5.85% of each grade level) were in this category (Table 1). Table 8 indicates that the fourth grade responses are more widely scattered than at the other levels

Table 7

Reasons Given by Students Who Predicted Green Water Will Sink

Reason	Percentage of this subgroup by Grade		
	4 (<i>n</i> = 19)	6 (<i>n</i> = 10)	8 (<i>n</i> = 9)
0. Behavior of water	10.52	0	11.11
1. Weight/density	36.84	70	77.77
2. Color of water	10.52	10	0
3. Volume of water	15.78	0	11.11
4. Apparatus	26.31	0	0
5. Force/pressure	0	10	0
6. Miscellaneous	0	0	0
7. No mark	0	10	0

The sixth grade most frequent reason was related to the weight of the water, while the eighth grade reason related to the volume of the water in the demonstration. Following are typical reasons written by sixth and eighth graders, respectively:

"If both waters were the same weight, then nothing will happen.

However, since the green water is lighter, the blue water can come in."

"There was more blue water than green, so therefore there was more pressure on the blue water."

Table 8

Reasons Given by Students Who Predicted Blue Water Will Enter Cup

Percentage of this subgroup by Grade			
Reason	4 (<i>n</i> = 4)	6 (<i>n</i> = 5)	8 (<i>n</i> = 7)
0. Behavior of water	25	0	0
1. Weight/density	0	60	28.57
2. Color of water	0	0	0
3. Volume of water	0	20	42.58
4. Apparatus	25	0	0
5. Force/pressure	25	20	28.57
6. Miscellaneous	25	0	0
7. No mark	0	0	0

Students who predicted the blue and green water would "mix evenly." Most of the fourth graders (Table 9) chose apparatus as their reason that this prediction was made, again referring to the hole in the cup making mixing possible. The sixth grade's most common reason, behavior of water, refers to water simply mixing: "Because water and water always mix together." Students referred to the video demonstration when giving weight/density as the reason: "I think this because the green water was weighed the same as the blue water." Note that only sixth graders used this reason. These students

(inappropriately) applied the information shown during the first segment of the video tape, when the two beakers were made to balance by adding more "green water to the green beaker." One eighth grader noticed that the water level in the cup (green water) was higher, and predicted the mixing "until the water level [in the two cups] is even." The percentage of "No Mark" responses is again highest for eighth grade.

Table 9

Reasons Given by Students Who Predicted Blue and Green Water Would Mix Evenly

Percentage of this subgroup by Grade			
Reason	4 (<i>n</i> = 22)	6 (<i>n</i> = 19)	8 (<i>n</i> = 23)
0. Behavior of water	13.63	42.10	43.47
1. Weight/density	0	15.78	0
2. Color of water	4.54	5.26	4.34
3. Volume of water	0	0	8.69
4. Apparatus	68.18	26.31	13.04
5. Force/pressure	4.54	10.52	8.69
6. Miscellaneous	9.09	0	4.34
7. No mark	0	0	17.39

4. Accuracy of Observations

It was hypothesized that more than two-thirds of the fourth, sixth, and eighth graders tested would accurately observe and report a situation demonstrated on video tape. Results support the hypotheses related to accuracy of observations.

Question 2 Observations

The students were asked to write what they saw on the video demonstration when the pin was actually pulled from the side of the paper cup. They finished this sentence: "I saw. . ." Table 10 indicates that the majority (73.03% for fourth, 85.71% for sixth, and 82.97% for eighth) of all students tested observed (correctly) the green water rise.

Overview: fourth. The fourth graders had more responses in the "water mixed" and "water came out of the cup" categories. One of the fourth graders said "The blue water went to the top." This response may reflect a confusion of the colors of water on the video screen, but it was listed in the "green water sank" category. The student was a male, and the possibility of color blindness cannot be overlooked. However, the health files were confidential and unavailable to the researcher.

Overview: sixth. These students had the greatest percentage (85.71%) of correct, or scientifically most accurate, observations (Table 8).

Overview: eighth. These students had a fairly large number (13.83%) of "water came out of the cup" responses. Those who gave this response had not predicted that the green water would rise as it left the cup. The one student who observed "no change" on the video gave no reason.

Table 10

Frequency of Question 2 Observations

"When the pin was pulled from the paper cup, I saw. . ."

Observation	Percentage by Grade		
	4 (<i>n</i> = 89)	6 (<i>n</i> = 91)	8 (<i>n</i> = 94)
1. No change	1.12	0	1.06
2. Green water rose*	73.03	85.71	82.79
3. Green water sank	2.24	1.09	0
4. Blue water entered the cup	0	0	0
5. Waters mixed evenly	12.36	7.69	2.12
6. Water came out of the cup	11.23	5.49	13.83

*correct

5. Explanations of Observations

It was hypothesized that there would be characteristic differences in the reasons given by fourth and sixth, sixth and eighth, and fourth and eighth graders for their observations of two water solutions mixing. Chi-square analysis of observation (Question 2) reasons reveal significant differences between fourth and sixth grade responses and fourth and eighth grade responses, but not between sixth and eighth grade responses at the .05 level

(Table 11). The hypotheses related to Explanations of Observations for the fourth and sixth, fourth and eighth grades are supported by these results. The hypothesis related to sixth and eighth grade Explanations of Observations is not supported.

Table 11

Chi-Square Analysis of Question 2 Reasons

Grades	χ^2	df	p
4 & 6	21.47	7	.0031
6 & 8	5.43	7	.6076
8 & 4	19.63	7	.0064

Question 2 Reasons

The students were asked to write a reason for the phenomenon they observed on the video tape (the green water rising to the top when the pin was pulled from the paper cup). They finished this sentence: "I think the reason was. . ." Table 12 indicates the frequency distribution of the reasons given by all grade levels. Note that reasons related to weight/density are the most common, with "apparatus" second for fourth graders, and "force/pressure" second for sixth and eighth graders.

Overview: fourth. Students at this level gave more reasons that attributed "human" actions to the water:

"Because it needed to go to the top so it went right to the top."

"The darker color was stronger so it got its way through the light blue water and sat on top."

The one student who said he saw "no change" on the video gave the following explanation: "The green water wasn't coming out of the cup because of the force."

Table 12

Frequency of Question 2 Reasons

Reason	Percentage by Grade		
	4	6	8
	(<i>n</i> = 89)	(<i>n</i> = 91)	(<i>n</i> = 94)
0. Behavior of water	1.12	3.29	1.06
1. Weight/density	38.20	52.74	50
2. Color of water	4.49	1.09	1.06
3. Volume of water	4.49	6.59	3.19
4. Apparatus	23.59	5.49	4.25
5. Force/pressure	14.60	25.27	26.59
6. Miscellaneous	7.86	2.19	5.31
7. No mark	5.61	3.29	8.51

Overview: sixth. Unlike the fourth grade, the sixth graders used "scientific" vocabulary more often, even though it was not always used correctly:

"Green water was more dence [sic] so it rose to the top."

"The green water rose because maybe it had more mass."

A scientific rule was used to explain why the green water rose: "Two of the same forms of matter cannot occupy the same space."

Overview: eighth. Half of the eighth graders responded with a weight or density reason similar to this: "Because the green water was lighter than the blue." Some students gave a more complete explanation: "Air was pushing down on the green water and forcing it out of the cup. On the scale, it [green water] weighed less, so it rose to the top." The next most common eighth grade reason (Table 12) related to "force/pressure": "Because the air pressure pushed the green water to the top."

Students who observed the green water rise. More than half of the students at each level gave weight/density as the reason for this observation (Table 13). The second most common reason across the grades was force or pressure. The fourth graders wrote:

"When the green water came out, the blue water pushed it up."

"The pressure was pushing so the blue water went to the bottom."

Human attributes appear again:

"Because the blue water was weaker and the green water was stronger."

One fourth grader referred to bubbles:

"Because the bubbles went up so it went with the bubbles."

Sixth and eighth graders refer to air pressure pushing the green water out of the cup as the reason it went to the top:

"Because of air pressure." (6th)

"The flow was so strong that naturally it went upwards." (6th)

"It squirted out." (8th)

"There was pressure on the green water to go into the blue water." (8th)

Table 13

Reasons Given by Students Who Observed Green Water Rise

Reason	Percentage of this subgroup by Grade		
	4	6	8
	(<i>n</i> = 65)	(<i>n</i> = 78)	(<i>n</i> = 78)
0. Behavior of water	0	2.56	1.28
1. Weight/density	52.30	60.25	57.69
2. Color of water	3.07	1.28	1.28
3. Volume of water	4.61	7.69	1.28
4. Apparatus	9.23	3.84	3.84
5. Force/pressure	13.84	19.23	20.51
6. Miscellaneous	10.76	2.56	5.12
7. No mark	6.15	2.56	8.97

Students who observed the green water sink. Only two students, one fourth grader and one sixth grader, observed the green water sink. The one fourth grader wrote: "The green water went to the bottom because it [the cup] had a hole." The sixth grader gave no reason (No Mark).

Students who observed the green and blue water mix. The fourth graders show a scattering of answers in Table 14. Once again

"apparatus" is the most frequently used reason at the fourth grade level: "The green and blue water did mix evenly, because the hole in the cup made it leak to the top." The one fourth grader who gave no reason for her observation had originally predicted that there would be no change. Color change as the main emphasis was seen by one student: "When the pin was pulled out the blue water turned green slowly, and the green was a darker color, so it turned the lighter color green."

Table 14

Reasons Given by Students Who Observed the Green and Blue Water Mix

Reason	Percentage of this subgroup by Grade		
	4	6	8
	(<i>n</i> = 11)	(<i>n</i> = 7)	(<i>n</i> = 2)
0. Behavior of water	0	14.28	0
1. Weight/density	0	0	0
2. Color of water	18.18	0	0
3. Volume of water	9.09	0	50
4. Apparatus	45.45	0	0
5. Force/pressure	18.18	85.71	0
6. Miscellaneous	0	0	50
7. No mark	9.09	0	0

Students who observed water come out of the cup. Fourth graders once again used "apparatus" as their reason more frequently than the other grades (Table 15). Once again, their reference to "a hole in the cup" focuses on the equipment used in the demonstration, not on the interaction of the water solutions, to explain what they saw on the video tape.

Typical of sixth grade reasons for water coming out of the cup were: "The green water is lighter, so it comes into the blue water easily" and "The air above is pushing the water out." The two sixth grade apparatus related responses referred to the hole in the cup making mixing possible: "Because there is a hole

Table 15

Reasons Given by Students Who Observed Water Come Out of Cup

Reason	Percentage of this subgroup by Grade		
	4	6	8
	(<i>n</i> = 10)	(<i>n</i> = 5)	(<i>n</i> = 13)
0. Behavior of water	10	0	0
1. Weight/density	0	20	15.38
2. Color of water	0	0	0
3. Volume of water	0	0	7.69
4. Apparatus	80	40	7.69
5. Force/pressure	10	40	69.23
6. Miscellaneous	0	0	0
7. No Mark	0	0	0

in the cup, and when you pull the pin out, the green water comes out."

Eighth graders refer to force/pressure most often for this observation. These students mention the weight of the water in the cup or the different water levels causing the green water to come out: "Because the weight of the water in the cup made the water be pushed out."

6. Prediction Bias

It was hypothesized that less than one fourth of the sample population would demonstrate prediction bias ("I saw what I predicted") in their responses. The hypothesis related to prediction bias is supported by the results of this study. Table 16 shows the percentage of students at each grade level who demonstrated prediction bias on the test. Far less than 25% of each group is represented. Predictions (other than the correct ones) from Question 1 were matched with the same responses from Question 2 observations to determine

Table 16

Frequency of Prediction Bias

Prediction	Percentage by Grade		
	4	6	8
	(<i>n</i> = 89)	(<i>n</i> = 91)	(<i>n</i> = 94)
No change	1.12	0	1.06
Waters will mix evenly	5.61	3.29	2.12

prediction bias. The researcher was looking for students who held to their "incorrect" predictions and saw what they predicted in spite of evidence to the contrary on the video.

Very few students did not change their responses after viewing the video demonstration which showed the green water rising. "Water mixed evenly" was the most common biased response. This means that all of the students represented in this observation category *also predicted* that the water would mix evenly.

Fourth grade reasons in this category exclusively refer to "apparatus": "The hole in the cup. . ." Two of the three sixth grade reasons deal with force/pressure pushing the water out of the cup and allowing the blue and green to mix evenly: "Air pressure was pressing down on the water in the cup, and there was no place for it to go except out of the hole." One eighth grade reason was related to volume: the waters mixed evenly "Because the green water had to go somewhere." The other reason was in the miscellaneous category: "The blue water was a type of disappearing ink."

Of the two "no change" prediction/observations, the eighth grader gave no reason (no mark), and the fourth grader's reason was "force/pressure": "The green water wasn't coming out of the cup because of the force."

7. Male vs. Female Responses

It was hypothesized that there would be no significant difference between the frequency of male and female responses at any one grade level. The results of this study support this hypothesis . Chi-square analyses of male vs. female response frequency for Question 1 (prediction and reason) and

Question 2 (reason) at each grade level show no significant difference at the .05 level (Table 17).

Table 17

Chi-Square Analyses of Male vs. Female Responses

Question 1			
Grade	χ^2	df	p
4	1.92	4	.75
6	8.98	4	.06
8	3.17	4	.52
Question 1 Reason			
Grade	χ^2	df	p
4	7.11	6	.31
6	10.73	7	.15
8	6.83	7	.44
Question 2 Reason			
Grade	χ^2	df	p
4	9.48	7	.21
6	5.66	7	.57
8	1.72	7	.97

The frequency distribution of male and female responses (Table 18) for the Question 2 observation shows that the overwhelming majority of males and females at all grade levels observed (correctly) the green water rise.

Table 18

Male vs. Female Correct Responses

Percent Observing the Green Water Rise by Grade			
Observation	4 (<i>n</i> = 89)	6 (<i>n</i> = 91)	8 (<i>n</i> = 94)
Male	67	80	76
Female	80	90	89

CHAPTER V

SUMMARY AND DISCUSSION

Summary

The purpose of this study was to explore and document patterns of student understanding of science concepts dealing with water, particularly in predicting behavior and interpreting observations of two water solutions of different density. Students from the fourth, sixth, and eighth grades in the Saratoga Union School District were given a paper and pencil assessment test accompanied by a video taped demonstration. The results of this test indicate differences in student ideas, which characterize each grade level studied, about the behavior of two water solutions of different weight or density.

Discussion

Following a consideration of the data collection methods used, a discussion is presented on the results of this study and its implications for classroom instruction.

The Written Instrument

The choice of assessment procedures can have an impact on the results of a study. There are advantages and disadvantages to written as well as oral interview methods of data collection.

Advantages. A written instrument can be administered to a whole classroom simultaneously, making testing of greater numbers of students

possible in a relatively short period of time. The researcher found that "whole class" testing made scheduling with the classroom teachers easier, since one 45 minute class period was all that was necessary. Since disruption of classroom routines was kept to a minimum, teachers did not hesitate to volunteer their classes. Uniformity of administration was assured, because the tests were identical for each group.

Disadvantages. Reading and writing ability levels can vary within a student population. A more detailed response might have been given in some instances in a clinical interview situation. Some fourth graders, in particular, might have found it tedious and difficult to write a complete explanation for their predictions and ideas. The researcher also found a few unclear responses that might have been clarified in an interview situation (4th):

"Because the air needed to go to the top so it went right to the top." (What went to the top, the "air" or the green water?)

"There will be no change because the water will hold the air."

"Green water wasn't coming out of the cup because of the force."

Questions could have been asked to urge these students to more clearly define his or her understandings. During the tests, if the researcher noticed an unclear response on a student paper, that pupil was asked to give a more complete written explanation on the test sheet. It was not possible to check each question for each student, however.

Video Taped Demonstration

There are definite advantages to the use of a video taped demonstration as an assessment tool. Following a listing of some of these advantages, the

researcher suggests several improvements when taping this particular demonstration if it were to be used in other classes.

Advantages:

1. Uniformity of presentation among classes. Each class was given exactly the same view of the demonstration, with identical narration and instructions.

2. All students can see the entire procedure on the TV monitor, with close-up views that would be impossible in a "live" demonstration.

3. If discussion during a later class period warrants repeating the demonstration, it can be done quickly and easily. Many classrooms are :equipped with tape player and monitor readily available.

4. Student attention is focused on the television monitor in a semi-darkened room, reducing distraction and taking advantage of conditioned TV watching habits.

Suggestions for improvement:

1. Use a clear cup, instead of a paper cup, for the fresh water. Then the relative water levels outside and inside the cup could be more readily observed by the students.

2. Use a short "map tack" instead of a large pin in the side of the cup. The length of the pin made pulling it out of the side of the cup difficult, and may have distracted some students during the taped demonstration. Since the pin had to be pulled out with an upward slant, one fourth grader thought the green water rose "because the hole was slanting upward."

3. Consider choosing different colors for the fresh and salt water. The various TV monitors showed different hues for the green and blue on the screen, causing possible confusion when the waters were referred to by color.

Perhaps the "dark" colored water and the "pale" colored water would be better terms.

4. Producing a video taped demonstration takes several hours of time.

Teachers might consider using a commercially prepared instructional tape and adapting it for classroom assessment by controlling the sound and pausing at appropriate times.

Student Ideas

A discussion of student ideas demonstrated on the concept assessment test reveals patterns of responses that are characteristic for each grade level tested.

Fourth grade. The results of this study are similar to findings of a number of investigations into student understanding of science concepts. Children *do* come to class with ideas about the natural world based on their own experiences (Champagen & Klopfer, 1990; Giese, 1987; Smith & Anderson, 1984; Eaton, 1983). For instance, one fourth grader who predicted "no change" when the pin was pulled from the side of the paper cup gave the following reason: "There have to be two holes in order for change to take place." The student focused on the hole left by the pin, and apparently ignored the "hole" provided by the top of the open cup. This might well have been an application of experience gained when pouring liquids from a punctured can. This particular example is characteristic of fourth grade responses because it focuses on the hole in the cup, or the "apparatus," as the reason for a predicted interaction. Sixth and eighth graders did not use the "apparatus" reason nearly so often as did the fourth graders (Table 4).

Fourth graders were less apt to use the information given about the relative weight of the water on the balance scale at the beginning of the video tape. This might be related to their developmental level. Inhelder and Piaget (1958) suggest that children in the fourth grade age range (9 years) tend to be "concrete operational," that is, able to handle only one variable at a time. This developmental group would be less likely to generalize, to apply the information provided at the beginning of the video tape to the situation depicted at the end when the pin is pulled from the side of the cup. The concrete stage would also account for the greater focus of the fourth grade group on "apparatus," or the cup and the hole left by the pin, to explain what happened.

This youngest group also did not use scientific vocabulary to explain their predictions and observations. Their comparative lack of exposure to formal science instruction would imply a heavier reliance on experiences in the "real" world when making predictions. The fourth grades took as much time as the other groups, and had no more questions about the test. They evidently came to the test with plenty of ideas about the natural world on which they could draw to answer the questions.

Sixth grade. The sixth graders used scientific vocabulary three times more often than did the fourth graders. However, it was not always used correctly:

[The green water rose] "because it may have had more mass."

This finding is similar to that of Champagne and Klopfer (1983). Increasing use of scientific vocabulary was seen as student age increased, but the vocabulary was not necessarily used correctly.

Sixth grade students, according to Inhelder and Piaget (1958), tend to be at a transition stage in their development. They are moving from the "concrete"

to the "formal" levels. Formal operational levels are characterized by an ability to see specific events as examples of general principles. They would be more able to generalize using the information shown on the balance scale at the beginning of the video. This did not seem to be the case, with both sixth and eighth grade explanations tending to be expressed less in general terms and more with specific reference to the demonstration using the balance scale. A common response (6th) was: [The green water will rise because] "It was lighter on the balance scale." These findings do not concur with Rodrigues (1980) who noted that explanations for phenomena became less specific and more general with increasing student age. However, the limited scope of the current study renders the results inconclusive. A test that encouraged the use of general explanations might produce different results.

Herman Epstein (1970) proposes a correlation between Piagetian cognitive developmental levels and periods of brain growth in children. His work suggests that there are predictable physiological patterns of brain growth that can help explain the onset of Piaget's stages of intellectual development.

When comparing Epstein's stages to the grade levels participating in this study, there do seem to be some parallels. The fourth grade age range is 9-10 years. According to Epstein, the brain is on a growth "plateau" during this concrete operational period. The same kind of brain growth plateau occurs during the eighth grade year, among the 13-14 year olds. No major advance in intellectual growth is expected on these plateaus. However, the sixth grade year, ages 11-12, there is evidence of brain growth that coincides with the beginning of the transition from "concrete" to "formal" Piagetian levels.

Perhaps this growth period can help explain the sixth graders' high frequency of "correct" responses when compared to the fourth grade. Maybe

physical activity in the brain associated with these growth periods creates an environment that facilitates insight and comprehension of events at higher cognitive levels than are the rule during earlier periods. However, Epstein's growth stages do not explain why the sixth graders chose the "correct" responses even *more* often than did the eighth graders. According to his growth periods, eighth graders should be at least on the *same* cognitive level as the sixth, but not necessarily increasing in intellectual ability, during the Junior High years. It is tempting to try to correlate Epstein's brain growth periods with the observed results of this study, but the relatively small, homogeneous sample used here cannot give definitive answers. This researcher attributes part of the discrepancy between sixth and eighth grade "correct" answers to the relatively high percentage of "No mark" answers given by the eighth graders for nearly every response (Tables 4,5,6,9,12,13). Perhaps a concern for "being correct" manifests itself at the Junior High level which leads students of this age to leave an answer blank rather than risk being wrong. Environmental effects like this confound the attempt to find straight-forward patterns in the development of student ability.

The second most common prediction among sixth graders, "the waters will mix evenly", was frequently explained by a response involving "force" or "pressure" (Table 4). Giese (1987) noted that students generally considered pressure in liquids to be only downwards. "When students did consider pressure to be in other directions, it was often pressure associated with movement of liquids" (p. 142). There were references to pressure on the hole in the cup, which would indicate sideways pressure. Student understanding of water pressure being equal in all directions at a given depth was not clearly

defined by their responses. This researcher suspects that concept was not well understood by the students.

The reference to the two beakers being "balanced to begin with" and "the green water was weighed the same as the blue water" as a reason for the waters mixing evenly indicates a failure to consider weight and volume simultaneously. In Piagetian terms, these students fail to "conserve weight." These students might benefit from experiences comparing weights and volumes of a number of different liquids on a balance scale.

Eighth grade. The sixth and eighth grade responses were similar in several ways:

1. Few references to "apparatus" explanations.
2. More use of scientific vocabulary (incorrectly as often as correctly) than fourth grade.
3. Frequent use of "force or pressure" to explain predictions.

The reference to "air" was interpreted by the researcher to mean "air pressure" and was coded under the "force/pressure" category. The older students made frequent reference to "air" (or a lack of air) as a necessary component for water movement:

"No air will be able to come into the cup to take the liquid's place."

"It is like a suction cup and the green water stays in."

The students do not appear to apply any experience they may have had with convection currents or density currents in water. Experiences with water of different densities placed together in a number of configurations would facilitate a fuller understanding of reasons for water movement. For example, two small "Club Soda" bottles: one bottle filled with colored salt water could be inverted

on top of the other bottle filled with clear fresh water. The students would see water movement without the "air pressure" they had considered necessary.

Table 2 illustrated a significant difference between sixth and eighth grade prediction choices. Since the eighth graders chose the "correct" prediction less often than did the fourth or sixth graders, they seem to be operating on the "concrete" rather than the "formal" level. This means they did not apply the information provided at the beginning of the video showing the relative weight of the water solutions. A gradual increase in scientific understanding cannot necessarily be expected for all topics in science, as shown by Novick and Nussbaum (1981).

A student thought the blue water would enter the cup because of a difference in the volume of the water: "There was more blue water than green, so therefore there was more pressure on the blue water." This explanation suggests a misconception of the accepted generalization that "water pressure increases with depth." The student apparently thought that the greater volume of blue water in the large cup meant more pressure at the hole from that side. The depth of the green water in the paper cup was not considered, evidently because the smaller volume (not all of the balanced volume of green water was used) in the paper cup was not thought to exert as much pressure. The reader is reminded that not all of the balanced volume of green water was used in the demonstration. Allowing further exploration of this "smaller volume means less pressure" viewpoint along with a presentation of the accepted view might facilitate a better understanding on the part of the student.

A pattern found among the eighth grade responses was the number of "No mark" answers. This figure reached more than 17% of the students who had predicted that the blue and green water would mix evenly (Table 9). Since

it was assumed each student answered to his or her best ability (Chapter I "Assumptions"), the researcher suggests that there is a growing concern for "being correct" as students enter Junior High School. Perhaps when the question puzzles them, students prefer to leave a blank than to take a chance that a guess might be wrong. A number of studies have indicated that older students might have as many misconceptions as the younger (Champagne & Klopfer, 1990; Westbrook & Marek, 1988; Osborne & Cosgrove, 1983). For the eighth graders who responded with "No Mark," it is difficult to determine the nature of their lack of understanding.

Implications for the Classroom

The literature and the results of this study suggest that there is enough evidence of the influence of student preconceptions on science learning to warrant consideration by teachers at every level. Pretests, such as the assessment used in this study, that probe previously held ideas in science appear to be an aid in effective lesson planning by providing the teacher with insight into student views of a topic. This strategy for evaluating student views is repeatedly suggested in the literature.

Driver (1987) suggests that effective science learning is a continuing process of:

1. Students articulating their ideas on a topic.
2. Student testing of those ideas with teacher guidance.
3. Adjustment of ideas based on those tests and group discussions.

Student articulation of ideas can be written, as in this study, or the result of large and small group discussion. This step of eliciting student understandings is very important for effective teacher planning.

The teacher's role is one of providing experiences that allow students to test their ideas alongside the scientific view. In the case of the students who thought the hole in the cup or the way the pin was pulled out determined whether the green water rose or sank, these students could try it again, changing the apparatus to try out their ideas. The fourth graders who thought the color of the water determined its rising or sinking could easily "try it again" with clear and colored water and see what happened. When teaching with student misconceptions in mind, teaching becomes less didactic, or imparting knowledge, and more providing experiences for students to test their ideas. The teacher's role is no longer one of "telling" but of guiding and suggesting. The use of an assessment instrument which asks for student explanation of ideas appears to be an aid in this process.

Video taped demonstrations that require students to explain their ideas about a topic provide an interactive evaluation tool for the teacher. Currently the California Department of Education is advocating performance-based testing through the statewide California Assessment Program (CAP). This task-oriented style of evaluation is considered more effective in evaluating student understanding of a concept, rather than merely requiring a recall of facts (California State Board of Education 1989). The new California *Science Framework* (1989) follows the lead of the American Association for the Advancement of Science's *Science for All Americans, Project 2061*. This publication, the first report of a long-term series of studies, delineates goals for "all Americans" in science, mathematics, and technology literacy. It urges an integrated, experiential, hands-on approach to teaching science. Conceptual understanding, rather than rote learning, is to be emphasized. California has built this "learning as conceptual change" idea into the plan for teaching

science in the public schools: "Conceptual understanding requires higher-level thinking [rather] than lower-level recall, and this requires more in-depth experience and reinforcement in the classroom" (*Science Framework Draft*, Sept. 1989, p. 136). Testing procedures must also reflect the emphasis on student investigation: "Assessment programs are aligned with the instructional program in both content and format; student performance and investigation play the same central role in assessment that they do in instruction" (*Science Framework Draft*, Sept. 1989, p. 3).

The use of a video taped demonstration that requires students to make predictions, observations, and give reasons for their responses is the kind of student-oriented evaluation tool advocated by the American Association for the Advancement of Science (*Science for All Americans*) and the California Board of Education. It is possible for the classroom teacher to create open-ended test questions which probe student understanding. Questions such as "What do you think will happen?", "What did you see when. . .?", and "What do you think the reason was?" can help a teacher uncover student understanding about a science topic. The video tape is, in effect, a "ready to go" evaluation tool that can be used over and over without the time-consuming setup of apparatus. It is possible to turn it off and on at appropriate times to allow students to respond to questions posed by the demonstrator. Video technology is readily available in most schools and can be used to stimulate student thinking and as a probe of science concept understanding. The use of classroom assessment tests such as the one used in this study can help prepare students for the coming changes in standardized state testing methods as well as provide teachers with insight into student understanding of science topics.

Implications for Further Research

This study was limited to a small, economically privileged group of students. More research should be done on student understanding of the relative density of fresh and salt water with a broader range of student backgrounds and abilities. Another study would help determine whether the ideas documented here are typical for a particular age range or are influenced by socioeconomic level.

Much more work needs to be done on student ideas about water. Some of the research questions that could be addressed are: What are student ideas about the physical characteristics of water? How would these ideas parallel the study done by Brook and Driver (1989) on pupil understanding of the physical characteristics of air? How are student ideas about water influenced by instruction?

An important factor in the teaching of science concepts is the understanding the *teacher* has about the topic. Studies of teacher misconceptions are uncommon in the literature, yet the teacher plays a crucial role in how the students learn. There are implications that the teacher's misconceptions might prevent an instructional focus on the most essential elements of a science concept (Smith & Anderson, 1984).

Investigations that document student ideas add to the growing body of research that can help teachers know what a child is likely to understand about a topic at a particular level.

Conclusion

As stated in Chapter II, there appear to be at least two major factors that affect student understanding of science:

1. Teacher awareness of the alternate conceptions held by students, which facilitates testing and comparison with the scientific viewpoint .
2. A classroom atmosphere that encourages exploration of ideas and risk-taking by the students.

Teachers can become aware of student conceptions by creating open-ended assessment tests, such as the one used in this study, to probe student understanding and reveal possible alternate conceptions. The alert teacher will also listen carefully to student explanations during group discussion. Attention to student ideas helps teachers devise activities that allow students to compare their understandings to the prevailing scientific view.

The goal of instruction is to help children learn, to help students restructure the models they carry in their heads. The two very powerful strategies discussed above have been proven successful by educators wishing to reach that goal.

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APPENDIX
Science Assessment Test Instrument

SCIENCE ASSESSMENT: ANSWER SHEET

Grade Level _____

Please circle the letter of the best answer and write a reason for your choice after each question.

1. When the pin is pulled from the side of the cup:
- a. There will be no change: the green water stays in the cup, and the blue water stays in the pan.
 - b. The green water will leave the cup and rise to the top of the pan
 - c. The green water will leave the cup and sink to the bottom of the pan
 - d. The green water will stay in the cup and the blue water will enter the cup
 - e. The blue and green water will mix together evenly.

Give the reason for your choice: _____

2. Describe what you saw when the pin was pulled from the side of the cup and write a reason for it:

I saw: _____

I think the reason was: _____

3. A candle is heating water in the pans. Circle the picture which shows how the water would move as it begins to heat up.

Please give the reason for your choice: _____

4. There is a dam with a big lake behind it that is completely full of water. One morning people noticed two cracks in the dam: one near the top of the dam and one near the bottom of the dam. Assuming the cracks were exactly the same, would you expect the streams of water coming from the cracks to be the same? With your pencil, show how the water comes from the two cracks. Then choose an answer below and give your reason.

- a. the top crack would have more water coming out.
- b. The bottom crack would have more water coming out.
- c. Both streams of water would be the same.

Please give a reason for your choice: _____

5. Imagine a balloon filled with air tied to the outside of a slowly sinking submarine. As the sub sinks deeper into the ocean, what will happen to the size of the balloon?

- a. balloon gets bigger
- b. balloon gets smaller
- c. balloon stays the same size

Please give a reason for your choice: _____

6. A bucket HALF FULL of water is on a spring scale. Will the weight of the bucket change if a fish is placed in the bucket? The fish is resting in the middle of the water.

- a. The weight will stay the same
- b. The weight will increase
- c. The weight will decrease

Please give the reason for your choice: _____

7. A bucket FILLED TO THE TOP with as much water as it can possibly hold is on a spring scale. Will the weight of the bucket change if a fish is placed in the bucket? The fish is resting quietly in the middle of the water without moving its fins.

- a. The weight will stay the same
- b. The weight will increase
- c. The weight will decrease

Please give the reason for your choice _____