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# Misconceptions in the Earth and Space Sciences: A Cross-Age Study

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# Misconceptions in the Earth and Space Sciences

## A Cross-Age Study

by

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VITA

Kenneth James Schoon, the son of Lester and Vivian Schoon, was born in Gary, Indiana, on August 23, 1946. He attended the Gary public school system and was graduated from Horace Mann High School in 1964.

He entered Indiana University in 1964 and received a Bachelor of Arts in geology in June of 1968. While an undergraduate, he was active in student government and was inducted into the Sigma Gamma Epsilon honorary society for the earth sciences. His Master of Science in secondary education was received at Indiana University in August, 1972.

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His review of In Suspect Terrain by John McPhee was published in Magill's Literary Annual of 1984. An experiment designed by him was published in Prentice-Hall's Science Activity Exchange Winners in 1987. He has also designed and written a tree identification guide book which, though privately printed, has been used by his students for 12 years.

TABLE OF CONTENTS

LIST OF TALBES

CHAPTER I

# INTRODUCTION

## Perspectives on Misconceptions

Misconceptions interfere with the educational process. Nussbaum and Novick (1982) summarized the numerous studies concerning the effects of misconceptions, by stating that they may play a crucial role in learning by interfering with science comprehension. Children with misconceptions have a great deal of difficulty learning new materials because their misconceptions provide a faulty foundation for the formation of new insights. Therefore, teachers who want to teach effectively need to know which misconceptions their students are likely to have, and then develop a plan so that these suspected misconceptions can be averted or overcome.

Fisher (Helm & Novak, 1983) defined misconceptions as ideas that are at variance with accepted views. Although the term is in common usage among scholars today, Driver and Easley (1978) dislike the use of the word misconceptions because of its connotation as being a wrong idea. They have proposed the more neutral term alternative frameworks to describe those misunderstandings which result from a student's independent conceptualization of the physical world. This attempt to use non-indicting terminology can be seen as Ausubel (1968) used preconceptions, Mintzes (1984) used naive theories, while Gilbert, Osborne, and Fensham (1982) called such pre-instructional conceptual structures, children's science. M. G. Hewson and P. W. Hewson (1983) used the term alternative conceptions to describe those ideas which are at variance with scientifically acceptable norms, even after formal instruction. Cohen and Kagan (1979) proposed the term, mixed-conceptions, to be used to describe some misconceptions which develop during instruction.

Accepted views in science are always in a state of flux and therefore it is possible that what is considered a science misconception today may be considered the scientifically acceptable conception tomorrow. The concept of continental drift was, for example, not considered the scientifically acceptable conception for more than 50 years after it was proposed in 1911. Discoveries in the 1960's, however, resulted in geologists' altering their understandings of how the earth reacts to various forces, and today continental drift is subscribed to by most earth scientists. In like manner, what is today considered to be a scientifically acceptable conception may be later proven to be a misconception. Such concepts as the flat earth, the earth-centered universe, the solar-centered universe, and the subterranean origin of rivers have all been discarded by scientists as new information has been found which contradicted the previously-current scientifically acceptable conceptions.

Fisher and Lipson (1986) noted that the term, misconception, is usually preferred by those whose job it is to teach, while the neutral or non-judgmental terms are often preferred by those who see student behavior purely from the research viewpoint. In spite of many scholars' dislike of the word misconception, it still remains as the most-used term to describe those ideas at variance with an accepted view. It was chosen by Helm and Novak for the title of their two International Seminars on Misconceptions in Science and Mathematics in 1983 and 1987, although its use was debated by those in attendance. The term was used to describe and organize papers presented at the 1988 annual meeting of the National Association for Research in Science Teaching, although the organization was strongly criticized by some participants for doing so. The term's general acceptance and durability are reflected in its being included in the Thesaurus of ERIC Descriptors, but only since August, 1986.

## The Formation of Misconceptions

Learning and the development of misconceptions are inextricably related. Ausubel (1968) postulated that learning is the result of an interaction between what students are being taught and what they already know or believe. Nussbaum (1979) similarly alleged that a student is not an empty container, or *tabula rasa*, ready to be filled by the outpourings of truth and theorems of the instructor. He believes that during the process of learning, the meaning of certain information may be distorted by the learner, resulting in the formation of a misconception. Because each child brings into the classroom his or her own experiences, knowledge, vocabulary, and existing conceptions, each child also reflects upon a teacher's explanations in an individual different manner, and each child incorporates it into his or her own cognitive structure in a different way. On occasion, this incorporation results in a conceptualization that is at variance with that which the teacher would expect.

When students have an inaccurate preconception and then use it to incorporate new material presented by a teacher, they are likely to give that new material a meaning slightly or completely different from that intended by the teacher. In such a case, Nussbaum argued, the students probably are unaware that they are misunderstanding the material, being completely satisfied with their own interpretation. The teacher also may not recognize that material is being misinterpreted and may have no idea that the misconception exists until later, when it may then be attributed to the student's "not understanding the lesson." (p. 184)

The term mixed-conceptions was proposed by Cohen and Kagan (1979) to describe that honest, but incorrect attempt by a person to integrate new material with his understandings of the world. They believe that a particular advantage in using the term, mixed-conception, is that it directs us to discover how the learner has mixed-up concepts in his mind.

Although misconceptions seem to interfere with learning, and even though they can be erroneous understandings, they are not necessarily the result of a lack of reasoning ability. Ault (1984b) has shown that misconceptions of children are often the result of imaginative and very perceptive thinking. Many times when an adult might dismiss a child's ideas as silly or incorrect, Ault believes that the child may actually be "intelligently wrong." (p.24) Such a child might have ideas and conceptions that are the result of very creative, although perhaps unsophisticated, thinking.

Nussbaum (1979) used the example of a 12 year old boy who declared that Columbus proved that the earth was round by sailing all the way around it. Historical accuracy aside, Nussbaum probed the boy's understanding a bit further and realized that in spite of the boy's apparent correct verbal description of the earth's being round, he still actually believed that the earth was quite flat. He had combined the naive flat-earth concept with the classroom round-earth concept by thinking of the earth as both flat and round--somewhat like a pancake. In the boy's mind, Columbus was able to sail completely around the earth by merely sailing along its perimeter.

Misconceptions breed misconceptions. Osborne (1981) found in his research on children's conceptions of electricity, that when students had misconceptions, they unknowingly misinterpreted what they were taught so that the new information would not conflict with their earlier ideas.

The author first became aware of mixed-conceptions when he realized that many of his eighth grade students believed that north was, literally, up. Upon further questioning, he learned that students create this misconception when they are told by teachers that north on a map is up, and then inappropriately apply that concept to their physical world. That misconception is reinforced by the terms, up north, and down south, as well as the fact that, in most of the continental United States, major rivers flow down to the south.

Researchers recognize that misconceptions are seldom the fault of the students who have them. Students do not deliberately learn things incorrectly. They are, however, subjected to misleading and erroneous statements on radio and television as well as in novels and textbooks

(Helm & Novak, 1983). Braddock-Rogers and Braddock (1978) noted many science errors that they had observed in print and various other media. In one motion picture, pirates nonchalantly toss a large chest of gold coins onto their shoulders and walk away. (They note that a small chest of gold coins, measuring 20 by 10 by 8 inches, would weigh 1130 pounds.) In another instance, the three wise men are shown in a photograph in Presbyterian Life (1969) observing the Star of Bethlehem through a telescope. Disney's television programs show a twinkling star which then falls to the earth. One of McDonald's Corporation's recent Happy Meal packages (copyright 1986) showed a five-pointed "star" falling to the earth.

Textbooks and books about science may include incorrect concepts and information. For instance, the children's book, What Makes the Weather? (Palazzo, 1982), incorrectly states that when water in clouds freezes, we have snow. Barrass (1984) pointed out 15 misconceptions and misunderstandings which he has found printed in biology textbooks. Johns (1984) took biology and elementary life science textbooks to task for not warning readers that even though they print diagrams of the human circulatory system using red ink for arteries and blue ink for veins, venous blood is not blue. Johns examined various textbooks of biological science (McGraw-Hill, Scott Foresman, Laidlaw) and noted that none of them pointed out the difference in color between their illustrations and the truth. Scott Foresman's You and Your Health (1977) even refers to venous blood as dark bluish. In an attempt to determine the extent of the misconception, Johns surveyed 897 fifth graders in his district and realized that nearly 50% of them believed that venous blood is actually blue. Johns' warning has evidently not been heeded, in that the 1987 edition of Life Science published by Silver Burdett and Ginn omitted the clarification.

Another cause of misconceptions in science is language usage. There are many words in the English language which have scientific as well as non-scientific meanings. (See Table 1) Students could be expected to assume that words with dual meanings have at least a partial overlap of meaning between their everyday and scientific meanings, a wrong assumption in many cases. Further complicating the situation is the fact that some terms have different meanings in one scientific discipline from that in another. (See Table 2)

A similar problem is created by misnomers in science terminology. Astronomical terms such as new moon, falling star, sunrise, and black hole all can cause confusion because the terms suggest meanings that are inaccurate. Teachers may know that a falling star is not a real star, and that a new moon is not actually new, but students need to be told.

Table 1

Scientific Terms with Meanings Different from Everyday Usage

Biology: family, fat, graft, kingdom, order, tissue

Earth Science: bed, cleavage, drift, fault, front, plastic, till

Chemistry: base, noble, rare, reduction, salt, shell

Physics: focus, matter, negative, pole, positive, wave, work

Space Science: hole (black), nova, resolution, revolution, satellite

Table 2

Terms with Different Meanings in Different Scientific Disciplines

| | |
|---|---|
| Cones: physiology/botany | Molar: physiology/chemistry |
| Conservation: ecology/physics | Phases: astronomy/physics |
| Foliation: geology/botany | Plutonic: geology/astronomy |
| Mass: meteorology/physics | Precipitation: meteorology/chemistry |
| Mercury: astronomy/chemistry | Sterile: physiology/chemistry |
| Mineral: geology/physiology | Weather: geology/meteorology |

## Eliminating Misconceptions

In 1968 Ausubel proposed that "preconceptions are amazingly tenacious and resistant to extinction." (p. 336) He recommended to teachers that they, "Find out what the learner already knows and teach him accordingly." (p. 337)

Meyer (1987) believes that misconceptions may survive because they serve a variety of functions for the people who hold them. He noted, for instance, that many Americans think of ground water as existing in lakes and rivers just the same as surface water does. Even though such a condition would be in many cases simply physically impossible, Meyer argues that underground rivers and lakes form a simple mental picture for those who haven't been exposed to the concept of water slowly moving through the pore spaces of subterranean materials. This mental picture is satisfactory for those who have it because it provides a ready explanation for most ground water-related problems.

In a study of several hundred European secondary and college students' conceptions about force, Viennot (1979), found that many had erroneous intuitive ideas about concepts before they were introduced in class. His study showed that these ideas or misconceptions often outlive teaching which contradicts them. Students appear to be quite comfortable with their misconceptions. Minstrell and Smith (1983) pointed out that students even go to great lengths to protect their misconceptions when they are threatened. Students can ignore, deny, or distort experiences that are inconsistent with their preconceived notions about the world.

While students may be willing to admit ignorance about a subject, the very nature of misconceptions results in students' not even being aware that they hold them. Therefore Nussbaum and Novick (1982) emphasized that the first step in an instructional strategy to help students overcome misconceptions should be making the students aware of their own conceptions. For students to be able to alter their misconceptions they must then believe that their existing conceptions are unsatisfactory. Posner, Strike, P. W. Hewson, and Gertzog (1982) proposed a model of four steps, or conditions, which they feel must be fulfilled before a misconception is likely to be abandoned by a student and a new conception adopted:

1. A student must be dissatisfied with an existing conception.

2. The new conception presented must be _intelligible_.

3. The new conception must appear initially _plausible_.

4. The new conception should be _fruitful_. That is it must have some benefit, or be able to solve problems for the learner.

Posner, et al. suggested that teachers should develop activities which can be used to create cognitive conflicts in students so that dissatisfaction can occur. M. G. Hewson and P. W. Hewson (1983) have shown that a teaching strategy which confronts, and explicitly deals with students' alternative conceptions about density resulted in a significantly larger improvement in the acquisition of scientific conceptions. Such a strategy might include experiments, demonstrations, or problems for students to solve.

Computers are a tool that many authors (Bork, 1978; Ganiel & Idar, 1985; Zietsman & P. W. Hewson, 1986) believe can successfully be used to overcome student misconceptions. Ganiel and Idar (1985) developed a simulation program which confronts certain physical science misconceptions. As students progress through the program, they become dissatisfied with their misconceptions and discard them while at the same time learning basic concepts about physics and motion.

Zietsman and P. W. Hewson (1986) showed that computer simulation programs can successfully be used to overcome certain misconceptions about velocity. Their program was designed to detect a certain misconception and deal with it directly by providing situations in which the student can see that this particular misconception is not plausible. They noted that while standard physics equipment can also be used for the same purpose, it is cumbersome and using it is time consuming. The computer program is less expensive and easier to use than the physical lab equipment, provides immediate feedback, and in addition can diagnose this particular misconception and provide remediation. Their study showed that microcomputer simulations are credible representations of reality and that students with misconceptions using the program were significantly able to change their conception of velocity.

Some misconceptions may be eliminated through classroom discussions of scientists who overcame misconceptions themselves. Wandersee's (1985) survey of 1405 students concerning their misconceptions about photosynthesis showed that many of the younger students hold misconceptions which are very similar to those held by scientists many years ago. He argues that the teaching of the history of science can help students recognize and overcome their own misconceptions.

Eaton, Anderson, and Smith (1983) pointed out that, although teaching a new science concept can be difficult, correcting a misconception is much more so. For, in both children and adults, a misconception seems like the truth. They noted that children often feel that science is an unusually difficult subject because their preconceived views of the world are so often contradicted by their science teachers. M. G. Hewson (1981) noted that students have alternative conceptions because they believe them to make better sense than anything else. She proposed that when students' prior knowledge is ignored, science is viewed as "abstruse, difficult, incomprehensible, and irrational." (p.10)

## Purpose of this Investigation: Questions to be Considered

Fisher, in the *Proceedings* of the International Seminar on Misconceptions in Science and Mathematics (Helm & Novak, 1983), noted that misconceptions are not isolated cases, but that often many students hold the same misconceptions. Helm, in the same monograph, suggested that research is still needed to determine which misconceptions are prevalent and robust. Despite the need for all teachers to know which misconceptions their students are likely to have, there has been no large scale effort of this kind in the earth sciences.

The purpose of this investigation is to determine which misconceptions in the earth and space sciences appear to be widespread, and to discover if certain individual characteristics such as gender and race are related to misconceptions held.

The research questions to be addressed by this investigation are:

1. How prevalent are certain earth and space science misconceptions among students and adults?
2. Do gender, race, educational level, urban versus suburban location, last grade received in science, and exposure to an earth science course affect these misconceptions?

## Definitions

Earth science/earth sciences: A broad field within the natural sciences composed of the disciplines of geology, meteorology and astronomy; also called: earth and space science.

Earth science misconception: A misconception concerning the broad and interrelated field referred to as earth science. It does not include misconceptions within geology, meteorology or astronomy which would be of interest only to specialists in those disciplines.

Functional misconception: A possible misconception, which, if it does exist, would make it difficult for its holder to function in society.

Misconception: An concept which is incompatible with established scientific theory.

Misinformation: A fact which is incompatible with established scientific theory.

Primary misconception: A misconception revealed by the results of a question on the instrument for this study, which was selected by the sample at large more often than was the scientific conception, and more than twice as often as the least selected distracter.

Race: A division of the sample into five categories based on geographic origin of one's ancestors:

Whites: Persons from, or descendants of persons from Europe.

Blacks: American Negroes. (No other Negroes are in the sample.)

Hispanics: Persons from, or descendants of persons from Latin America.

Asians: Persons from, or descendants of persons from Asia. This division includes Caucasians from India as well as Orientals from East Asia.

Other: Persons who consider themselves to belong to more than one group, as well as persons who do not consider themselves to belong to any of the above groups.

Secondary misconception: A misconception revealed by the results of a question on the instrument for this study, which was selected by the sample at large less often than was the scientific conception, but more than twice as often as the least selected distracter.

## Importance of this Investigation

Nussbaum (1979) suspected that parents and teachers are usually unaware of the erroneous notions that their children have about the world. An example of this was reported by Lightman and Sadler (1988) who noted that a group of second grade teachers believed that 95% of their students knew that the earth was round when actually only 5% did.

Teachers and curriculum planners need to know what misconceptions students are likely to have. Osborne, Bell, and Gilbert (1983) stressed the need to identify children's current views. They urged planners and teachers "to design curricula which build on, rather than ignore, children's views." (p. 6) Doran (1972) proposed that knowledge of common misconceptions can be of great value to both classroom teachers and curriculum developers. Specifically, he argued for curriculum development which begins with what the student already knows. Yet in spite of these calls for identification of students' misconceptions, there has been little research to discover them in the earth and space sciences.

Tyler (1949) emphasized that teachers and subject specialists should ask themselves, "What can your subject contribute to the education of young people who are not going to be specialists in your field?" (p. 26) In the earth sciences there are several answers. All citizens need information from the earth and space sciences, not only to understand the world around them, but also to intelligently make practical decisions about life. The direction of the sun at various parts of the day should dictate to landscapers, park developers, and home owners where shade trees should be planted. Architects can design eaves over windows which can allow the lower winter sun to penetrate a window and thus help warm the building, while preventing the higher summer sun from doing the same. The possibility of shoreline erosion, floods and earthquakes should affect planning, construction, and zoning decisions.

Finson and Enochs (1988) noted that it is the earth science class which addresses many of the complex issues which are currently affecting civilization. They include acid rain, radioactive waste disposal, ground water shortage and mineral exploitation. To that list could be added solid waste disposal, fluctuating lake levels, drought, and the greenhouse effect, all of which are currently affecting the Chicago area.

A pilot study completed during the summer of 1987 has convinced the author that many misconceptions in the earth sciences are widespread and should be the topic of further research. Once these misconceptions are identified, authors, textbook publishers, and curriculum developers must be made aware of them so that future generations will not be burdened by these hindrances to understanding.

CHAPTER II

# A REVIEW OF RELATED LITERATURE

The origins of the study of misconceptions in the earth and space sciences is lost in the early history of civilization and learning. As the development of scientific thought advanced in the ancient world, scientists and philosophers, many of whom established their own schools, were concerned with convincing others of what had been discovered.

It is known that a scientific understanding of the earth developed as early as 2500 years ago, for by 500 b.c. Pythagoras had asserted that the earth was round. A generation later, Anaxagoras postulated that the moon reflects sunlight, also explaining solar and lunar eclipses.

Aristotle, ca. 350 b.c., understood enough about the earth to state that "down" is toward the center of the earth, although he also believed the earth to be the center of the universe. Eratosthenes (ca. 270 b.c.) estimated the earth's circumference to be 25,000 miles, just slightly over than the correct amount. Aristarchus (ca 250 b.c.) then proposed that the sun, not the earth, was the center of the universe, a notion usually credited to Copernicus seventeen hundred years later.

Even after Copernicus reinvented the geocentric model of the solar system, convincing others of his new theories wasn't easy. Galileo, the first scientist to aim a telescope at the stars, had more than his share of problems in attempting to get others to overcome what he could have called scientific misconceptions.

## Early Misconceptions Research

The formal study of scientific misconceptions is primarily a 20th-century phenomenon. Driver and Easley (1978) suggested that misconceptions research has its origins in the work of psychologists like Piaget who in the early part of this century showed that children's conceptions are sometimes quite different from accepted scientific conceptions. Although his learning theories are not universally accepted, Piaget's clinical interview technique and his stages of causality have been used in much subsequent misconceptions research.

Inbody (1963) stated that Piaget's work had little influence on science curriculum in the 1940s and 1950s and that his work was seldom mentioned in the science education literature of those decades. This he attributes in part to the Deweian desire of many to build science curricula around the interests of the child.

By mid-century, however, educational psychologists began to understand the tenacity of these misconceptions and were developing theories on how to overcome them. Piaget's work was then rediscovered by those concerned with science education. Nussbaum and Novick (1982) noted that it was by this time generally agreed among psychologists that for a misconception to be eliminated, there must first be a recognition by the learner that a problem exists with the old conception. This recognition would then result in a feeling of dissatisfaction. Festinger (1957) referred to this dissatisfaction as cognitive dissonance, Piaget (1964) as disequilibrium, while Berlyne (1965) coined the currently more accepted term conceptual conflict.

Berlyne (1965), Ausubel (1968), and Novak (1977) all have advocated teachers' finding means to create cognitive dissonance in classrooms in order to create the need in students' minds for eliminating their misconceptions. So much emphasis was placed by Ausubel (1968) upon what a student already knows, that he postulated that, "preconceptions . . . may very well be the more important manipulable factor in the individualization of instruction." (p. 335)

## General Misconceptions Research since 1980

Osborne (1981) noted from his research that children were often misinterpreting what they were taught in class in an attempt to make the new information agree with their preconceptions. The term children's science was used by Gilbert, Osborne, and Fensham (1982) to denote those conceptual structures which provide a sensible understanding of the world from the child's point of view.

Nussbaum and Novick (1982) also reported that student's misconceptions can severely interfere with their learning science. When students use an inaccurate preconception to interpret information being presented by a classroom teacher, they are likely to give it a meaning which differs from that intended by the teacher. They noted that the learners may not even be aware of a problem, being perfectly satisfied that their interpretation is the same as the teacher's. Teachers also can be completely oblivious to the fact that their students have misinterpreted a concept, chalking it up later to their "not understanding" the lesson. (p. 184) Nussbaum and Novick emphasized that it is not a matter of not understanding, but of understanding differently from that which was intended.

Many researchers now view learning not merely as an addition to existing knowledge, but rather as a series of changes in students' conceptions. In light of this view, Posner, Strike, P. W. Hewson, and Gertzog (1982) and P. W. Hewson (1981b) proposed a new theory of conceptual change. They believe that learning proceeds differently when students are building upon correct assumptions than when they need instead to modify their assumptions (misconceptions or alternative conceptions) before proceeding further. They proposed that the term assimilation be used to describe that process which occurs when students use their existing concepts to deal with new ideas, and accomodation when students must replace or reorganize their concepts. Their model of four steps which must be fulfilled before a misconception is likely to be abandoned by a student and a new conception adopted is discussed in Chapter I. It is, for the convenience of the reader, repeated here:

1. A student must be dissatisfied with an existing conception.
2. The new conception presented must be intelligible.
3. The new conception must appear initially plausible.
4. The new conception should be fruitful.

Posner, et al. (1982) claimed that most current science teaching is directed towards assimilation and recall of new material. They feel that many teachers simply do not recognize the difficulty that students have when their alternative conceptions prevent assimilation.

McClelland (1984) disagreed with the model of conceptual change as proposed by Posner, et al. and P. W. Hewson, suggesting that students do not have alternative conceptions frameworks at all. He postulated that the reason for children's misconceptions is instead a "strategic inattention" displayed when they find it necessary to answer questions on physical concepts which are not relevant to them. He also noted that young students often answer questions very quickly, not giving themselves time to analyze them well before coming to conclusions.

Countering McClelland's findings, Gil and Carrascosa (1987) noted that many misconceptions, particularly those in physical science, do not affect just children. Their research showed the existence of deeply rooted and tenacious preconceptions in both college students and secondary school physics teachers. Many of these preconceptions can be called common sense or intuitive physics, believed by the students long before they enter a physics classroom. Gil and Carrascosa affirmed the idea of science learning as a series of conceptual changes.

Targan (1987) also questioned the assumption of conceptual change theorists that students often enter science classes with misconceptions in place. He found that his students initially had very little knowledge of, and few misconceptions about, the moon. As students made required observations of the moon, however, many of them acquired misconceptions. Targan believes that advance organizers presented before the observations were made, rather than teaching for accomodation, may often be the more appropriate model to follow.

Similarly Lawson (1988) questioned the need to complicate the teaching of biology with conceptual change strategies. He did not find that his subjects had naive misconceptions about biology, stating that biological knowledge basically proceeds from blank slate to complicated picture. Lawson admitted that although this does seem to apply to biology, perhaps it does not apply to the physical sciences.

Despite these criticisms, the conceptual change theory continues to be widely accepted by researchers. It provided the epistemological basis for several of the 15 papers about current misconceptions research presented at the 1988 annual meeting of the National Association for Research in Science Teaching.

## International Seminars on Misconceptions in Science and Mathematics

Cornell University has been a center of much misconceptions research in the United States with Ault, Cohen, Gertzog, P. W. Hewson, Nussbaum, Novak, Posner, and Strike all having either studied, or been members of the faculty there. In June of 1983, the first International Seminar on Misconceptions in Science and Mathematics was held on the Cornell campus at Ithaca, New York. Organized in less than a year by Helm and Novak, the three-day seminar attracted 118 participants, most of whom were personally invited by the organizers.

The seminar brought together many of the other scholars doing research in misconceptions and there were many spirited discussions (including the discussions on terminology described in Chapter I). Several of the papers presented at the seminar have been referred to in subsequent publications. Although by this time there had been much research on specific misconceptions in several of the natural science disciplines, the lack of much research on misconceptions in the earth sciences was made evident at the seminar when, of the 55 papers presented, 6 dealt with biology, 12 were concerned with with physical sciences, while none dealt with any of the earth sciences.

The participants made several suggestions concerning research that needed to be done. Among these were continued studies to identify consistent or robust misconceptions, and studies on particular populations including minority groups and adult learners.

A second seminar was held at the Cornell campus in July of 1987. Much larger than the first, it saw the presentation of 162 papers. This time there were three papers presented dealing with astronomy and one in geomorphology.

## Earth Science Misconceptions Studies

Meyer (1987) believes that "everyman" is his own earth scientist; that all persons, children and adults, have their own ideas about the earth, rivers, rain, and other geological concepts whether thay have had formal instruction or not. He believes that in the earth sciences, more than in the other sciences, students enter formal instruction with many preconceived notions.

Although within the last decade volumes have been written on the extent of scientific misconceptions, most of those studies have been concerned about misconceptions specifically related to the physical and biological sciences. Studies about children's misconceptions in the earth and space sciences are rare. Studies of adults' misconceptions in earth science are even more so. In many cases the work on misconceptions in earth science has been done by psychologists studying the processes of learning who happen to have used earth science topics in their studies.

In an early work, predating the work of psychologists such as Piaget, hydrologist R. E. Horton (1915) listed many common mistaken ideas about groundwater in New England. One such belief was the inexhaustibleness of many wells as a result of their being fed by rapidly flowing underground rivers. He noted that many people thought of underground water as existing in the same forms, such as rivers and lakes, as does surface water. A study by MacIver in 1970 showed that many of the misconceptions found by Horton, such as this belief in large underground rivers and lakes, were still prevalent 55 years later.

Hancock conducted a study as early as 1940 to determine the 100 most common "popular science" misconceptions, as he called them, and rank them in importance. Thirty-four years later, Goldsmith replicated the study to determine if the relative importance of these popular misconceptions had changed over the years. Although both authors used the term science misconceptions they did not include a single misconception related to the earth or space sciences. Hancock did, however, differentiate between superstitions and misconceptions, defining misconceptions as unfounded beliefs that do not embody the elements of fear, luck, or the supernatural.

Two of the first scientific studies which included some earth and space science misconceptions were published in the early 1960s. Inbody (1963) used 50 kindergarten children to study their understandings of natural events such as wind, rain, buoyancy, and electricity. Using an interview style similar to Piaget's, he found that most of the children had many misunderstandings of natural phenomena. Concerned more with conceptions than misconceptions, he classified student's explanations into six levels of understanding, similar to Piaget's levels of causation.

Kuethe, also in 1963, querried male high school graduates about general science. Among the earth science misconceptions he discovered was the belief by 70% of his subjects that the phases of the moon were caused by the moon's being in the earth's shadow. His study was concerned primarily with common misconceptions, which he delineated as questions which often evoked the same wrong answer.

Za'rour (1975) defined misconceptions as erroneous notions which occur with relatively high frequency. His study using high school and university students in Lebanon identified 20 common science misconceptions of which 2 were related to the earth sciences: the density of dry air is less than moist air, and, air is mostly composed of oxygen. Neither Kuethe nor Za'rour differentiated between misconceptions and misinformation.

The following year, Za'rour conducted a study similar to that done by Inbody in 1963 using 220 Lebanese elementary school students. He found that only the age of the students, not their gender or religion, had any significant effect on types of explanations given to questions about rain, the moon, evaporation, and falling objects.

## The National Assessments of Educational Progress

Beginning in 1969 the National Assessment of Educational Progress (NAEP) began a systematic study to determine how well students were doing in various school subjects, including science. Not concerned with misconceptions per se, the study was done to see how much information and skills students had learned as well as what attitudes students had toward science and learning. The assessments are composed of various exercises each of which is designed to test students' knowledge, skills or attitudes.

NAEP science assessments consist of content items, such as "What is a galaxy?" and inquiry questions which ask students to apply principles and draw conclusions. The results from the four completed assessments have shown a consistent drop in scores for 17 year old students on content and inquiry items. The major contributor to the decline in content questions in the last assessment was a 3.1 percentage point drop in earth science items (Rakow, Welch, & Hueftle, 1984). On content items, males have scored about five percentage points higher than females for ages 13 and 17; for inquiry questions there has been no difference in scores by gender (Linn, de Benedictis, Delucchi, Harris, & Stage, 1987).

While NAEP results can be used by those educators concerned with students' concepts or understanding, they have limited usefulness for those whose primary concern is misconceptions. The questions written by NAEP have limited usefulness as they were not designed to identify any particular misconceptions.

## Studies of Concept Development in the Earth Sciences

Nussbaum and Novak (1976) were two of the first to extensively and scientifically study the formation of children's concepts and misconceptions of the earth. In one of the first scientific experiments related to the learning of earth science concepts, they utilized open-ended interviews of 52 second grade children. Although the experiment was carried out not to determine the extent of misconceptions, but rather to determine effective ways of presenting new materials, a great deal of information concerning earth science misconceptions was garnered. The study showed that their subjects had one of five different notions about the earth listed below. They range from the most egocentric view, the earth is flat, to the scientific conception that the earth is spherical and gravity pulls objects to its center.

1. The earth is flat and extends indefinitely. All the children stated at first that the earth was round, but failed to comprehend that that spherical earth is actually the planet we live on. Some thought of Earth as being a round object that can be seen in the sky. Some combined the opposing concepts of flat and round earth resulting in an earth shaped somewhat like a pancake.
2. The earth is spherical; gravity pulls objects toward a surface below the sphere. This notion is similar to the ancient Greek model of Atlas holding the earth on his shoulders. People could only live on the upper half. If objects were dropped from any point in the southern hemisphere they would fall off. When children who held this notion were questioned further, their views were not much different from notion 1.
3. The earth is spherical, surrounded by space, gravity still pulls things "downward" --this time to the sky which is below as well as above the earth. People could still only live on the upper half of the earth.
4. The earth is spherical, surrounded by space; gravity pulls objects toward the earth, but not exactly to its center, rather to the

"lower" part of the solid earth.

5. _The earth is spherical, surrounded by space, objects fall to its center_. Students fully understood the concepts involved.

Nussbaum (1979) replicated this experiment three years later in a cross-age study of 240 students at an experimental school in Jerusalem. The 240 subjects interviewed were students in grades four through eight (48 in each grade level). In his results, Nussbaum combined notion 2 with notion 1 as listed above, but found an additional notion, undetected in the first study, which became the new notion 2.

2. _The earth is composed of two hemispheres, one ground, the other sky_. We live inside the earth, where the two hemispheres meet. Gravity pulls all objects downward to a level beneath the earth.

Notions 3 - 5 were found to be similar to those described in the first study. Nussbaum noted that some students as late as eighth grade still cling to notion 1, yet, as expected, the older students showed more inclination for the more scientifically compatible notions.

Nussbaum and Novak's classic experiment has been replicated by others as well. Mali and Howe (1979) conducted the study in Nepal among students who had had little exposure to western ideas and scientific thought; Sneider and Pulos (1983) repeated it with 159 children in grades three through eight in San Francisco. Both studies achieved results similar to Nussbaum's first study. Mali and Howe also found a correlational relationship between the most conceptual views of the earth and logical reasoning abilities.

Tyler's Challenge

In spite of the availability of statistics on achievement at the national level, Tyler (1977) has urged local school systems to conduct their own assessments to determine what problems in student achievement are common in their own areas. In a response to Tyler's challenge, and in an attempt to add earth science concept attainment information to the literature, a state-wide investigation of earth science concepts was conducted in Texas in 1978 (Rollins, Denton, & Janke, 1983). Four hundred ninety-two seniors from 100 high schools in Texas completed a questionnaire designed to assess the attainment of five specific concepts: cause of the seasons, interdependence of man and environment, the changing earth, day and night, and solar energy.

The study by Rollins, et al., was carried out to determine concept attainment, rather than misconceptions in the earth sciences. Their results showed that concepts about the changing earth (erosion, mountain building), day and night, and the interdependence of man and environment were best understood by the students, being correctly identified 80% of the time. The concept of seasonal change averaged 67% and solar energy concepts averaged only 59%. Results also showed that seniors who had completed more than two years of science scored higher than those who took only the required two courses. The authors noted that this higher score may have occurred because students with more interest and knowledge in science are the ones most likely to take extra science courses. Concept attainment was found to be higher in suburban schools than in small rural schools.

Critical Barriers and Pseudoscience

Hawkins, a physical scientist, proposed in 1978 the term critical barrier to describe any concept which seemed "exceedingly unobvious" (p.4) and very difficult for students to comprehend. He noted that students who fail to overcome critical barriers are then unable to understand other scientific phenomena. His examples of critical barriers included the lack of up or down in outer space, as well as many physical science concepts such as images on mirrors, heat, and elementary mechanics.

Ault (1979), concurring with Hawkins, added the concept of bigness especially as it relates to geological time, volume, and area. He noted that critical barriers affect learners of all ages by contradicting our everyday or non-scientific view of the world. In 1982, Ault conducted a cross-age study of childrens' conceptions of time. His results showed that, although time could well be called a critical barrier, it was no more so to young children learning about the geologic past than it was to older persons who were uninformed about geologic events and records.

Problems related to scale and the difficulty of decentralizing one's spacial perspective often combine to make natural phenomena difficult to understand. Ault (1984a) noted that, although the phases of the moon can easily be shown using a lamp and a baseball, science education graduate students still struggle when asked to imagine how the moon seen from the U.S. as a crescent would appear to an Australian observer.

Feder (1985) believes that a major source of misconceptions in earth science is the widespread belief in various pseudosciences such as astrology. His survey of 186 Connecticut undergraduates showed that more than 24% of the participants believed that astrology is an accurate predictor of personality, that time travel is possible, that our government is hiding information about UFOs, and that there's a mysterious force in the Bermuda Triangle. That there is intelligent life out there in the universe was subscribed to by 68% of the students. Feder used cross-tabulation to ferret out possible correlations between personal data and levels of belief. His findings showed that some previous science coursework did at least seem to have a positive impact on beliefs related to those disciplines.

A Hands-On Approach to Meteorology

Stepans and Kuehn (1985) conducted an interview survey of 60 second and fifth grade students to examine their understanding of weather. In order to determine whether a hands-on type of instruction helped children develop true causality, half the subjects were taken from classes which used the activity-based Elementary Science Study curriculum, and half from classes where textbooks were the primary source of instruction. Children were asked open-ended questions such as "What is rain?" The children's answers were then placed into one of five developmental categories based on Piaget's stages:

1. Animism (The clouds think it's too hot and start to sweat)
2. Artificialism (It rains so that crops will grow)
3. Religious finalism (Thunder is when God yells at the angels)
4. Nonreligious finalism (White bears cut-out and drop snowflakes)
5. True causality

It was found that second graders who were using the hands-on approach gave more true causal responses about wind and rain. More fifth graders using the hands-on approach gave true causal answers to questions about clouds, snow, and rainbows. However, more fifth graders using textbooks gave true causal responses to questions about rain. No student gave a true causal answer to the questions about thunder--even though the concept had been taught in class.

Stepans and Kuehn determined that the majority of students in both grades were at the stage of nonreligious finalism whether or not they were in the hands-on oriented class. No second grader had attained the true causality stage while nearly 25% of the fifth graders had.

## Recent Studies in Astronomy

Sadler (1987) reported at the Second International Seminar on Misconceptions in Science and Mathematics some of the results of his study of misconceptions in astronomy of 213 ninth graders. He found that more than half of them could not draw a diagram correctly showing what causes the seasons to change, nor could explain how long it took for the moon to go around the earth. Nearly half couldn't explain how long it took the earth to go around the sun. For a question which required students to apply and synthesize two concepts, 90% of them could not explain how long it took the moon to go around the sun. Sadler noted that scores did improve after the completion of an experimental lesson on the topics.

Lightman, Miller, and Leadbeater's (1987) paper on contemporary cosmological beliefs was also presented at this second seminar. Using the facilities of the Public Opinion Laboratory at Northern Illinois

University in 1986, 1120 adults were asked quesions about their knowledge and concepts of the universe. The results of that survey showed that 55% of the respondents correctly believed the sun to be a star (25% thought it was a planet) but only 24% correctly responded that the universe is expanding. They found that younger adults, males, and more educated people are more knowledgable in astronomy than older adults, females, and less educated people, respectively. Nineteen percent of the adults expressed negative feelings about the discovery of an expanding universe.

The second part of their study employed 83 high school students who were asked to write open-ended essays. They were asked, "If astronomers learned that the universe is increasing in size, with all the galaxies moving away from each other, how would this make you feel?" Results showed that 23% of the essayists expressed a positive reaction to an expanding universe while 43% revealed negative reactions such as fears of unknown change, loss of control, and a sense of helplessness or insignificance. Lightman, et al., believe that these negative feelings might help explain the historical attraction to the static or stable concept of the universe.

## Summary

The study of misconceptions in science is one which has attracted considerable attention within the last decade. In papers published on the topic there are two themes upon which there seems to be a general agreement: that misconceptions are remarkably resistant to change, and that a student with misconceptions will have considerable difficulty learning and absorbing new materials.

With studies about misconceptions in the earth and space sciences so rare, and with the resultant scarcity of useful information for practitioners about problems concerning misconceptions in these two interrelated disciplines, the time is ripe for a study of the extent of earth and space science misconceptions.

CHAPTER III

# METHODOLOGY

## Research Questions

The primary research question addressed in this investigation is: How prevalent among students and adults are certain earth and space science misconceptions?

The secondary research question is: How do gender, race, grade level, urban versus suburban location, last grade received in science, and exposure to earth science courses affect misconceptions?

## Hypotheses

The following null hypothesis for the primary research question is tested:

$H_o1$: There are no misconceptions revealed by the responses to the questions on the instrument.

The following six null hypotheses for the secondary research question are tested:

$H_o2$: There is no difference in misconceptions across gender.

$H_o3$: There is no difference in misconceptions across race.

$H_o4$: There is no difference in misconceptions across grade level.

$H_o5$: There is no difference in misconceptions between urban and suburban students.

$H_o6$: There is no difference in misconceptions across exposure to earth science classes.

$H_o7$: There is no difference in misconceptions across last science grade received.

## Subjects

Purposive sampling was used to obtain a representative sample of approximately 1200 elementary, secondary, and adult students, drawn from both inner-city and suburban public and private schools within and near Northwest Indiana. The sample included a mixture of white, black, Hispanic, and Asian participants, although the number of Asian participants is much smaller than the other three groups, a reflection of their representation in the general population of the area. Adults were students at a trade school or at local universities.

## The Pilot Study

To create the instrument used in the pilot study, 63 multiple choice questions were compiled by the author. These questions contained the misconceptions which were suspected to be widespread among the American public, in both children and adults. Questions were included about geology (earthquakes, diamonds, dinosaurs, flooding, gravity, seasons), meteorology (precipitation, storms, rainbows, humidity), and visible astronomy (comets, meteors, the sun, and the moon).

It was decided that the questions on the survey would be drawn from information and concepts to which a fifth grader should have been exposed. A subsequent study of elementary science texts indicated that most of the topics contained in the preliminary survey were addressed by the texts by the time students were in the fifth grade. Recognizing that not all textbook material is actually covered in the classroom and that some material in addition to that in the text is covered, the list of questions was screened by a jury of three elementary school teachers for content and readability for fifth grade students. Subsequent to this review, 10 questions were eliminated from the survey.

The questionnaire was then submitted to a second jury of three science teachers for confirmation of clarity and accuracy. This screening resulted in some questions being eliminated and others reworded to eliminate ambiguities and misleading stems and distracters. From this list, a questionnaire of 50 earth and space science questions was created, and from July to September of 1987 it was administered to 156 persons.

The pilot study was given to two groups of students (n=39) and two groups of practitioners (n=42) in July of 1987. Since it was felt that a 50-question survey would take longer to complete than cooperating teachers might wish to allow, the survey was divided in two. Forty-one persons responded to the first 25 questions while the other 40 persons responded to questions 26-50.

In August and early September of 1987, the entire survey was administered to 42 inner-city high school students in East Chicago, Indiana, and 33 undergraduate students at Purdue University Calumet in

Hammond, Indiana. All participated in the survey on their first day of class for the fall semester. As was done when the final survey was conducted, a discussion followed each administration of the pilot study in which the scientifically acceptable response for each question was identified and students were encouraged to discuss their feelings about their misconceptions.

The results of the pilot study revealed many misconceptions worthy of inclusion on the final instrument, while the discussions resulted in several valuable rewording suggestions. It was also discovered that the final instrument needed to be shorter than the pilot instrument, as several high school students who were given the entire 50-question survey were unable to finish it within their 55-minute class period. As it was planned that the survey would be both administered and discussed within 45 minutes, it was decided that the instrument used should have a maximum of 20 questions.

## Instrumentation

The instrument used in this investigation consisted of 18 multiple choice questions each of which was drawn from questions that were on the pilot instrument. Following the format for misconceptions surveys suggested by Gilman, Hernandez, and Cripe (1970), each question has one correct or scientifically acceptable response, one or two distracters which are the misconceptions to be measured, and with the exception of question 16, additional distracters to make a total of four alternatives. Because it was necessary to list all four directions (north, south, east, and west) as distracters, question 16 has five alternatives.

The additional distracters were written so that, to the uninformed person, they would appear to be just as plausible as any of the other answers. As a result, they are, for each question, a measure of the amount of random guessing. Common misconceptions were then identified only when the response for a particular distracter was twice that of the least popular distracter.

## Procedure

Permission to administer the survey was obtained in advance from teachers (and their principals, as necessary) at several local public, private, and parochial schools and colleges. An agreeable time and place for the survey to take place was set.

The instrument was administered by the author to intact classes of 5th grade, 8th grade, and high school (primarily 11th grade) students, and to adult students in classes at two local universities and one trade school. The author was unable to personally administer the survey to the last of five classes at Munster High School as the the timing for that class conflicted with the time for the administration of the survey to an elementary school nearby. The classroom teacher administered the survey to that one class.

The purpose of the investigation was explained to all students before they were given the instrument, and approximately 15 to 20 minutes was allotted for students to answer the questions on the survey. The remainder of the class period was then used for a discussion of the survey and misconceptions involved.

Students were asked to provide their grade level, gender, race, and last grade received in a science class. High school and adult students were asked to list any earth science classes completed or being taken on the date the survey was administered. To insure confidentiality, all students were asked not to write their names on the instrument. Only group data was used in the reporting and interpretation of the results of this study.

## Design and Statistical Analyses

### Research question 1:

For research question 1, the frequency was recorded of student selection of each distracter for each of the 18 questions on the instrument. Common misconceptions were identified from the responses whenever a particular distracter was chosen more than twice as often as the least chosen distracter for that question.

### Research question 2:

Research question 2 involves analysis of the subgroups within the sample by gender, race, demographic location, level of education, last science grade received, and the exposure to earth science courses.

For testing null hypotheses two through seven an analysis of variance was calculated. The hypotheses were rejected only when the probability of F was less than 0.01.

## Potential Risks

The Institutional Review Board for the Protection of Human Subjects, Loyola University of Chicago, has determined that there were no potential risks for the participants involved other than those associated with attending school and taking tests.

## CHAPTER IV

## RESULTS

Results of the survey showed that the participants hold many misconceptions in the earth sciences and that some subgroups within the sample were more likely to have particular misconceptions than others. This chapter is divided into four sections: The Sample, which describes the participants in this survey, Misconceptions Revealed by the Survey which defines and lists the different types of misconceptions identified by the results of this study, Item Analyses of the individual questions on the instrument, listing the frequency of responses broken down by gender, race, location, level of education, and whether an earth science class had been taken, and Analysis of the Subgroups which shows how the frequency of holding misconceptions compares with gender, race, location, level of education, and exposure to earth science classes.

### The Sample

The survey was administered in April and May of 1988 to 1213 students in schools and colleges all located in northwest Indiana and northeast Illinois. Of the participants, 307 were students in the 5th grade, 237 were in the 8th grade, and 340 were in 11th grade high school classes. The remaining 318 were adults enrolled in classes at regional campuses of Indiana and Purdue Universities (n=226) or at a local trade school (n=92).

The author personally administered the survey to each class with one exception which resulted when, because of constraints set by the teachers involved, two classes needed to be surveyed at the same time. As none of the three high schools in the study had an 11th grade science class, permission was received at each of those schools to administer the surveys in a United States History or Government class. No classes used in the survey had been taught at any time previously by the author.

The sample can be described as follows:

male: 51% female: 49%

white: 63% black: 16% Hispanic: 17.5% Asian: 2%

urban: 40% suburban: 55% rural: 3%

The 1980 Federal United States Census lists the following percentages for North Township, Lake County, Indiana, the township in which most of the participants lived: 76% white, 9.6% black, 14.0% Hispanic, and 0.4% other. For the whole Lake and Porter County area in northwest Indiana, the source for nearly all the adult students in the sample, the percentages are: 70% white, 19% black, 7% Hispanic and 4% other. Because the sample of Asian (n=24) and rural (n=41) students was so small, they are not included in the statistical reports within Chapter IV. They are, however, listed in Appendix C.

Of the 340 high school students, 206 had taken, or were currently taking an earth science class, 129 had never taken an earth science class, and 5 did not indicate if they had or had not. Of the 226 college students, 57 had taken a high school level, but not a university level earth science course, 85 had taken, or were currently taking, a university level but had not taken a high school level earth science course, 34 had taken earth science courses at both levels, 48 had never taken an earth science class, and 2 did not indicate whether they had or not. It should be pointed out that neither the high school nor college level earth science class would necessarily cover all, or even most, of the topics covered by this survey.

In order to infer social-economic status, most of the grade school students were selected from schools within two very different types of communities of northwest Indiana: East Chicago, a highly industrialized urban area composed primarily of working class families, and Munster, a suburban community most of whose citizens are employed in managerial or professional occupations. One high school was selected which was located near, but not within, either of these communities. This school, a private high school located in suburban Lansing, Illinois, was chosen because of its science curriculum (unique in this area) in which all students take some earth science in their Freshman year. Students at this school are drawn from many different communities including Munster. A list of all schools participating in this survey is contained in Appendix A. For more information about the East Chicago and Munster communities and their school systems, see Appendix B.

The adults chosen for this study were either students at Indiana University Northwest in Gary, Indiana, Purdue University Calumet in Hammond, Indiana, or the Emilio De La Garza Center in East Chicago, Indiana. Purdue Calumet and Indiana University Northwest are regional campuses of Indiana's two largest state universities with much larger, main campuses located downstate. Both regional campuses are commuter schools with no dormitory facilities and so serve the local population.

Thirteen of the 226 college students were graduate students who were teachers, another 32 were seniors who planned to be teaching school within a few months.

The De La Garza Center is a vocational school which serves East Chicago Central High School students during regular school hours and adult members of the community after 5:00 p.m. For adults, it offers basic adult education, GED classes for adults who have no high school diploma, data and word processing classes, and apprenticeship programs in various trades.

## Misconceptions Revealed by the Survey

The purpose of this section is to answer the primary research question: How prevalent are certain earth and space science misconceptions among students and adults?

Kuethe (1963) and Za'rour (1975) both used questionnaires in their individual studies in order to determine the extent of specific scientific misconceptions. Kuethe identified misconceptions from questions on his instrument which often evoked the same error. Za'rour similarly identified them from his instrument as "erroneous notions which occur with relatively high frequency." This author chose a similar means to identify misconceptions.

It is recognized that not every participant who chose a wrong answer to a question had a misconception, nor did every person who chose the correct answer necessarily understand the scientific conception. Undoubtedly random guessing played a part in the selection of answers by some participants. A measure of the amount of random guessing for each question can be inferred from the number of responses received by the least popular distracter. Therefore, for the purposes of this study, misconceptions from each question were identified from erroneous responses which were chosen by the sample more than twice as often as the least popular response.

## Primary Misconceptions

In many cases a particular misconception is so commonly accepted that it was chosen by the participants more often than the correct, or scientifically acceptable, conception. In this paper, these misconceptions are called Primary Misconceptions. Six of them were identified. They are listed in descending order of acceptance in Table 3. Most are constructed from the stem of the question and the particular alternative; in some cases the statement has been reworded or shortened from the form that was used on the instrument by eliminating a nonessential word or phrase. In every case, the original form of the question used on the instrument is included as part of the item analysis later in this chapter.

Table 3. Primary Misconceptions Revealed by the Survey

| No: | Misconception: | Percent: |
|---|---|---|
| 5 | At 12:00 noon, the sun is directly overhead. | 82.4 |
| 1 | Summer is warmer than winter, because in summer the earth is nearer the sun. | 77.6 |
| 6 | In May, June, and July, the sun sets in the west. | 58.6 |
| 9 | When we have a full moon, people that same night in Australia will have a different phase of the moon. | 52.9 |
| 7 | The different phases of the moon are caused by the shadow of the earth falling on the moon. | 48.1 |
| 2 | In each day during summer the amount of daylight is more than the day before. | 32.4 |

## Secondary Misconceptions

In many other cases, the scientifically acceptable response was the most-chosen response, however a large number of participants chose a particular misconception over the other possible answers. These less popular misconceptions are referred to in this paper as Secondary Misconceptions. They are identified here from those incorrect responses which were less popular than the scientific conception, but were still chosen at least twice as often as the least chosen response for that question. Table 4 lists them in descending order of acceptance.

Table 4. Secondary Misconceptions Revealed by the Survey

| No: | Misconception: | Percent: |
|---|---|---|
| 15 | If a crystal can scratch glass, it is a diamond. | 44.4 |
| 11 | We can often see planets at night but only with a telescope or a pair of binoculars. | 41.5 |
| 10 | It takes about one day for the moon to go around the earth. | 35.9 |
| 14 | The terrible floods that occur along a river occur only when snow melts in the spring. | 33.6 |
| 17 | The dinosaurs lived at the same time as cave-men. | 32.6 |
| 18 | It is not possible that in the near future Chicago could be severely damaged by an earthquake. | 25.6 |
| 4 | We have day and night because the earth goes around the sun. | 19.6 |
| 10 | It takes about one year for the moon to go around the earth. | 19.5 |
| 8 | The moon shines because it is like a star, just bigger. | 15.7 |
| 13 | Earthquakes can be accurately predicted by observing the behavior of wild animals. | 15.4 |
| 3 | We can predict whether there is going to be a very cold winter by looking at the thickness of fur on animals in the fall. | 12.0 |
| 8 | The moon shines because it makes its own light like the sun. | 9.5 |
| 11 | We can often see the planets because every night they are in the same place in the sky. | 9.1 |
| 4 | We have day and night because the sun goes around the earth. | 8.8 |

The data above, substantiated by Tables 6 through 23 which follow, show that 20 primary and secondary misconceptions were identified from the results of this study. Therefore null hypothesis one is rejected.

Functional Misconception

Question 16 on the instrument was unique in that it had only one misconception and four answers, each of which was correct at some point in the survey. That misconception, which was chosen by only 4.7% of the participants was, as expected, the least chosen response for that question. However, because it is quite common in some classrooms (chosen by 19% of urban fifth graders) and because holding this misconception can greatly interfere with one's ability to function in today's world, this erroneous concept is herein defined as a functional misconception and is listed in Table 5 below.

Table 5. Functional Misconception Revealed by the Survey

| No: | Misconception: | Percent: |
|---|---|---|
| 16 | The direction, north, is straight up. | 4.7 |

## Item Analyses

For ease of access, readability, and comprehension, the results of each question on the survey are grouped into two tables: Table a and Table b. For each Table a, the total number of responses for each of the answers, as well as the percent that that frequency represents, is listed. In these tables, two plus signs (++) indicates the correct or scientifically acceptable answer, two asterisks (**) indicate a primary misconception, one asterisk indicates a secondary misconception, while *F marks the functional misconception.

Each Table b provides the percent of subgroup members (e.g. males or females) who chose a particular misconception, as well as the percent who chose the scientifically acceptable answer. Trade school refers to those adult students enrolled at the De La Garza Career Center in East Chicago. Figures for Asian and rural participants are not included in the tables as the sample sizes of these two groups was small (n= 24 for Asians, n= 42 for rural). For comparison purposes, they are included in the figures used in Appendix C.

The responses of high school students on Tables b are broken down into two groups, no earth science and earth science, dependent upon whether such a class had been taken at the high school level. Responses of college students were broken down into four categories: no earth science, H.S. earth science for those who had taken an earth science course but only at the high school level, univ earth science for those who had taken such a class but only at the university level, and both earth science for those who had taken the class at both the high school and university levels. This last subgroup is included in spite of the fact that only 34 of the 226 college students had taken such a class at both levels. As the surveys were conducted in April and May, all students currently enrolled in an earth science class were nearing its completion.

Questions are analyzed in the order in which they appeared on the instrument. Questions about the seasons are first, followed by questions about astronomy, and then questions about the earth.

| Table 6a. Question 1 Responses. | Frequency: | Percent: |
|---|---|---|
| Summer is warmer than winter, because in summer: | | |
| a. the sky has fewer clouds. | 48 | 4.0 |
| b. the earth is nearer the sun. | 941 | 77.6** |
| c. the earth is better insulated. | 51 | 4.2 |
| ++ d. the sun is higher in the sky. | 160 | 13.2 |
| no answer or more than one answer marked: | 13 | 1.1 |

Misconception b was chosen by more than 70% of every subgroup studied except for those college students who had taken earth science but only at a university level. High school students with earth science courses were less likely to have the misconception than those without. More females than males had this misconception, as did more of the minorities than whites. Eighth graders were more likely to have this misconception than students in any other grade level.

Table 6b. Percent of Subgroups Holding Misconception b and the Scientific Conception in Question 1.

| | misconception b | | scientific conception | |
|---|---|---|---|---|
| | ($\bar{M}$ = 77.6) | | ($\bar{M}$ = 13.2) | |
| Gender: males | 74.1 | | 16.5 | |
| females | 81.5 | | 9.5 | |
| Race: white | 76.2 | | 16.5 | |
| black | 80.3 | | 5.2 | |
| Hispanic | 81.1 | | 8.0 | |
| Location: urban | 79.7 | | 8.8 | |
| suburban | 77.3 | | 15.5 | |
| Level: 5th grade | 75.9 | | 9.1 | |
| 8th grade | 82.7 | | 8.4 | |
| 11th grade | 78.8 | | 15.6 | |
| no earth science | | 82.2 | | 10.1 |
| earth science | | 76.2 | | 19.4 |
| college | 72.1 | | 19.5 | |
| no earth science | | 72.9 | | 22.9 |
| H.S. earth science | | 78.9 | | 19.3 |
| univ earth science | | 67.1 | | 18.8 |
| both earth science | | 70.6 | | 17.6 |
| trade school | 80.4 | | 14.1 | |

Table 7a. Question 2 Responses.

| Each day during the summer months, the amount of daylight: | Frequency: | Percent: |
|---|---|---|
| a. is more than the day before. | 393 | 32.4** |
| ++ b. is less than the day before. | 314 | 25.9 |
| c. is the same as the day before. | 185 | 15.3 |
| d. has nothing to do with the day before. | 314 | 25.9 |
| no answer or more than one answer marked: | 7 | .6 |

The misconception that during the summer the days increase in length was held more by males than by females, and more by whites than minorities. White participants were also more likely to hold the scientific conception. There was an increase in acceptance of the scientific conception across grade level, but no decrease in acceptance of the misconception across grades 5 through 11.

Table 7b. Percent of Subgroups Holding Misconception a and the Scientific Conception in Question 2.

| | misconception a | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 32.4) | ($\bar{M}$ = 25.9) |
| Gender: males | 37.8 | 25.9 |
| females | 26.7 | 25.6 |
| Race: white | 34.7 | 32.8 |
| black | 22.8 | 13.5 |
| Hispanic | 31.1 | 13.7 |
| Location: urban | 27.5 | 18.0 |
| suburban | 35.0 | 31.1 |
| Level: 5th grade | 31.6 | 10.1 |
| 8th grade | 30.8 | 18.6 |
| 11th grade | 31.2 | 32.6 |
| no earth science | 32.6 | 30.2 |
| earth science | 29.1 | 34.5 |
| college | 26.1 | 45.1 |
| no earth science | 29.2 | 50.0 |
| H.S. earth science | 26.3 | 47.4 |
| univ earth science | 24.7 | 40.0 |
| both earth science | 26.5 | 47.1 |
| trade school | 58.7 | 23.9 |

Table 8a. Question 3 Responses.

| | Frequency: | Percent: |
|---|---|---|
| We can know in advance if there is going to be a very cold winter by: | | |
| a. seeing how cold it was in the last winter. | 58 | 4.8 |
| b. seeing how hot it was in the last summer. | 108 | 8.9 |
| c. looking at the thickness of fur on some animals in the fall. | 145 | 12.0* |
| ++ d. cold winters cannot be accurately predicted by any of these methods. | 888 | 73.2 |
| no answer or more than one answer marked: | 14 | 1.1 |

That cold winters can be predicted by the thickness of animal fur is not subscribed to by more than 15% of any group. White participants were more likely to subscribe than minorities and relatedly, suburbanites more so than urbanites. Generally, the higher the level, the less likely one was to have this misconception. Those high school students who had taken earth science were more likely than those who did not.

Table 8b. Percent of Subgroups Holding Misconception c and the Scientific Conception in Question 3.

| | misconception c | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 12.0) | ($\bar{M}$ = 73.2) |
| Gender: males | 11.3 | 74.7 |
| females | 12.6 | 71.6 |
| Race: white | 13.3 | 74.0 |
| black | 9.8 | 69.4 |
| Hispanic | 8.0 | 75.5 |
| Location: urban | 10.2 | 72.3 |
| suburban | 12.9 | 73.7 |
| Level: 5th grade | 17.6 | 64.2 |
| 8th grade | 12.2 | 72.2 |
| 11th grade | 8.8 | 75.6 |
| no earth science | 3.9 | 79.8 |
| earth science | 11.7 | 73.3 |
| college | 8.4 | 82.7 |
| no earth science | 12.5 | 83.3 |
| H.S. earth science | 10.5 | 80.7 |
| univ earth science | 5.9 | 83.5 |
| both earth science | 5.9 | 85.3 |
| trade school | 13.0 | 75.0 |

| Table 9a. Question 4 Responses. | Frequency: | Percent: |
|---|---|---|
| We have day and night because: | | |
| a. the sun goes around the earth. | 107 | 8.8* |
| b. the moon goes around the earth. | 47 | 3.9 |
| c. the earth goes around the sun. | 238 | 19.6* |
| ++ d. the earth spins on its axis. | 810 | 66.8 |
| no answer or more than one answer marked: | 11 | .9 |

Two secondary misconceptions became apparent through question 4. Misconception a, is one subscribed to much more by females than males, and blacks and Hispanics much more than whites. Its popularity generally decreases with age. Misconception c is subscribed to by more than 15% of every subgroup but one. Racial, gender and location differences made less difference in the subscribing to misconception c.

Table 9b. Percent of Subgroups Holding Misconceptions a and c and the Scientific Conception in Question 4.

| | misconception a | misconception c | scientific conception |
|---|---|---|---|
| | ($\bar{M}$ = 8.8) | ($\bar{M}$ = 19.6) | ($\bar{M}$ = 66.8) |
| Gender: males | 6.2 | 17.5 | 72.6 |
| females | 11.7 | 21.7 | 61.1 |
| Race: white | 3.7 | 18.2 | 73.6 |
| black | 17.6 | 19.7 | 58.5 |
| Hispanic | 18.9 | 23.1 | 51.4 |
| Location: urban | 16.4 | 21.7 | 57.2 |
| suburban | 3.7 | 18.1 | 74.1 |
| Level: 5th grade | 18.9 | 24.4 | 50.5 |
| 8th grade | 8.4 | 16.9 | 70.5 |
| 11th grade | 3.8 | 15.3 | 77.4 |
| no earth science | 4.7 | 18.6 | 72.9 |
| earth science | 3.4 | 12.6 | 81.1 |
| college | 4.0 | 19.9 | 71.7 |
| no earth science | 4.2 | 25.0 | 70.8 |
| H.S. earth science | 5.3 | 21.1 | 66.7 |
| univ earth science | 3.5 | 15.3 | 75.3 |
| both earth science | 2.9 | 23.5 | 70.6 |
| trade school | 7.6 | 22.8 | 66.3 |

| Table 10a. Question 5 Responses. | Frequency: | Percent: |
|---|---|---|
| We can use the sun to tell time, because at 12:00 noon, the sun is: | | |
| a. in the eastern sky. | 63 | 5.2 |
| b. in the western sky. | 64 | 5.3 |
| ++ c. in the southern sky. | 76 | 6.3 |
| d. directly overhead (straight up). | 999 | 82.4** |
| no answer or more than one answer marked: | 11 | .9 |

The sun's being straight up at noon is the most popular misconception revealed by this survey, being chosen by 999 participants. It is one of the few misconceptions which actually increased in popularity with age. It is more popular with whites than minorities, and with males more than with females. It was chosen by all but one of the 22 members of one eighth grade honors class and all but one of the 13 graduate students who were teachers.

Table 10b. Percent of Subgroups Holding Misconception d and the Scientific Conception in Question 5.

| | misconception d | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 82.4) | ($\bar{M}$ = 6.3) |
| Gender: males | 83.6 | 7.3 |
| females | 81.2 | 5.3 |
| Race: white | 88.9 | 6.1 |
| black | 64.2 | 5.7 |
| Hispanic | 77.4 | 7.1 |
| Location: urban | 74.2 | 5.9 |
| suburban | 88.3 | 6.3 |
| Level: 5th grade | 69.4 | 7.5 |
| 8th grade | 85.7 | 5.1 |
| 11th grade | 85.9 | 6.8 |
| no earth science | 88.4 | 2.3 |
| earth science | 84.5 | 9.2 |
| college | 87.6 | 7.1 |
| no earth science | 97.9 | 2.1 |
| H.S. earth science | 84.2 | 10.5 |
| univ earth science | 83.5 | 8.2 |
| both earth science | 91.2 | 5.9 |
| trade school | 94.6 | 2.2 |

Table 11a. Question 6 Responses.

| | Frequency: | Percent: |
|---|---|---|
| In May, June, and July, the sun sets: | | |
| a. in the north. | 90 | 7.4 |
| ++ b. in the north-west. | 224 | 18.5 |
| c. in the west. | 711 | 58.6** |
| d. in the south-west. | 177 | 14.6 |
| no answer or more than one answer marked: | 11 | .9 |

Misconception c, that in May, June, and July, the sun sets in the west, was subscribed to by more white than minority participants, more suburban than urban participants. It increased with age of the participants and was most subscribed to by those who had taken a college level earth science course. Black participants were most likely to choose the scientific conception.

Table 11b. Percent of Subgroups Holding Misconception c and the Scientific Conception in Question 6.

| | | misconception c | scientific conception |
|---|---|---|---|
| | | ($\overline{M}$ = 58.6) | ($\overline{M}$ = 18.5) |
| Gender: | males | 60.8 | 18.8 |
| | females | 56.5 | 18.0 |
| Race: | white | 68.8 | 13.8 |
| | black | 42.5 | 28.5 |
| | Hispanic | 39.6 | 24.1 |
| Location: | urban | 46.9 | 24.0 |
| | suburban | 66.5 | 14.6 |
| Level: | 5th grade | 42.3 | 21.8 |
| | 8th grade | 57.0 | 22.8 |
| | 11th grade | 61.2 | 20.6 |
| | no earth science | 60.5 | 20.2 |
| | earth science | 61.2 | 20.9 |
| | college | 73.5 | 10.2 |
| | no earth science | 72.9 | 4.2 |
| | H.S. earth science | 70.2 | 10.5 |
| | univ earth science | 75.3 | 14.1 |
| | both earth science | 73.5 | 8.8 |
| | trade school | 69.6 | 10.9 |

| Table 12a. Question 7 Responses. | Frequency: | Percent: |
|---|---|---|
| The different shapes (or phases) of the moon are caused by: | | |
| a. weather on the earth. | 74 | 6.1 |
| b. the shadow of the earth falling on the moon. | 584 | 48.1** |
| ++ c. the lighted half of the moon sometimes facing away from us. | 416 | 34.3 |
| d. the large dark craters that are on the moon. | 122 | 10.1 |
| no answer or more than one answer marked: | 17 | 1.4 |

That the phases of the moon are caused by the earth's shadow, was the fifth most popular misconception in this survey. It was chosen by more than 50% of 12 subgroups below. Its popularity increased with age. It was more accepted by white participants than minorities, and by males more than females. High School students without an earth science class were less likely to have the misconception than those who had.

Table 12b. Percent of Subgroups Holding Misconception b and the Scientific Conception in Question 7.

| | misconception b ($\overline{M}$ = 48.1) | scientific conception ($\overline{M}$ = 34.3) |
|---|---|---|
| Gender: males | 50.6 | 35.0 |
| females | 45.5 | 33.4 |
| Race: white | 54.7 | 33.9 |
| black | 36.3 | 35.8 |
| Hispanic | 39.2 | 32.1 |
| Location: urban | 42.6 | 31.4 |
| suburban | 50.2 | 37.7 |
| Level: 5th grade | 30.0 | 33.9 |
| 8th grade | 39.2 | 44.3 |
| 11th grade | 54.1 | 34.7 |
| no earth science | 53.5 | 35.7 |
| earth science | 54.4 | 34.0 |
| college | 69.5 | 26.1 |
| no earth science | 75.0 | 22.9 |
| H.S. earth science | 71.9 | 26.3 |
| univ earth science | 63.5 | 29.4 |
| both earth science | 73.5 | 20.6 |
| trade school | 55.4 | 30.4 |

| Table 13a. Question 8 Responses. | Frequency: | Percent: |
|---|---|---|
| The moon shines because it: | | |
| ++ a. reflects sunlight. | 857 | 70.7 |
| b. makes its own light like the sun. | 115 | 9.5* |
| c. is like a star, just bigger. | 191 | 15.7* |
| d. is so very hot that it glows. | 44 | 3.6 |
| no answer or more than one answer marked: | 6 | .5 |

Two secondary misconceptions were identified by the results to this question. Both were chosen more by females than males, and by minorities far more than by whites. Neither decreases noticably with level of education. Grade level made little difference, but trade school participants were much less likely to have misconception c than other students.

Table 13b. Percent of Subgroups Holding Misconceptions b and c and the Scientific Conception in Question 8.

| | misconception b | misconception c | scientific conception |
|---|---|---|---|
| | ($\bar{M}$ = 9.5) | ($\bar{M}$ = 15.7) | ($\bar{M}$ = 70.7) |
| Gender: males | 6.6 | 10.4 | 79.7 |
| females | 12.4 | 21.1 | 61.5 |
| Race: white | 6.1 | 10.7 | 80.9 |
| black | 18.1 | 25.9 | 49.7 |
| Hispanic | 14.2 | 25.0 | 53.3 |
| Location: urban | 14.5 | 23.4 | 56.4 |
| suburban | 5.8 | 10.5 | 81.0 |
| Level: 5th grade | 10.7 | 16.6 | 65.8 |
| 8th grade | 11.4 | 14.3 | 68.4 |
| 11th grade | 7.1 | 16.8 | 74.4 |
| no earth science | 10.1 | 20.2 | 69.0 |
| earth science | 5.3 | 14.6 | 77.7 |
| college | 9.3 | 16.8 | 71.2 |
| no earth science | 4.2 | 22.9 | 68.8 |
| H.S. earth science | 5.3 | 8.8 | 82.5 |
| univ earth science | 17.6 | 15.3 | 64.7 |
| both earth science | 2.9 | 20.6 | 76.5 |
| trade school | 8.7 | 9.8 | 79.3 |

Table 14a. Question 9 Responses.

| When we have a full moon, people that same night in Australia: | Frequency: | Percent: |
|---|---|---|
| ++ a. will also have a full moon. | 368 | 30.3 |
| b. will have a different phase of the moon. | 642 | 52.9** |
| c. won't be able to see the moon at all because of clouds. | 67 | 5.5 |
| d. will have a full moon, but only for half the night. | 120 | 9.9 |
| no answer or more than one answer marked: | 16 | 1.4 |

Misconception b, the fourth most common misconception revealed in this survey, was cited as correct by more than half of all subgroups except urban participants (who, more than the other groups, chose distracter d) and college students, who were most likely to name the scientific conception. The popularity of the scientific conception increases with the level of schooling.

Table 14b. Percent of Subgroups Holding Misconception b and the Scientific Conception in Question 9.

| | misconception b | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 52.9) | ($\bar{M}$ = 30.3) |
| Gender: males | 50.9 | 32.7 |
| females | 55.0 | 28.0 |
| Race: white | 54.0 | 35.6 |
| black | 50.3 | 22.3 |
| Hispanic | 50.5 | 21.2 |
| Location: urban | 48.6 | 27.7 |
| suburban | 55.9 | 32.6 |
| Level: 5th grade | 52.1 | 20.2 |
| 8th grade | 57.4 | 22.8 |
| 11th grade | 55.0 | 35.6 |
| no earth science | 51.9 | 36.4 |
| earth science | 57.3 | 34.5 |
| college | 46.5 | 41.2 |
| no earth science | 43.8 | 41.7 |
| H.S. earth science | 38.6 | 54.4 |
| univ earth science | 50.6 | 31.8 |
| both earth science | 55.9 | 38.2 |
| trade school | 54.3 | 35.9 |

Table 15a. Question 10 Responses.

| It takes about one ______ for the moon to go around the earth one time. | Frequency: | Percent: |
|---|---|---|
| a. hour | 22 | 1.8 |
| b. day | 435 | 35.9* |
| ++ c. month | 511 | 42.1 |
| d. year | 237 | 19.5* |
| no answer or more than one answer marked: | 8 | .7 |

Two secondary misconceptions were identified by this question. Both were chosen more by minorities than by whites and similarly by urbanites more than by suburbanites. Misconception b was chosen more by males and misconception c more by females. Both misconceptions become less popular with age. College students with both levels of earth science were most likely to have the scientific conception.

Table 15b. Percent of Subgroups Holding Misconceptions b and d and the Scientific Conception in Question 10.

| | misconception b | misconception d | scientific conception |
|---|---|---|---|
| | ($\overline{M}$ = 35.9) | ($\overline{M}$ = 19.5) | ($\overline{M}$ = 42.1) |
| Gender: males | 38.6 | 15.1 | 44.7 |
| females | 33.3 | 24.1 | 39.4 |
| Race: white | 32.8 | 14.0 | 51.8 |
| black | 39.4 | 33.2 | 21.8 |
| Hispanic | 45.8 | 27.8 | 24.5 |
| Location: urban | 39.5 | 27.5 | 29.5 |
| suburban | 34.2 | 14.2 | 50.4 |
| Level: 5th grade | 43.6 | 30.3 | 20.5 |
| 8th grade | 38.8 | 19.0 | 40.9 |
| 11th grade | 34.7 | 17.6 | 46.8 |
| no earth science | 41.1 | 17.1 | 41.9 |
| earth science | 31.1 | 17.5 | 50.5 |
| college | 27.4 | 12.8 | 58.8 |
| no earth science | 25.0 | 10.4 | 64.6 |
| H.S. earth science | 35.1 | 10.5 | 54.4 |
| univ earth science | 27.1 | 14.1 | 56.5 |
| both earth science | 20.6 | 11.8 | 67.6 |
| trade school | 25.0 | 9.8 | 60.9 |

Table 16a. Question 11 Responses.

| | Frequency: | Percent: |
|---|---|---|
| Venus, Mars, and Jupiter are planets. We can often see them at night: | | |
| a. but only after midnight. | 35 | 2.9 |
| b. but only with a telescope or a pair of binoculars. | 503 | 41.5* |
| c. because every night they are in the same place in the sky. | 110 | 9.1* |
| ++ d. because they are often brighter than the brightest stars. | 554 | 45.7 |
| no answer or more than one answer marked: | 11 | .9 |

Misconception b was chosen more often by females, and misconception c by males. Blacks were more likely than the other racial groups to accept misconception b and less likely to accept misconception c. Misconception b decreases with age, yet is more popular than the scientific conception in six subgroups. College students with earth science classes were most likely to subscribe to the scientific conception.

Table 16b. Percent of Subgroups Holding Misconception b and c and the Scientific Conception in Question 11.

| | misconception b | misconception c | scientific conception |
|---|---|---|---|
| | ($\bar{M}$ = 41.5) | ($\bar{M}$ = 9.1) | ($\bar{M}$ = 45.7) |
| Gender: males | 37.1 | 10.9 | 47.5 |
| females | 46.5 | 7.0 | 43.8 |
| Race: white | 32.9 | 9.0 | 54.9 |
| black | 60.6 | 8.8 | 26.9 |
| Hispanic | 56.1 | 9.4 | 29.2 |
| Location: urban | 52.0 | 11.3 | 32.8 |
| suburban | 34.4 | 7.6 | 54.9 |
| Level: 5th grade | 50.8 | 11.7 | 30.9 |
| 8th grade | 47.3 | 7.2 | 42.2 |
| 11th grade | 36.8 | 7.1 | 55.3 |
| no earth science | 38.8 | 8.5 | 51.9 |
| earth science | 36.4 | 5.8 | 56.8 |
| college | 35.0 | 9.3 | 53.5 |
| no earth science | 39.6 | 12.5 | 47.9 |
| H.S. earth science | 40.4 | 14.0 | 43.9 |
| univ earth science | 29.4 | 5.9 | 62.4 |
| both earth science | 35.3 | 5.9 | 52.9 |
| trade school | 32.6 | 10.9 | 52.2 |

Table 17a. Question 12 Responses.

| Falling or shooting stars are really: | Frequency: | Percent: |
|---|---|---|
| ++ a. rocks that are falling down to the earth. | 286 | 23.6 |
| b. stars that are falling down to the earth. | 292 | 24.1 |
| c. the same as asteroids. | 286 | 23.6 |
| d. the same as comets. | 343 | 28.3 |
| no answer or more than one answer marked: | 6 | .5 |

No misconceptions could be identified from the results to this question although it is possible that three of them do exist. However the frequencies are too similar to those which could also be received from purely random guessing. The popularity of no response is twice that of another. Males were more likely than females, and trade school students more than other level students, to accept the scientific conception.

Table 17b. Percent of Subgroups Holding Distracters b, c, and d and the Scientific Conception in Question 12.

| | distracters b | distracters c | distracters d | scientific conception |
|---|---|---|---|---|
| | ($\bar{M}$ = 24.1) | ($\bar{M}$ = 23.6) | ($\bar{M}$ = 28.3) | ($\bar{M}$ = 23.6) |
| Gender: males | 19.0 | 23.2 | 25.1 | 32.3 |
| females | 29.0 | 23.9 | 31.7 | 14.8 |
| Race: white | 21.3 | 26.9 | 26.6 | 24.5 |
| black | 30.6 | 16.6 | 31.6 | 20.7 |
| Hispanic | 28.8 | 18.9 | 29.2 | 23.1 |
| Location: urban | 29.7 | 16.2 | 30.5 | 23.4 |
| suburban | 19.3 | 28.3 | 28.1 | 23.8 |
| Level: 5th grade | 22.8 | 24.4 | 30.0 | 22.5 |
| 8th grade | 22.8 | 24.1 | 32.9 | 19.8 |
| 11th grade | 25.0 | 23.2 | 26.2 | 25.6 |
| no earth science | 20.9 | 20.9 | 36.4 | 21.7 |
| earth science | 26.7 | 25.2 | 19.9 | 28.2 |
| college | 24.3 | 23.9 | 27.4 | 23.5 |
| no earth science | 29.2 | 31.3 | 22.9 | 16.7 |
| H.S. earth science | 21.2 | 21.1 | 29.8 | 24.6 |
| univ earth science | 27.1 | 21.2 | 25.9 | 25.9 |
| both earth science | 17.6 | 26.5 | 29.4 | 26.5 |
| trade school | 26.1 | 22.8 | 18.5 | 31.5 |

Table 18a. Question 13 Responses.

| | Frequency: | Percent: |
|---|---|---|
| Earthquakes can be accurately predicted by: | | |
| a. observing stars and planets. | 68 | 5.6 |
| b. listening for loud thunder. | 45 | 3.7 |
| c. observing the behavior of wild animals. | 187 | 15.4* |
| ++ d. earthquakes cannot be accurately predicted by any of these methods. | 897 | 73.9 |
| no answer or more than one answer marked: | 16 | 1.4 |

The scientific conception for this question was the most accepted on the survey, yet was chosen less by 11th graders who had taken earth science than those who had not. There was little difference in the popularity of the misconception across gender or the different racial groups. Trade school students were most likely to accept the scientific conception and least likely to subscribe to the misconception.

Table 18b. Percent of Subgroups Holding Misconception c and the Scientific Conception in Question 13.

| | misconception c | scientific conception |
|---|---|---|
| | ($\overline{M}$ = 15.4) | ($\overline{M}$ = 73.9) |
| Gender: males | 15.4 | 75.2 |
| females | 15.3 | 72.8 |
| Race: white | 15.9 | 76.3 |
| black | 14.5 | 66.8 |
| Hispanic | 13.7 | 74.1 |
| Location: urban | 13.7 | 73.0 |
| suburban | 17.2 | 73.7 |
| Level: 5th grade | 17.6 | 61.6 |
| 8th grade | 18.1 | 74.7 |
| 11th grade | 14.4 | 77.9 |
| no earth science | 11.6 | 80.6 |
| earth science | 16.0 | 76.2 |
| college | 15.5 | 79.6 |
| no earth science | 27.1 | 66.7 |
| H.S. earth science | 12.3 | 82.5 |
| univ earth science | 10.6 | 85.9 |
| both earth science | 14.7 | 79.4 |
| trade school | 4.3 | 87.0 |

Table 19a. Question 14 Responses.

| | Frequency: | Percent: |
|---|---|---|
| The terrible floods that occur along a river: | | |
| a. occur only once every 100 years. | 120 | 9.9 |
| ++ b. can be caused by man. | 452 | 37.3 |
| c. occur only when snow melts in the spring. | 408 | 33.6* |
| d. are worst during a full moon. | 216 | 17.8 |
| no answer or more than one answer marked: | 17 | 1.5 |

Misconception c was chosen more often by males than females and minorities than whites. There was an increase in the popularity of the scientific conception with age. The taking of an earth science class often was associated with a greater subscription to the misconception. There was an increase in acceptance of the scientific conception with each higher level of education.

Table 19b. Percent of Subgroups Holding Misconceptions c and d and the Scientific Conception in Question 14.

| | misconception c | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 33.6) | ($\bar{M}$ = 37.3) |
| Gender: males | 35.0 | 37.4 |
| females | 32.1 | 37.2 |
| Race: white | 31.0 | 41.9 |
| black | 39.4 | 25.9 |
| Hispanic | 37.7 | 33.5 |
| Location: urban | 37.3 | 32.2 |
| suburban | 30.8 | 41.4 |
| Level: 5th grade | 38.1 | 27.7 |
| 8th grade | 38.4 | 35.9 |
| 11th grade | 29.4 | 40.6 |
| no earth science | 27.1 | 40.3 |
| earth science | 30.6 | 40.8 |
| college | 27.0 | 47.8 |
| no earth science | 25.0 | 54.2 |
| H.S. earth science | 17.5 | 49.1 |
| univ earth science | 34.1 | 41.2 |
| both earth science | 26.5 | 52.9 |
| trade school | 39.1 | 35.9 |

| Table 20a. Question 15 Responses. | Frequency: | Percent: |
|---|---|---|
| If a crystal can scratch glass, then: | | |
| a. it is a diamond. | 539 | 44.4* |
| b. it is not a diamond. | 43 | 3.5 |
| ++ c. it may be a diamond. | 570 | 47.0 |
| d. it probably is not a diamond. | 47 | 3.9 |
| no answer or more than one answer marked: | 14 | 1.1 |

Females chose this misconception more often than males and minorities more often than whites. It was chosen more often than the scientific conception by eight of the subgroups listed below. The misconception became less popular with age except with trade school participants. Those who had taken earth science classes were least likely to have this misconception.

Table 20b. Percent of Subgroups Holding Misconception a and the Scientific Conception in Question 15.

| | misconception a | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 44.4) | ($\bar{M}$ = 47.0) |
| Gender: males | 41.0 | 50.1 |
| females | 48.0 | 43.8 |
| Race: white | 40.7 | 53.2 |
| black | 46.1 | 37.3 |
| Hispanic | 53.8 | 36.3 |
| Location: urban | 48.0 | 40.4 |
| suburban | 43.2 | 50.4 |
| Level: 5th grade | 54.4 | 32.2 |
| 8th grade | 50.6 | 39.7 |
| 11th grade | 39.1 | 55.9 |
| no earth science | 44.2 | 51.2 |
| earth science | 36.4 | 58.3 |
| college | 29.6 | 64.6 |
| no earth science | 35.4 | 56.3 |
| H.S. earth science | 38.6 | 56.1 |
| univ earth science | 24.7 | 69.4 |
| both earth science | 17.6 | 79.4 |
| trade school | 51.1 | 40.2 |

| Table 21a. Question 16 Responses. | Frequency: | Percent: |
|---|---|---|
| Right now, the direction, north, is: | | |
| ++ a. toward the front of this room. | 398 | 32.8 |
| ++ b. toward the back of this room. | 247 | 20.4 |
| ++ c. toward my left. | 303 | 25.0 |
| ++ d. toward my right. | 195 | 16.1 |
| e. straight up. | 57 | 4.7*F |
| no answer or more than one answer marked: | 13 | 1.0 |

The correct answer for this question was based on the orientation of each particular classroom. If a student chose a wrong answer, but still chose answers a through d, he was expressing misinformation. Only students who responded with answer e held a misconception. This misconception was chosen more by females, blacks, and Hispanics than other subgroups. Its popularity decreased with age. It is the only misconception completely unaccepted by any of the adult subgroups.

Table 21b. Percent of Subgroups Holding Misconception e in Question 16.

| | | $(\bar{M} = 4.7)$ | |
|---|---|---|---|
| Gender: | males | 2.4 | |
| | females | 7.1 | |
| Race: | white | 1.4 | |
| | black | 14.0 | |
| | Hispanic | 8.5 | |
| Location: | urban | 9.0 | |
| | suburban | 1.3 | |
| Level: | 5th grade | 11.4 | |
| | 8th grade | 4.6 | |
| | 11th grade | 2.4 | |
| | no earth science | | 3.9 |
| | earth science | | 1.5 |
| | college | .9 | |
| | no earth science | | 2.1 |
| | H.S. earth science | | .0 |
| | univ earth science | | 1.2 |
| | both earth science | | .0 |
| | trade school | 1.1 | |

Table 22a. Question 17 Responses.

| The dinosaurs: | Frequency: | Percent: |
|---|---|---|
| ++ a. lived long before cave-men. | 751 | 61.9 |
| b. lived at the same time as cave-men. | 396 | 32.6* |
| c. are still living someplace on earth. | 27 | 2.2 |
| d. never lived anywhere on earth. | 23 | 1.9 |
| no answer or more than one answer marked: | 16 | 1.4 |

Misconception b that the dinosaurs lived at the same time as cave men was accepted by about one in three persons in every subgroup except college students. Minorities were more likely to opt for it than white participants, and relatedly, city dwellers more than suburbanites. High school students with an earth science class were more likely to have this misconception than those without.

Table 22b. Percent of Subgroups Holding Misconception b and the Scientific Conception in Question 17.

| | misconception b | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 32.6) | ($\bar{M}$ = 61.9) |
| Gender: males | 31.6 | 62.2 |
| females | 33.8 | 61.6 |
| Race: white | 30.0 | 65.5 |
| black | 36.8 | 56.5 |
| Hispanic | 38.2 | 54.7 |
| Location: urban | 37.3 | 56.8 |
| suburban | 30.2 | 65.8 |
| Level: 5th grade | 31.9 | 59.0 |
| 8th grade | 38.4 | 59.9 |
| 11th grade | 34.7 | 60.9 |
| no earth science | 27.1 | 69.0 |
| earth science | 38.8 | 56.3 |
| college | 23.9 | 72.6 |
| no earth science | 31.1 | 66.7 |
| H.S. earth science | 21.1 | 73.7 |
| univ earth science | 20.0 | 76.5 |
| both earth science | 29.4 | 67.6 |
| trade school | 34.8 | 55.4 |

Table 23a. Question 18 Responses.

| | Frequency: | Percent: |
|---|---|---|
| It is possible that in the near future Chicago could be severely damaged by: | | |
| ++ a. either a tornado or an earthquake. | 622 | 51.3 |
| b. neither a tornado nor an earthquake. | 132 | 10.9 |
| c. a tornado, but not an earthquake. | 311 | 25.6* |
| d. an earthquake, but not a tornado. | 121 | 10.0 |
| no answer or more than one answer marked: | 27 | 2.2 |

Males more so than females subscribed to this misconception. Of the racial groups, blacks were most likely and Hispanic least likely to hold it. There was no noticeable pattern related to level of schooling, but college students with a university level earth science course were most likely to subscribe to this no-earthquake misconception and were also among those least likely to subscribe to the scientific conception.

Table 23b. Percent of Subgroups Holding Misconception c and the Scientific Conception in Question 18.

| | misconception c | scientific conception |
|---|---|---|
| | ($\bar{M}$ = 25.6) | ($\bar{M}$ =51.3) |
| Gender: males | 27.6 | 47.8 |
| females | 23.9 | 54.8 |
| Race: white | 26.6 | 54.0 |
| black | 30.1 | 50.3 |
| Hispanic | 18.9 | 42.5 |
| Location: urban | 25.0 | 48.8 |
| suburban | 26.5 | 53.2 |
| Level: 5th grade | 17.3 | 51.8 |
| 8th grade | 30.4 | 43.9 |
| 11th grade | 30.6 | 52.1 |
| no earth science | 31.0 | 51.9 |
| earth science | 30.1 | 52.4 |
| college | 28.3 | 56.6 |
| no earth science | 18.8 | 64.6 |
| H.S. earth science | 19.3 | 70.2 |
| univ earth science | 38.8 | 44.7 |
| both earth science | 29.4 | 52.9 |
| trade school | 16.3 | 55.4 |

## Analysis of the Subgroups

The purpose of this section is to answer the secondary research question: Do gender, race, educational level, urban versus suburban location, last grade received in science, and the exposure to earth science courses affect misconceptions in the earth and space sciences?

In order to do this all participants were asked to describe themselves by gender, race, educational level, location of residence (e.g. urban, suburban), and last grade received in science. High school students were asked whether they had taken, or were currently taking a high school earth science course. College students were also asked if they had taken, or were currently taking such a course, and if so, at what level (high school only, university level only, or both levels).

The results contained in this section are the average (mean) number of common misconceptions held by each subgroup of the sample. It is noted that this is not the same as the average number of wrong answers. For these purposes, a student has a common misconception only when one of the misconceptions listed in Tables 3, 4, or 5 is chosen. The maximum number of misconceptions possible for any one person or subgroup is 17, one for each question on the instrument except question 12 which had no proven misconceptions.

The results by subgroup are displayed in the 12 tables which follow. It should be noted that a smaller number of misconceptions in any of the tables which follow may, but does not necessarily, infer that a concept was better understood. Fifth graders, in particular, held to fewer misconceptions than did eighth graders in all six subgroups in Table 24 below; they also chose the scientific conception less often as well. The small number of misconceptions is a reflection, in this case, of a greater amount of random guessing.

Following the results about misconceptions for each subgroup, the average number of correctly identified scientific conceptions will be given.

Table 24. Total Misconceptions Analyzed by Gender

$H_0 2$: There is no difference in misconceptions across gender.

| Gender: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| Male | 617 | 12 | 0 | 6.64 | 2.06 | -.115 |
| Female | 589 | 14 | 1 | 6.97 | 1.89 | -.043 |

Results of this study show that males held fewer misconceptions than females. Analysis of variance showed that this difference was significant at alpha = 0.01. The summary table may be seen in Appendix D. The F ratio was 8.16 with a probability of 0.004. The null hypothesis is rejected. See Tables 26, 28, and 32 for a breakdown of gender across race, location, and educational level. For comparison purposes, the means of scientific conception acceptance by gender are listed here:

Males 8.57 Females 7.74

Table 25. Total Misconceptions Analyzed by Race

$H_0 3$: There is no difference in misconceptions across race.

| Race: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| White | 759 | 14 | 1 | 6.64 | 2.00 | .053 |
| Black | 193 | 11 | 1 | 7.10 | 1.99 | -.256 |
| Hispanic | 212 | 12 | 2 | 7.18 | 1.78 | -.162 |

White participants were shown by the results to have held fewer misconceptions than blacks, and blacks fewer than Hispanics. Analysis of variance showed that there was a significant difference between the three racial groups with alpha equal to 0.01. The summary table may be seen in Appendix D. The F ratio was 8.91 which had a probability of 0.0001. Therefore null hypothesis three is also rejected. See Tables 26, 28, and 39 for a breakdown of race across gender, educational level, and location.

A Tukey-b multiple comparison test on this data showed that the differences across grade level are significant at the 0.05 level only between white participants and the two minority groups, but not between blacks and Hispanics. For comparison purposes, the means of scientific conception acceptance by race are listed here:

White: 8.87 Black: 6.80 Hispanic: 6.94

Table 26. Total Misconceptions Analyzed by Race and Gender

| Race/Gender: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| White male | 412 | 12 | 1 | 6.47 | 2.08 | -.058 |
| Black male | 83 | 11 | 3 | 7.24 | 2.03 | -.011 |
| Hispanic male | 95 | 11 | 2 | 6.82 | 1.88 | -.103 |
| White female | 346 | 14 | 3 | 6.82 | 1.90 | .297 |
| Black female | 110 | 11 | 1 | 7.00 | 1.97 | -.395 |
| Hispanic female | 116 | 12 | 3 | 7.30 | 1.72 | -.167 |

Results broken down by race and gender indicate that white and Hispanic females held more misconceptions than white and Hispanic males, however black males held more misconceptions than black females. For comparison purposes, the means of scientific conception acceptance by gender and race are listed here:

White male: 9.18 Black male: 7.12 Hispanic male: 7.22

White female: 8.50 Black female: 6.56 Hispanic female: 6.73

Table 27. Total Misconceptions Analyzed by Educational Level

$H_o4$: There is no difference in misconceptions across educational level.

| Level: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| 5th grade | 307 | 14 | 1 | 6.97 | 1.91 | .089 |
| 8th grade | 237 | 11 | 0 | 7.09 | 1.95 | -.177 |
| 11th grade | 340 | 11 | 1 | 6.65 | 1.03 | -.203 |
| College | 226 | 12 | 1 | 6.43 | 2.01 | .012 |
| Trade | 92 | 12 | 3 | 7.00 | 2.03 | -.178 |

Eighth grade students hold more misconceptions than other educational levels. Although fifth graders are shown here to have fewer misconceptions than eighth grade, the data below shows that they also held fewer scientific conceptions as well. An analysis of variance showed that there was a significant difference across grade levels. The summary table may be seen in Appendix D. The F ratio was 4.49 which had a probability of 0.001. Therefore null hypothesis four is rejected. Tables 28, 30, 32, 34, and 39 show educational level broken down across race, gender, location, and exposure to earth science courses.

A Tukey-b multiple comparison test on this data showed that the differences across grade level are significant at the 0.05 level only between the college level and the fifth and eighth grades.

For comparison purposes, the means of scientific conception acceptance by educational level are listed here. It shows how scientific conception compares with educational level.

5th grade: 6.76 8th grade: 7.85 11th grade: 8.85

College: 9.31 Trade school: 8.52

Table 28 below displays the data above broken down by educational level, race, and gender.

Table 28. Number of Misconceptions by Gender, Race, and Level

| | White | | Black | | Hispanic | |
|---|---|---|---|---|---|---|
| Grade level: | M | F | M | F | M | F |
| 5th grade | 7.31 | 7.20 | 7.10 | 6.38 | 6.54 | 6.98 |
| 8th grade | 6.80 | 7.20 | 7.55 | 6.91 | 7.33 | 7.52 |
| 11th grade | 5.98 | 6.50 | 7.75 | 7.82 | 7.22 | 7.43 |
| College | 5.92 | 6.70 | 6.67 | 6.89 | 6.20 | 7.00 |
| Trade school | 6.72 | 7.00 * | 5.50 * | 8.33 * | 7.57 | 8.11 |

* denotes a cell with fewer than 5 persons

Table 29. Total Misconceptions Analyzed by Location

$H_o5$: There is no difference in misconceptions between urban and suburban students.

| Location: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| Urban | 488 | 12 | 1 | 7.06 | 1.88 | -.190 |
| Suburban | 669 | 14 | 0 | 6.64 | 2.04 | -.027 |

Urban residents held more misconceptions than suburbanites. An analysis of variance showed that the difference was significant with alpha = 0.01. The summary table may be seen in Appendix D. The F ratio was 13.04 which had a probability of 0.0003. Therefore null hypothesis five is rejected. Tables 30, 31, 32, and 39 show location broken down by educational level, high school, and gender. For comparison purposes, the means of scientific conception acceptance by location are listed:

Urban: 7.28 Suburban: 8.78

Table 30. Total Misconceptions Analyzed by Location and Level

| Location/Level: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| Urban 5th | 142 | 11 | 1 | 6.78 | 1.82 | -.295 |
| Suburban 5th | 162 | 14 | 2 | 7.16 | 1.98 | .281 |
| Urban 8th | 105 | 11 | 1 | 7.36 | 1.98 | -.267 |
| Suburban 8th | 132 | 11 | 0 | 6.87 | 1.91 | -.134 |
| Urban 11th | 115 | 11 | 2 | 7.42 | 1.85 | -.438 |
| Suburban 11th | 212 | 11 | 1 | 6.24 | 1.98 | -.080 |
| Urban college | 82 | 11 | 3 | 6.65 | 1.76 | .015 |
| Suburban college | 127 | 12 | 1 | 6.31 | 2.16 | .052 |
| Urban trade | 39 | 12 | 3 | 7.10 | 2.01 | .200 |
| Suburban trade | 33 | 12 | 3 | 6.97 | 2.27 | .176 |

Urban students held more misconceptions at every level other than 5th grade. For urban students, the number of misconceptions increases with educational level up through 11th grade. For suburban students the number of misconceptions decreases with level of education through 11th grade. The suburban 11th grade category contained nearly twice as many participants as the urban 11th grade category because of the inclusion of the private high school in Lansing, Illinois. To show how much variance is accounted for by this school, the 11th grade statistics, broken down by individual school are reported below.

Table 31. Total High School Misconceptions Analyzed by School

| High School: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| E. C. Central | 115 | 11 | 2 | 7.40 | 1.85 | -.477 |
| Munster | 110 | 11 | 2 | 6.51 | 1.92 | -.104 |
| Illiana | 102 | 11 | 1 | 5.95 | 2.01 | -.222 |

Results indicate that East Chicago Central students held more misconceptions than suburban Munster high school students, who in turn held more misconceptions than Illiana Christian students.

For comparison purposes, the means of scientific conception acceptance by level of education are listed here:

| | | | |
|---|---|---|---|
| Urban 5th | 6.26 | Suburban 5th | 7.23 |
| Urban 8th | 6.83 | Suburban 8th | 8.67 |
| Urban 11th | 7.37 | Suburban 11th | 9.61 |
| | | (Munster | 9.40) |
| | | (Illiana | 9.83) |
| Urban college | 9.13 | Suburban college | 9.44 |
| Urban trade | 8.26 | Suburban trade | 9.00 |

Table 32. Number of Misconceptions by Gender, Location, and Level

| | Urban students | | Suburban students | |
|---|---|---|---|---|
| Grade level: | M | F | M | F |
| 5th grade | 6.87 | 6.71 | 7.11 | 7.22 |
| 8th grade | 7.60 | 7.21 | 6.59 | 7.22 |
| 11th grade | 7.17 | 7.63 | 6.09 | 6.43 |
| College | 6.60 | 6.69 | 5.56 | 6.79 |
| Trade school | 6.50 | 8.07 | 6.97 | ---- |

There were no female, suburban, trade school students.

All other cells represent at least fifteen participants.

Table 33. Total Misconceptions Analyzed by Earth Science Courses Taken

$H_o6$: There is no difference in misconceptions across exposure to earth science classes.

| Level/Course: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| no earth science | 207 | 12 | 2 | 6.84 | 2.05 | .056 |
| high school only | 304 | 12 | 1 | 6.59 | 2.07 | -.175 |
| university only | 89 | 11 | 1 | 6.31 | 1.99 | .130 |
| both levels | 38 | 9 | 2 | 6.32 | 1.77 | -.386 |

A analysis of variance showed that there was no significant difference between any of the subgroups above. The summary table may be seen in Appendix D. The F ratio was 1.7857 which had a probability of only 0.1486. Therefore null hypothesis six is not rejected.

It is recognized that one reason for there being no significant difference is that high school students and college students were combined above. Table 34 shows the results when the groups are broken down both by course and level of education.

Table 34. Total Misconceptions Analyzed by Earth Science Courses Taken Broken down by Grade Level

| Level/Course: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| 11th graders | | | | | | |
| no earth science | 129 | 11 | 2 | 6.77 | 1.90 | -.133 |
| earth science | 206 | 11 | 1 | 6.54 | 2.08 | -.244 |
| College students | | | | | | |
| none | 48 | 12 | 3 | 6.88 | 2.33 | .073 |
| high school only | 57 | 10 | 1 | 6.30 | 2.04 | -.237 |
| university only | 85 | 11 | 1 | 6.28 | 1.91 | .059 |
| both levels | 34 | 9 | 2 | 6.38 | 1.69 | -.367 |

An analysis of variance using both educational level and courses as independent variables showed that there was still no significant difference between the subgroups above. This summary table may be seen as well in Appendix D.

For comparison purposes, the means of scientific conception acceptance by educational level are listed:

| | | | |
|---|---|---|---|
| 11th graders | | College students | |
| no earth science | 8.60 | none | 9.00 |
| earth science | 9.02 | high school only | 9.53 |
| | | university only | 9.27 |
| | | both levels | 9.50 |

Table 35. Total Misconceptions Analyzed by Last Science Grade Received

$H_o7$: There is no difference in misconceptions across last science grade received.

| Grade: | N: | Maximum: | Minimum: | Mean: | StdDev: | Skewness: |
|---|---|---|---|---|---|---|
| A | 242 | 12 | 1 | 6.43 | 2.12 | .064 |
| B | 451 | 12 | 0 | 6.88 | 1.96 | -.192 |
| C | 374 | 14 | 1 | 6.90 | 1.94 | .112 |
| D | 89 | 12 | 1 | 6.89 | 1.99 | -.345 |
| F | 22 | 10 | 4 | 6.73 | 1.39 | .186 |

A oneway analysis of variance showed that there was no significant difference in total misconceptions across the last grade received in science with alpha = 0.01. The summary table may be seen in Appendix D. The F ratio was 2.56 which had a probability of 0.0371. If alpha had been set at 0.05, it would have been significant. Null hypothesis seven is not rejected.

A Tukey-b multiple comparison test on this data showed that the differences across grade level are significant at the 0.05 level only between A students and B and C students.

For comparison purposes, the means of scientific conception acceptance by educational level are listed:

| | | | |
|---|---|---|---|
| A | 9.19 | D | 7.29 |
| B | 8.36 | F | 6.27 |

CHAPTER V

DISCUSSION

## Implications of the Questions and their Misconceptions

### Implications of Question 1:

Summer is warmer than winter, because in summer:
- a. the sky has fewer clouds.
- b. the earth is nearer the sun.
- c. the earth is better insulated.
- d. the sun is higher in the sky.

In a survey of 492 Texas high school seniors, Rollins, Dentn, and Janke (1983) found that the cause of the seasons was one of the least understood concepts for which they tested. Their study was concerned with concept attainment rather than misconceptions and thus a different form of questioning was used in their instrument. An example of their instrument item is contained in Table 36 below.

Table 36. Question about Seasons used by Rollins et al., 1983

The tilt of the Earth's axis is a cause of:
- a. the Coriolis Parameter
- b. earthquakes
- c. day and night
- d. the seasons

The problem posed by this question began the post-survey discussion in each class. Without exception, as about three out of four students in each class surveyed had selected answer b, the earth is nearer the sun, classes were surprised to learn that that is a misconception.

The concept of the changing seasons is often explained by textbooks and by teachers as being caused by the tilting of the earth's axis. Indeed one participant voiced the opinion during the survey that there was no correct answer for this question because the tilt was not one of the possible answers. The results of the survey seem to indicate that students do not understand that the earth's tilt causes the sun to be higher in the sky for part of the year and lower for another part. Many students justified answer b by the fact that in the summer, the northern hemisphere is somewhat closer to the sun than is the southern hemisphere. All students did agree that the warmest part of the day follows that time when the sun is the highest in the sky. They however had not transferred that concept to the changing seasons; most had never noticed that the sun is much higher in the sky in the summer than it is in the winter.

As noted in Chapter One, researchers have found that misconceptions are remarkably resistant to change (Ausubel, Novak, & Hanesian, 1978; Viennot, 1979). The tenacity of this particular misconception was demonstrated in many classrooms when, following the discussion of the above question, the author noted the fact that we are actually closest to the sun in the month of January and many students immediately expressed amazement.

Implications of Question 2.

Each day during the summer months, the amount of daylight:

a. is more than the day before.
b. is less than the day before.
c. is the same as the day before.
d. has nothing to do with the day before.

There seems to be an inherent feeling among many persons that because summer is warmer than winter, the length of daylight must be increasing. This in spite of the fact that most students are taught that June 21st (or whichever day is the summer solstice) is the longest day of the year. In one classroom discussion, a particular student, dismayed at the number of students who believed that daylight increases throughout the summer, vociferously proclaimed, "If June 21st is the longest day of the year, they can't get any longer."

Although schools are usually not in session at the time of the summer or winter solstice, teachers can help students overcome the misconception by having them research day length with the aid of an almanac or by doing problems associated with day length and the various seasons.

There was concern among some participants during the survey, that if June is considered a summer month (9 days of June do fall in summer) then no answer is entirely correct, for within the month of June the days get longer up until the summer solstice and then diminish after that. To answer such querries, summer months were defined as the months which follow the summer solstice. Although this was of apparent concern to only two participants, perhaps if this question had begun, "During the months of July and August," even that confusion would not have arisen.

Implications of Question 3.

We can know in advance if there is going to be a very cold winter by:

a. seeing how cold it was in the last winter.
b. seeing how hot it was in the last summer.
c. looking at the thickness of fur on some animals in the fall.
d. cold winters cannot be accurately predicted by any of these methods.

Thirty-three years ago, Kimble (1955) stated that the misconception that a cold winter can be predicted by the thickness of fur on some animals in the fall is part of the popular folklore. He noted that mule deer, woolly-bear caterpillars, and squirrels have all been used to predict the severity of the coming winter, but with no more success than "man has hitherto been." (p. 44) Data from this survey show that it is still believed by about 12% of the participants which might be due to the fact that it is still occasionally promulgated by persons on television talk shows. Students also claim to have heard it from parents and friends.

Posner et al. (1982) claimed that dissatisfaction with existing conceptions can lead to rejection of a misconception. This seemed to be provided in the post-survey class discussions with the question, "Suppose you found five woolly-bear caterpillars in the woods in the fall, and they had five different amounts of fur. Which one would predict the severity of the coming winter?"

Implications of Question 4.

We have day and night because:
- a. the sun goes around the earth.
- c. the earth goes around the sun.
- b. the moon goes around the earth.
- d. the earth spins on its axis.

Rollins et al. (1983) found that the conception of day and night was better understood by their 492 Texas high school seniors (at 79%) than was their conception of the seasons (at 67%). That same order of understanding was revealed by the participants of this study.

Until Copernicus postulated otherwise, the accepted conception of the cause of day and night was that the sun went around the earth. It might still be a much more popularly accepted conception if it weren't for scientists and teachers telling us otherwise.

Nussbaum and Novick (1982), Nussbaum (1983), and Wandersee (1985) have shown that student's cognitive development often parallels the history of scientific ideas. Day and night caused by an orbiting sun is such a misconception. This misconception was shown to be quite common among the elementary students, especially in urban classrooms where it reached 32.4%. It quickly decreases in acceptance with level of schooling as 18.1% of urban 8th graders, 7.8% of urban 11th graders, and only 2.4% of urban college students subscribed to the idea. Suburban students of every level except college students were less likely to believe this archaic idea than urban students.

This question was similar to one asked by NAEP in 1969 of 9 year old students. The percentages in Table 37 below reflect the number of students who answered each option.

Table 37. Responses by 9 year olds to a NAEP Question about Day and Night

One reason that there is day and night on Earth is that the

| | | | |
|---|---|---|---|
| 8% | Sun turns. | | |
| 4% | Moon turns. | 6% | Sun gets dark at night. |
| 81% | Earth turns. | 1% | I don't know. |

The NAEP question was not designed to identify misconceptions and the author believes that the reason for the high number of correct responses was due to the lack of three very plausible distracters.

Misconception a will continue to be chosen by students who observe the daily passing of the sun and have not been exposed to the scientific conception. Elementary school teachers who try to help students overcome this misconception may find themselves in the position described by Osborne, Bell, and Gilbert (1983) where the scientists' viewpoint may appear to the student to be <u>less</u> intelligible, plausible, and fruitful than the student's current belief. A good analogy for teachers to use is the apparent movement of nearby objects when one is moving in an automobile. The scientific conception of what causes day and night should be understood by greater than 66.8% of our population.

<u>Implications of Question 5</u>.

We can use the sun to tell time, because at 12:00 noon, the sun is:
a. in the eastern sky. c. in the southern sky.
b. in the western sky. d. directly overhead (straight up).

Braddock-Rogers and Braddock (1978) decry authors, producers, and editors who often depart from their fields of specialization and inadvertently promote scientific misconceptions. They include the sun's being straight up at noon as such a misconception, promulgated in print by Zane Grey in his novel, The Maverick Queen. The fact that this misconception, as shown by the results from this study, increases in popularity with age attests to its being reinforced by the community.

Most students were very surprised to learn that the sun has not been straight overhead one single day of their lives. Although many misconceptions, such as day and night being caused by the circling sun, are the result of logical reasoning patterns, this misconception seems to be the result of references in the media and erroneous teaching. Many participants could even name the particular teacher or scout leader who had told them that the noon sun is directly overhead. In this survey, 12 of the 13 teacher participants believed it to be so, as did 20 of the 32 teacher candidates.

Teachers can, of course, eliminate this misconception by direct observation of the sun or by using a sun-dial. Interestingly, there was a sun-dial in the courtyard of one of the suburban schools; it was in a courtyard visible from a distance, but off limits, to students. It was also positioned incorrectly.

Although in discussion, many students claimed to have heard of the Tropic of Cancer, few could explain that it is the furthest north on the earth where the sun is ever directly overhead. The discussion of this question always included references to the importance of knowing where the sun is at various parts of the day. The placing of shade trees on the south side of a house, as well as the southward orientation of solar panels was discussed.

It is recognized by the author that the answer to this question is contingent upon the location of the observer, that between the Tropics of Cancer and Capricorn the sun may be, on various days, north, south, or directly above the viewer, and that south of the Tropic of Capricorn the sun is in the northern sky at noon. Only one of the participants claimed to have ever lived south of the Tropic of Cancer, an (Asian) Indian student who had asked during the survey if the question was to be thought of as being from the latitude of northwest Indiana.

Implications of Question 6.

In May, June, and July, the sun sets:

a. in the north.
b. in the north-west.
c. in the west.
d. in the south-west.

Misconception c, that in May, June, and July, the sun sets in the west, is, like the sun's being believed to be straight up at noon, a culturally promoted misconception. This is reflected by the fact that it also increases, rather than decreases, in popularity with age. Everyone seems to know that the sun sets in the west, (as opposed to east, north, or south) and therefore believes that this means exactly west and every day of the year. Yet, as anyone could observe if he cared to, in these three months, especially near the 21st of June, the sun sets far north of west just as in the months around the 21st of December the sun sets in the southwest.

The conception of this phenomena seems to be lost to many even within the scientific community. Although Kuethe (1963) showed himself to be a man with great attention to detail, one of the 50 questions used in his study of sophisticated errors, which he called one of the "easiest" was "In what direction does the sun appear to rise?" He justifies the term, easiest, with the fact that 97 of the 100 subjects answered it correctly. Implicit in his argument is the answer is "east" as it would be "west" if the question were about sunset.

For six months following the vernal equinox (March 21st for most years) the sun sets north of true west. The sun is also above the horizon for more than 12 hours during this time period. The longer the day becomes, the farther north the sun both rises and sets. On the evening of the summer solstice (usually June 21), and from the latitude of the cities of Chicago and northwest Indiana, the sun sets at its farthest northern point, 32 degrees north of west (22.5 degrees, the halfway mark, being the angle separating "western" from "northwestern"). The sun sets north of 22.5 degrees from about May 5th in the spring to August 2nd in the summer.

The exact angular direction of sunrise and sunset are of little interest to most persons, yet everyone should be aware in general of the annual movements of the sun. There are times when knowledge of the sun and its location can be of benefit to people. It is to everyone's best interest to know that if one wishes to read an outdoor thermometer first thing in the morning, it should neither be placed in an eastern, northern nor southern window because all three exposures will receive morning sunlight at sometime during the year (northern from March through September, southern from September through March, eastern every day). Sunlight, of course, on a thermometer will give an inflated reading.

Photographers can photograph the north side of a building using natural sunlight only in the early mornings and late evenings of May, June, and July when the sun is far enough north to cast its rays on north-facing exteriors. While this fact may not be terribly relevant to most students, the fact that summer sun shines on the north side of a house in the morning also means that a house will remain cooler in the summer, if north-facing window shades are pulled in the very early morning.

In the same way as with the misconception about the overhead sun, the author believes that teachers can help eliminate this misconception by having students observe the sun at various times during the day.

<u>Implications of Question 7</u>.

The different shapes (or phases) of the moon are caused by:
- a. weather on the earth.
- b. the shadow of the earth falling on the moon.
- c. the lighted half of the moon sometimes facing away from us.
- d. the large dark craters that are on the moon.

Kuethe (1963) found that 70% of his subjects, all males who had recently been admitted to a college or university, had the misconception that the moon's phases are caused by the shadow of the earth. Twenty-four years later, Sadler (1987) found that 37% of his ninth grade students also had this misconception. Forty-eight percent of the participants in this survey ascribed to this belief, but the misconception became more popular with age, and at the college level was accepted by 69.5%, exceedingly close to Kuethe's figure 25 years ago.

Kuethe believes that the reason for this misconception is the fact that great emphasis is placed on the role of the earth's and moon's shadows during eclipses. He noted that the cause of the moon's phases is harder to understand and is less dramatic. Sadler noted that his participants attributed their ideas to their schooling. He believes that commonly published diagrams of the earth and moon, which never show the two objects in their true scale size and distance, contribute to the misconception. It might be added that planetaria sold by science supply houses also show the earth and moon being very close to each other. In all such models the moon is incorrectly in the earth's shadow several days each month.

Teachers could help students overcome this misconception if they would take their students outside on some clear day when the sun and moon were both visible. At such a time the moon is never full, and it can easily be seen that the earth is not between the sun and moon, and therefore its shadow cannot be falling on the moon.

Implications of Question 8.

The moon shines because it:
a. reflects sunlight.
b. makes its own light like the sun.
c. is like a star, just bigger.
d. is so very hot that it glows.

An integral part of understanding the causes of the lunar phases is the cause of moonlight itself. The conception that the moon shines because it reflects sunlight was the most subscribed to scientific conception about astronomy revealed by this survey. Yet the misconception that the moon is like a star, just bigger, was chosen by nearly one in four urban students and reveals not merely a misconception about the moon, but one about stars as well.

Objects that shine do so either because they reflect light or are luminous themselves. Answers b, c, and d are all variations of the false notion of the moon's being luminious. Results from NAEP testing in 1969 showed that 48% of nine year old children do not know that the sun is a star. Therefore, to be able to find all students who believed the moon to be luminous, (a term not known to most fifth graders) the misconception was stated in two forms on the survey, distracters b and c. When the results for these two responses are combined, more than 25% of fifth and eighth graders and more than 40% of blacks and Hispanics are shown to have the apparent misconception of luminosity.

Implications of Question 9.

When we have a full moon, people that same night in Australia:
a. will also have a full moon.
b. will have a different phase of the moon.
c. won't be able to see the moon at all because of clouds.
d. will have a full moon, but only for half the night.

Not one participant claimed to have ever thought of this concept before and therefore all had to try to figure out the answer from conceptions already held about the moon. All students who volunteered comments spoke to how difficult an exercise it was. Ault (1984a) noticed the same reaction and described how even science-education graduate students struggle when asked this question.

The post-survey classroom discussion about this question centered on two means of solving the problem. The author believes that the best way to approach the problem is to decenter one's spacial perspective; to imagine looking at the earth and moon from various points on the earth and from outer space. The moon is so far from the earth in relation to its diameter that no matter where on, or near, the earth one stands to observe the moon, it will look practically the same.

The second means of solving the problem, although not the means by which the author would approach it, is referring to the way a full moon is indicated on a calendar, specifically the absence of any "North America only" or other location-specific designation. The designation is not mentioned simply because it's not needed.

Implications of Question 10.

It takes about one _____ for the moon to go around the earth one time.
a. hour c. month
b. day d. year

The ancient world believed that the moon, like the sun, passed over the earth once every day. Casual observation by any person on the earth today might lead one to the same belief. In the same way that many participants, especially children held to the belief that the circling sun caused day and night, so they could be expected to believe that the moon daily circled the earth. By doing so, a person would be guilty only of what Ault (1984b) called being "intelligently wrong."

This misconception decreases with age as did the misconception about the circling sun, but to a much lesser extent. Even one in four adults subscribed to this misconception. Although not considered a primary misconception in this paper because it was subscribed to by fewer participants than the scientific conception, this misconception was chosen by fifth graders twice as often as the scientific conception.

Because of both air pollution and particularly the amount of outdoor light in cities, the night sky is plainly easier to see to persons in rural areas than it is from the cities. Persons in rural areas therefore might be expected to be more familiar with the moon than persons in cities. This was dramatically shown in the results of this survey where rural students, though small in number, opted for the scientific conception twice as often as urban students, and selected the misconception b only half as often.

Because the populous sections of Asia are closer to the Equator than Europe and therefore experience less seasonal change, many Asian cultures use a lunar calendar rather than our solar calendar. Although the sample of Asian participants in this survey was very small and was not reported in Chapter IV, it was no surprise to see that Asians chose the scientific conception more often than the any of the other racial groups.

The results of this question seem to show that for many persons, the changing phases of the moon and the lunar revolution have no relationship. To correct this misconception, teachers might take students outside to see the moon when it is visible in the daytime, and have students look for the moon when it is, and when it is not, visible at night. After several days of observation, students could then be asked to predict what the moon will look like on subsequent days. Activities such as these can then be done simultaneously with those which show the relationship between the various lunar phases and the moon's revolution about the earth.

Implications of Question 11.

Venus, Mars and Jupiter are planets. We can often see them at night:
 a. but only after midnight.
 b. but only with a telescope or a pair of binoculars.
 c. because every night they are in the same place in the sky.
 d. because they are often brighter than the brightest stars.

The author believes that the popularity of misconception b is partly due to the dependence of much science learning upon instruments such as the microscope and telescope. Those participants who believed that planets are in the same place in the sky every night, misconception c, have not attained either the concept of the rotating earth nor that of orbiting planets.

During the two months that the survey was being administered, Venus was often the brightest object in the nighttime sky. Even when the moon was visible at night, Venus was still very obvious and upon two occasions formed a striking image near the crescent moon. In classroom discussions it became apparent that suburban students were more aware of this "evening star" (as it is unfortunately often called) than were urban students.

Although planets are not visible during regular school hours, teachers can help eliminate this misconception by referring to the planets when they are visible in the evening and having their students look for them at night.

This author teaches an early evening college level earth science class and last November, when two visible planets were in close proximity to the moon, took his students out of the building to observe the sky. He knows of no better way to eliminate the misconception that planets can only be seen with optical aid, than to have students look at them with their own eyes. This particular class had been used earlier for the pilot study for this research and was not part of the subsequent study.

Implications of Question 12.

Falling or shooting stars are really:
a. rocks that are falling down to earth.
b. stars that are falling down to earth.
c. the same as asteroids.
d. the same as comets.

No misconception could be positively identified from the data. Each of the possible answers was chosen by about 25% of the participants and there is no means to show definitively whether each of the three possible misconceptions is indeed a misconception or merely the result of a lack of information about the subject. Of all the questions on the survey about astronomy, this one alone dealt with objects which most of the respondents had never seen.

Yet the results for this question are quite valuable in pointing out, at the very least, the lack of conceptions for many students about meteors. Meteors were first called falling stars because that is, in fact, what they appear to be when seen in the nighttime sky. This particular misconception is reinforced, not only by their common name but by the media as well. As mentioned in Chapter I, the television program Disneyland's twinkling and falling star and McDonald's Happy Meal carton of 1986 all help to reinforce the idea, to children anyway, that meteors are stars that are falling.

Falling stars are called meteors by astronomers, while small bits of rock in space could which could become meteors are called meteoroids. Students' confusing meteoroid with asteroid could have been the cause of the high response of distracter c. The confusion with comets is partially the cause of still photography, in that a photograph of a comet looks very much like the photograph of a falling star. The fact that a meteor is visible for only a second and the comet may be visible for months is lost to the observer of a photograph. Neither comets nor meteors can easily be seen and so belong, to many students, in the realm of books and science classrooms.

There are several meteor showers in the course of a school year. Teachers would do well to note these to their students when discussing this most misunderstood concept. The confusions of meteors with asteroids and comets would not survive classroom discussions if, as Kuethe (1963) suggested, science teachers make themselves aware of these tendencies to confuse, and then be sure that the lessons included examples that make the separation clear.

Implications of Question 13.

Earthquakes can be accurately predicted by:
a. observing stars and planets.
b. listening for loud thunder.
c. observing the behavior of wild animals.
d. earthquakes cannot be accurately predicted by any of these methods.

Many misconceptions about the earth, such as a flat earth or a sun which revolves around the earth, were at one time accepted as the correct conception by informed people. Misconception c, the prediction of earthquakes by the behavior of animals, is a modern case. Chinese geologists recently believed that they could actually use animal behavior for accurate earthquake prediction but were disappointed when an unexpected earthquake destroyed their theory.

Judson, Kauffman, and Leet (1987) noted that there are several natural phenomena which have been shown to precede earthquakes. Among these are crustal movements, surface tilting, changes in fluid pressure and in electrical and magnetic fields. They noted that some animals may indeed behave strangely before some earthquakes if they feel minute changes in the earth which are unobservable to humans. Judson et al. believe that while no single predictor is sufficient, continued close observation of the earth may soon result in a more reliable method of accurate earthquake prediction.

Teachers can discuss this misconception while at the same time emphasizing how extremely valuable it would be to have a means of accurate earthquake prediction. Such a discussion could easily lead into exciting career opportunities now available in the earth sciences.

Implications of Question 14.

The terrible floods that occur along a river:
a. occur only once every 100 years.
b. can be caused by man.
c. occur only when snow melts in the spring.
d. are worst during a full moon.

Many devasting floods do occur in the spring when melting snows release large quantities of water into the nation's waterways. Such floods occur frequently along the Kankakee River, a river which forms the southern boundary of Lake County, Indiana. Undoubtedly many of the participants of this survey, probably including all rural participants are aware of these floods. Rural and urban participants chose this misconception more often than the scientific conception.

The Little Calumet River, which forms the boundary between Munster and Hammond, Indiana, does not regularly flood in the spring, but rather is very susceptible to flooding after heavy rains in any season. Environmentalists are often quoted in the local newspaper warning about developments which might add to the flooding of this river. Two very damaging floods have occurred along this river in this decade, one in June of 1981 and the second in December of 1982. As neither flood occurred in early spring, it is not surprising that suburbanites were least like to choose misconception c and were most likely to choose the scientific conception.

Flooding is a topic that is likely covered in most high school and introductory university level earth science classes. The results of this survey, however, showed that students with the benefit of earth science classes tended to ascribe to the misconception c more often than those who did not. The author believes that this indicates that the interrelationships of earth processes and human activity needs to be emphasized more in introductory classes than is presently done.

Implications of Question 15.

If a crystal can scratch glass, then:
a. it is a diamond.
b. it is not a diamond.
c. it may be a diamond.
d. it probably is not a diamond.

Mineral hardness is a concept taught in nearly all earth science classes, both at the high school and college levels. Moh's Hardness Scale, which is often drawn to show that 5 of the 10 minerals on the scale can all scratch glass, is included in every earth science text that the author has ever examined. It was, therefore, gratifying to the author to see that, for students who have had earth science classes, the concept of hardness does seem to transfer to a problem such as this.

This misconception can be reworded to, diamonds are the only crystals which can scratch glass. The fact that even among students who have had these classes, a sizable minority still subscribed to this misconception might be attributed to the fact that a geology laboratory is not always required of geoscience students. Such required laboratory classes in which students find the hardness of various minerals by scratching them on glass could help eliminate this misconception.

Implications of Question 16.

Right now, the direction, north, is:
a. toward the front of this room.
b. toward the back of this room.
c. toward my left.
d. toward my right.
e. straight up.

The author recognizes that not all of the misconceptions listed in Tables 3 and 4 are equally important to the well-being of the world's population. One can live a healthy, normal life while still subscribing to many of the misconceptions revealed by this paper. There was one misconception, however, which although it was accepted by only 4.7% of the total sample (yet 19.0% of urban fifth graders) can greatly interfere with one's ability to function in today's world. This misconception is referred to in this paper as a functional misconception.

Meyer (1987) noted that many of his undergraduate students believe that rivers must flow "down" from north to south. This misconception is unfortunately reinforced by the fact that as a result of Pleistocene glaciation, most major rivers in the United States do flow southward. The cause of this misconception is a confusion of the concepts of north and up, and of south and down. The author noted earlier that he first became aware of this second misconception when teaching eighth grade general science several years ago. He asked a class which direction was north and a number of students pointed straight up.

This misconception of north being up is, in the author's opinion, a very serious one for those persons who hold it, thus the designation of a functional misconception. It may be, in fact, the most important misconception discussed in this paper. Although in general not a common misconception, it tended to be more common among younger, urban, black and Hispanic children. In urban fifth grade classes, this misconception was chosen by 19% of the students.

Fisher and Lipson (1986) noted that misconceptions are particularly undesirable when they have a negative effect on a person's ability to solve a problem. North's being up is such a misconception.

When in post-survey discussions students admitted to believing that north was up, in almost every case the students holding this misconception claimed that it was created by an elementary school teacher. The teacher, of course, was referring to a map, but the student interpreted it as meaning directly overhead.

The concept of north is not as easy a concept as many people might think. During the post-survey discussion in one of the classes of teacher candidates, the author pointed to a map of Antarctica and asked which direction on that map was north. One student volunteered that it was toward the top of the map; none of the others had any idea.

Teachers, especially in urban areas, need to be aware that this type of misconception can occur and make sure that they don't assist its happening by being anything less than careful when they discuss the direction, north.

Implications of Question 17.

The dinosaurs:
- a. lived long before cave-men.
- b. lived at the same time as cave-men.
- c. are still living someplace on earth.
- d. never lived anywhere on earth.

Movies and cartoons have both done their part to reinforce the misconception that dinosaurs lived at the same time as cave-men. Although two-thirds of the participants recognized that as fantasy and chose the scientific conception, nearly one-third still opted for the misconception. With the exception of the two small subgroups, rural and Asian participants, this misconception transcends age, gender, and location. College students were most likely to select the scientific conception, yet nearly one in four of them subscribed to the misconception.

Of the 27 persons who answered with option c, many admitted in the post-survey discussions, that they were confusing alligators or other reptiles with dinosaurs. Two of the 23 who answered with option d stated their belief that because dinosaurs are not mentioned in the Book of Genesis, they therefore could not have ever lived on earth.

Question 17 was similar to one asked by NAEP in 1969 of 17 year old students. The percentages in Table 38 below reflect the number of students who answered each option.

Table 38. Responses by 17 year olds to a NAEP Question about Dinosaurs

Which of the following animals that have been found as fossils in rocks have NEVER been seen alive by man?

| | | | |
|---|---|---|---|
| 89% | Dinosaurs | 1% | Oysters |
| 1% | Horses | 1% | Shrimp |
| 5% | Locusts | 3% | I don't know. |

The NAEP question was not designed to identify misconceptions, and the author believes that the reason for the high number of correct responses was due to the lack of any very plausible distracters. Most students have seen the other four animals and so would not choose them.

A discussion of the extinction of dinosaurs might help eliminate this misconception, for whatever killed the dinosaurs might well have killed off human beings also, had there been any alive at that time.

Implications of Question 18.

It is possible that in the near future Chicago could be severely damaged by:

a. either a tornado or an earthquake.
b. neither a tornado nor an earthquake.
c. a tornado, but not an earthquake.
d. an earthquake, but not a tornado.

This question was worded so that it could actually identify two separate misconceptions: that Chicago cannot be severely damaged by a tornado, and that Chicago cannot be severely damaged by an earthquake. To the 25.6% who chose misconception c could be added the 10.9% who in choosing distracter b also professed the misconception that Chicago could not be severely damaged by an earthquake. This would then equal 36.5%.

The midwest, not the west coast, was the site of North America's largest earthquake, New Madrid, Missouri, in 1811-12. Yet the author has long maintained that few Chicago area residents were aware that earthquakes could do any damage at all to cities located in mid-America. In a case of unfortunate timing for the purposes of this paper, the city of Chicago and northwest Indiana felt an earthquake (centered near Lawrenceville, IL) on Wednesday June 10, 1987, which registered 5.0 on the Richter Scale. The quake was front page news and the newspapers once again were referring to the old, but still threatening, New Madrid Fault. Yet, in spite of the earthquake and all the publicity it engendered, over one-third of the participants still subscribed to the notion that Chicago could not be severely damaged by earthquakes.

Post-survey discussions confirmed the other suspicion which the author had held, that many persons in the Chicago area believe the city, and others around it, immune to tornadoes. This immunity, claimed by many, was caused by the cities' juxtaposition to Lake Michigan. If the sums of misconceptions b and d were totaled, the results of the survey would then show that this apparent misconception was subscribed to by more than one in five participants.

Because the New Madrid earthquake occurred before the development of cities in the Mississippi Valley, there was little human damage. Textbooks often do not even include mention of it inspite of the fact that there was physical damage to the earth in an area exceeding 40,000 square miles (Tazieff, 1964). Geologists, however, predict that another major quake will occur along the New Madrid Fault at sometime within the next 150 years. Although this could mean tomorrow, it is sufficiently unlikely, so that it causes little concern to most midwesterners. Yet the citizens of the midwest, especially city planners and architects, should be aware of the possibility so that buildings, which might still be standing generations from now, would be designed to withstand the shock of another major earthquake.

Teachers, when covering earthquakes or tornadoes, should include local examples in their discussions. Research projects about local disasters are another means of helping to assure that students are aware that the Chicago area is not immune to either of these two dangers.

## Discussion of the Subgroups

The variability of total misconceptions held was much greater within the subgroups than between them. Each subgroup studied had a mean of approximately 6 or 7 misconceptions, and each had a range from a low of about 1 or 2 to a high of about 12 or 13.

It cannot be assumed that a low mean for total misconceptions indicates a high level of understanding of the scientific conception. In many cases, particularly for fifth graders and minorities, the low mean for misconceptions parallels a low mean for the scientific conception as well. This parallelism indicates a lack of understanding, as opposed to a misconception about the concept, and is reflected by an increase in the selection of the other distracters.

### Gender

The results of this study concerning gender are complex. The multivariate analysis shows that white females held more misconceptions than white males, however black and Hispanic males held more misconceptions than black and Hispanic females respectively. There were no discernible patterns whereby it could be stated that one gender had more misconceptions in a particular field, (e.g. astronomy) than the other.

Males of all racial groups appeared to understand more scientific conceptions than their female counterparts. These concept attainment results are similar to those obtained on NAEP science content questions where males have scored about five percentage points higher than females (Linn, de Benedictis, Delucchi, Harris, & Stage, 1987). On science inquiry questions there was no significant gender difference. Lightman, Miller, and Leadbeater (1987) independently noted from their research that males are more knowledgable than females in the area of astronomy. The concept attainment results of this study confirm these results obtained by Lightman, et al. in that males outscored females on all nine of the astronomy questions on this instrument and all but one of the remaining questions. Za'rour (1975), in an earlier study of 1444 Lebanese high school and college students, showed that males held fewer misconceptions in science than did females.

For this study, the analysis of variance showed that females have significantly more misconceptions than males (alpha = 0.01). Although the difference was shown to be statistically significant, the author does not believe it to be important. Another way of stating this result is that out of seventeen possible misconceptions, the "average female" had 1/3 of a misconception more than the "average male." This difference is the smallest significant difference between two subgroups in the study. What is important here is that classroom teachers need to know that both males and females are likely to have and hold onto misconceptions.

Race

White students in this study were shown to have fewer misconceptions than minorities. They are also much more likely to accept the scientific conceptions. White participants were more likely to show misconceptions if it were one of those based on popular folklore, such as winters' being predictable by looking at fur of animals, the sun being straight up at noon, and the June sun setting in the west.

The data which show that black and Hispanic students were less likely to accept the scientific conceptions is very similar to NAEP results which have consistently shown that these two minority groups score well below white students on questions concerning science content and science inquiry skills (Rakow, 1985).

Level

As might be expected, there was revealed by this study a correlation between educational level and acceptance of scientific conceptions. This is similar to Lightman, Miller, and Leadbeater's (1987) findings that astronomical knowledge is associated with age and education. There was not, however, a parallel correlation between misconceptions and grade level. Fifth graders showed the lowest level of acceptance of scientific conceptions and also a lower than might be expected mean of misconceptions. This lower mean of misconceptions for many fifth graders was due simply to more random guessing on their part.

Eighth graders as a whole held more misconceptions than any other grade level. These results are similar to those obtained by Stepans, Beiswenger, and Dyche (1986) who conducted a cross-age survey in misconceptions in the physical sciences and found that, though junior high students used more sophisticated science vocabulary than elementary students, this was not accompanied by increased understanding. Surprisingly, when broken down by race, gender, and level, eighth graders did not have the largest number of misconceptions in any of the subgroups except for white females. (See Table 28)

White and Hispanic 11th grade students were more likely than 8th graders to choose scientific conceptions, having apparently eliminated some of their misconceptions. College students generally scored better than the high school students, having both fewer misconceptions and a higher acceptance of scientific conceptions. Trade school students' acceptance of the scientific conceptions was lower than that of the high school students, and their misconceptions mean approached the high level set by the eighth graders.

Location

The data show that results for urban and suburban location are similar to the racial group results. This is due in part to the high predominance within the urban area of both minority groups, which as seen above, held significantly more misconceptions than white participants. Of the 20 common misconceptions identified by this study, urban residents subscribed to 13 of them in greater numbers than did suburbanites.

Because of the social-economic differences between the communities from which the grade schools were selected, it may be inferred that this difference is due to social-economic status. To determine whether urban and suburban participants of the same racial group differed in their holding of misconceptions, a multivariate examination of the racial groups' misconceptions mean across urban and suburban location was attempted. However there were too few black and Hispanic suburban participants, and too few white elementary and middle school children to make a statistical comparison. Table 39 shows this data broken down by race, location, and level.

Urban adults and 11th grade students did have more misconceptions than their suburban counterparts which may indicate that social-economic status is related to the holding of misconceptions. It may also be due to the racial differences, or possibly a difference attributable to the school systems, curricula involved, other unanticipated factors, or a combination of several factors. This is an area in which more research should certainly be done.

Table 39. Number of Misconceptions by Race, Location, and Level

| | White | | Black | | Hispanic | |
|---|---|---|---|---|---|---|
| Grade level: | Urban | Suburban | Urban | Suburban | Urban | Suburban |
| 5th grade | 7.00 * | 7.27 | 6.77 | 6.00 ** | 6.88 | 5.75 ** |
| 8th grade | 8.00 ** | 6.95 | 7.25 | 4.50 ** | 7.42 | 8.00 ** |
| 11th grade | 6.54 | 6.21 | 7.72 | ---- | 7.33 | 7.25 ** |
| College | 6.44 | 6.34 | 6.82 | 6.00 ** | 7.86 * | 6.00 * |
| Trade school | 6.74 | 6.71 | 6.71 * | ---- | 7.75 | 8.25 ** |

* denotes a cell with fewer than 10 persons
** denotes a cell with fewer than 5 persons
---- denotes a cell with no persons

## Earth Science Courses Taken

One would hope that students who had taken an earth science class would have a better understanding about the earth and space than those who had not, especially since high school earth science courses include sections on astronomy as well as meteorology and physical geology. Results from this study show that for the high school earth science class, (taken by either high school or college students) this is often the case.

The item analysis in Chapter IV, however, shows that there were several questions for which those who had not taken earth science did better than those who had. High school students without the benefit of an earth science course were less likely to subscribe to animal fur as a predictor of the severity of a winter or animal behavior of an impending earthquake, than those who had taken such a class. Surprisingly, those who had taken the earth science class were more likely to place the dinosaurs alongside the cave-men.

The author would not have been surprised if those high school students who had not taken earth science had actually scored better than those who had. In many high schools, including the two public high schools used for this study, the earth science course is recommended only for those who appear to be academically unable to succeed in the mathematically more rigorous chemistry or physics courses. Those more academically oriented are encouraged instead to take biology and chemistry. Physics is reserved for the most academically oriented. It is possible, therefore, that those students who opt not to take earth science already understand more about the earth than those who choose to take it. If so, then at the least it might be argued that earth science is being taught to those who need it most.

Sadler's (1987) results of his study of misconceptions in astronomy showed that students who were completing a one-year course in earth science did not seem to understand scientific conceptions any more often than those who had not. He noted, however, that they did tend to use many more "scientific" terms in their discussions.

In a manner similar to high school, university level geoscience classes are often taken by students who need to satisfy a physical science requirement, but who are afraid to take the more mathematically rigorous chemistry or physics courses. University level earth science courses come in varying forms. Usually, they are primarily geology courses sometimes including a little astronomy or some meteorology. The geoscience course at Indiana University Northwest, where more than half of those surveyed who had taken such a class were attending, contains no astronomy. One of the two courses offered at Purdue Calumet, the other university used, contains no meteorology.

Exposure to a university level course would not then necessarily help eliminate many of the misconceptions revealed by this study except, perhaps, those dealing directly with physical geology--questions 13 through 18. Although the data show that this is often the case, it was not so with each of those questions. Although these college students were more likely than those who hadn't taken the course to understand about earthquake prediction, they were also far more likely to subscribe to the idea that Chicago could not be severely damaged by one.

It might be assumed that a student who chose to take earth science at both the high school and the university level would have more interest in and a better conception about the earth and space. However, the results from this study show that this is not necessarily the case, although with a sample of only 34 persons no inferences will be made from their results.

### Last Grade Received in Science

"A" students had fewer misconceptions than students who received any other grade. There was however no significant difference between last grade received in science and number of misconceptions held with alpha = 0.01. As was noted in Chapter IV, there would have been a difference if alpha had been set at 0.05. The multiple correlation test did show that there was a difference between the A students and the B and C students, and might have shown the same with D and F students if there had been a larger sample. It is suspected by the author that some students may have inflated their reported grade; thirty-three participants left this item blank.

In any event, it is recognized that letter grades are more likely to be given to students because they appear to have more correct scientific conceptions, not for appearing to have fewer misconceptions. Sadler (1987) noted that even the best students have misconceptions.

## Discussion of Miscellaneous Subgroups

The three groups discussed below provide interesting information and suggest possible avenues for further research. However, no inferences can be drawn from them because of their small sample sizes.

### Eighth Grade Honors Class.

The suburban middle school in this study had one honors science class whose results were included with the suburban eighth grade sample, but whose means were also tabulated separately. With a mean of 5.68, this class of 22 students held fewer misconceptions than the other suburban eighth graders. Their scientific conception mean of 10.32 was higher than any other group studied except for the small group of graduate students who were also teachers. That they held any misconceptions at all, however, was a surprise to their teacher.

### Teachers

The 13 graduate students who were teachers were enrolled in a course about computers in the curriculum. None were science teachers although those who taught elementary school did teach some science. Their misconceptions mean was 5.31, lower than the college level average of 6.43. In addition, their scientific conception mean at 11.15 was the highest of any group studied.

### Teacher Candidates

The 32 teacher candidates were seniors who all hope to be teaching full-time in the 1988-1989 school year. They had a misconceptions mean of 6.37, slightly lower than the college level average of 6.43. Their scientific conceptions mean of 9.19 was lower than most other college students and lower as well than the suburban high school mean.

## The Earth Science Required Curriculum

Illiana Christian High School was included in this study as a means to determine the possible effects of a science curriculum which included a required earth science course during the Freshman year. It is recognized by the author that many variables, other than the curriculum, may affect the holding of earth science misconceptions by students. Teaching styles, choice of textbooks, social-economic status, religious affiliation, class size, attitudes of administrators, and differing concern of parents all could play a part in the holding of misconceptions. Illiana Christian is a private school, operated by a board made up of parents, most of whom belong to churches of the (Dutch) reformed tradition. With parents on the school board and paying a hefty tuition, perhaps more parental concern would be expected.

As was reported in Chapter IV, Illiana Christian High School had a lower misconceptions mean (5.95) than either of the two other high schools, and also had a higher mean of scientific conceptions (9.83). This low misconceptions mean was the lowest achieved by any subgroup except the 13 teachers and 22 eighth grade honors students mentioned above.

If the higher attainment of scientific conceptions and the lower mean of misconceptions attained by Illiana High School is a result of their required earth science curriculum, then a case might be made for state boards of education to recommend or require the same curriculum for all high schools in their states. However, the existence of so many other differences between the three high schools, even between Illiana and Munster, makes it impossible to verify that the difference in misconceptions and concept attainment is due to the curriculum alone. While Munster High School is an excellent, highly respected, public school, Illiana is a private school, and this alone may be responsible for much of the difference. The two schools do not draw from the same population.

More research is needed in this area. A school more similar to Illiana should be studied and compared to it. A public school with such an earth science requirement should be compared to similar public schools without the requirement. If an earth science course were to be required, a study should be made of the course material as well.

Interviews should be conducted with adults who have had earth science courses to determine which elements of the course proved to be most useful in adult life. The design of high school earth science courses should be studied to determine whether it should be altered to make them more relevant.

Several other questions need to be answered. If earth science were to be required of all students, would some other course have to be dropped from the list of required courses? Should students then have fewer electives? Would a required course meet the needs of all students? Is there another way to meet these needs? Only upon further research and the resolution of these questions can it be decided whether an appeal to state authorities for a change in graduation requirements should be made.

# SUMMARY

Data from this study have verified that misconceptions in the earth sciences are widespread. Six primary misconceptions and 14 secondary misconceptions were identified. In addition one functional misconception is suspected to be common among some subgroups.

Misconceptions are found with great regularity in both males and females, in all racial groups, among urban and suburban students, and across all five educational levels studied. Students who have taken earth science classes have slightly fewer misconceptions than those who have not. Although significant (alpha = .01) differences were found across genders, races, educational levels, and locations, the differences in misconceptions means were smaller than the differences in scientific conception means.

Stepans and Kuehn (1985) maintained that children come into the classroom with their own ideas about how the world works. In spite of the best efforts by teachers, many children maintain their misconceptions of the world for several years, and even into adulthood. They stated, as well the author could by using the data from this study, that a large number of adults give responses similar to elementary school children when interviewed on fundamental science concepts.

There are many things which teachers can do to help students ferret out and recognize the misconceptions which they have. Direct observation of natural phenonema is one of the best devices that teachers can encourage for their pupils. A student who has watched Venus or Jupiter move above the constellation Orion in the night-time sky will not later believe that planets are only visible with a telescope. A student who has traced the sun across the sky through the course of a day or a year will not believe that the sun is straight up at noon or sets due west every day.

Classroom discussions can be used to help students create within themselves cognitive dissonance or conceptual conflict. With this dissonance established, the students may then be on their way to discarding a misconception if it can be shown to be unsatisfactory. In all such discussions, students should feel free to express their own ideas and opinions. Teachers can learn much about their students, and their students' understanding of natural phenonema, though classroom discussions. Teachers can also use this teaching mode to interject comments and questions which may cause students to think more deeply about their own interpretations of events.

As Wandersee (1985) and others have noted, discussions of the history of science can help students overcome some misconceptions. This strategy is particularly useful for those misconceptions, such as the sun's circling the earth, which were accepted as true explanations by learned people in the past. As students metacognitively understand the thought processes which others went through to discover a new truth, they may incorporate that new truth into themselves.

Teachers must recognize that students may misinterpret what is taught in class. Scientific misnomers and terms with scientific meanings which are different from their everyday meaning both contribute to the formation of misconceptions. To help prevent misinterpretation, the limitations of models used in class should be noted. Whenever analogies are used in discussions, their limitations should be noted as well. It has been shown that classroom instruction sometimes leads to the formation of misconceptions. Students don't instinctively believe that north is up, they assimilate it through instruction.

It is unfortunate that many students are taught science without any accompanying form of hands-on or laboratory experiences. For many students, the manipulation of physical materials, as well as discoveries made for themselves, helps in the retention of important information.

The author contends that science should not be taught in a vacuum, that all the senses should be used when learning about the natural world, and that relationships between the natural sciences and other disciplines should be emphasized during instruction.

Much still needs to be done. One identifies misconceptions so that one may then find ways to prevent or overcome them. The misconceptions discovered in this study must be made known to other researchers, teachers, curriculum designers, and textbook publishers as well. Others doing research in this field may discover better teaching strategies than the ones known now. Research is also needed to determine the advantages of a required earth science course.

Nearly 40 years ago, Tyler (1949) advised teachers to first consider the needs of the learner. Twenty years ago, Ausubel (1968) proposed that teachers "Find out what the learner already knows and teach him accordingly." (p. 337) This study has shown that most learners have many misconceptions in the earth and space sciences. Research must now be done to determine which teaching methods can best be used to help eliminate these misconceptions. Designing curricula which begin with students' preconceptions, while ensuring that students avoid developing additional misconceptions during instruction, should be a primary goal of earth science educators.

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# APPENDIX A

## APPENDIX A

### LIST OF PARTICIPATING SCHOOLS

5th grade:

Washington Elementary School
1401 East 144th Street, East Chicago, Indiana 46312

Franklin Elementary School
4215 Adler Street, East Chicago, Indiana 46312

Eads Elementary School
8001 Harrison Avenue, Munster, Indiana 46321

Elliott Elementary School
8718 White Oak Avenue, Munster, Indiana 46321

St. Thomas More School
8435 Calumet Avenue, Munster, Indiana 46321

8th grade:

J. L. Block Junior High School
2700 Cardinal Drive, East Chicago, Indiana 46312

Wilbur Wright Middle School
8650 Columbia Avenue, Munster, Indiana 46321

11th grade:

Central High School
1100 West Columbus Drive, East Chicago, Indiana 46312

Munster High School
8808 Columbia Avenue, Munster, Indiana 46321

Illiana Christian High School
2261 Indiana Avenue, Lansing, Illinois 60437

Adult:

Indiana University Northwest
3400 Broadway, Gary, Indiana 46408

Purdue University Calumet
2233 171st Street, Hammond, Indiana 46324

Emilio De La Garza Center
410 East Columbus Drive, East Chicago, Indiana 46312

# APPENDIX B

APPENDIX B

# A DESCRIPTION OF THE COMMUNITIES AND SCHOOLS OF EAST CHICAGO AND MUNSTER, INDIANA

In order to infer social-economic status, most of the grade school students were selected from schools in two very different communities of northwest Indiana: East Chicago, a highly industrialized urban area composed primarily of working class families, and Munster, a suburban community most of whose citizens are employed in managerial or professional occupations. The only school selected which was not located in either of these communities was a private high school in suburban Lansing, Illinois, a village which is located immediately across the state line from Munster. This school was chosen because of its science curriculum (unique in this area) in which all students take some earth science in their Freshman year.

East Chicago, which boasts Indiana's newest and most expensive high school, has a population of 39,000 persons. There are eight public elementary, two junior high schools, and one high school with a total enrollment of over 7000 students. In addition there are three Roman Catholic elementary schools. East Chicago Central High School has approximately 2300 students. Approximately fifty per cent of East Chicago's students are Hispanic and forty percent are Black.

East Chicago has felt the full impact of the steel industry's recession and is now one of the most economically depressed areas in northwest Indiana. There was in 1987 a 13 per cent unemployment rate. Sixty percent of the students qualify for some sort of welfare support. According to the North Central Association, scholastic aptitude and achievement results from SAT scores range from average to below average while only fifty-six per cent of the high school students continue their education at any type of post-secondary school.

Munster, located just seven miles south-southwest of East Chicago, had a population in 1980 of 20,646. It has three public elementary schools, one middle, and one high school. There are two parochial elementary schools, one Catholic and one Lutheran, within the town and two elementary schools operated by members of the Reformed and Christian Reformed Churches located nearby. The enrollment at the public high school is about 1200 students, most of whom are white.

Munster schools are very academically oriented with 83% of their graduates continuing their education at four-year colleges or universities. The school offers five levels of three foreign languages, advanced mathematics, and three advanced placement science courses. SAT scores are high; 15% of the class of 1986 scored better than 600 in math while 16% scored better than 550 in verbal skills.

# APPENDIX C

APPENDIX C

SUBGROUP PERCENTAGES FOR EACH QUESTION

<u>Question 1</u>.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 4.0 | $\overline{M}$ = 77.6 | $\overline{M}$ = 4.2 | $\overline{M}$ = 13.2 |
| Gender: males | 3.6 | 74.1 | 4.7 | 16.5 |
| females | 4.4 | 81.5 | 3.7 | 9.5 |
| Race: white | 1.8 | 76.2 | 4.0 | 16.5 |
| black | 8.8 | 80.3 | 5.7 | 5.2 |
| Hispanic | 7.5 | 81.1 | 3.3 | 8.0 |
| Asian | .0 | 75.0 | 8.3 | 16.7 |
| Location: urban | 7.2 | 79.7 | 3.9 | 8.8 |
| suburban | 1.6 | 77.3 | 4.6 | 15.5 |
| rural | 4.8 | 64.3 | 2.4 | 26.2 |
| Level: 5th grade | 9.1 | 75.9 | 5.2 | 9.1 |
| 8th grade | 3.4 | 82.7 | 5.5 | 8.4 |
| 11th grade | 2.1 | 78.8 | 3.2 | 15.6 |
| no earth science | 3.1 | 82.2 | 3.9 | 10.1 |
| earth science | 1.5 | 76.2 | 2.9 | 19.4 |
| college | 2.2 | 72.1 | 4.4 | 19.5 |
| no earth science | 4.2 | 72.9 | .0 | 22.9 |
| H.S. earth science | 1.8 | 78.9 | .0 | 19.3 |
| univ earth science | 2.4 | 67.1 | 8.2 | 18.8 |
| both earth science | .0 | 70.6 | 8.8 | 17.6 |
| trade school | .0 | 80.4 | 1.1 | 14.1 |

Question 2.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 32.4 | $\overline{M}$ = 25.9 | $\overline{M}$ = 15.3 | $\overline{M}$ = 25.9 |
| Gender: males | 37.8 | 25.9 | 13.6 | 22.4 |
| females | 26.7 | 25.6 | 17.1 | 29.7 |
| Race: white | 34.7 | 32.8 | 10.7 | 21.1 |
| black | 22.8 | 13.5 | 27.5 | 36.3 |
| Hispanic | 31.1 | 13.7 | 21.2 | 33.5 |
| Asian | 41.7 | 16.7 | 16.7 | 25.0 |
| Location: urban | 27.5 | 18.0 | 21.7 | 32.6 |
| suburban | 35.0 | 31.1 | 11.4 | 21.8 |
| rural | 40.5 | 35.7 | 2.4 | 19.0 |
| Level: 5th grade | 31.6 | 10.1 | 27.7 | 30.6 |
| 8th grade | 30.8 | 18.6 | 15.2 | 34.6 |
| 11th grade | 31.2 | 32.6 | 10.9 | 25.3 |
| no earth science | 32.6 | 30.2 | 10.1 | 27.1 |
| earth science | 29.1 | 34.5 | 11.7 | 24.8 |
| college | 26.1 | 45.1 | 8.4 | 19.0 |
| no earth science | 29.2 | 50.0 | 10.4 | 10.4 |
| H.S. earth science | 26.3 | 47.4 | 5.3 | 21.1 |
| univ earth science | 24.7 | 40.0 | 9.4 | 22.4 |
| both earth science | 26.5 | 47.1 | 5.9 | 20.6 |
| trade school | 58.7 | 23.9 | 8.7 | 8.7 |

Question 3.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 4.8 | $\overline{M}$ = 8.9 | $\overline{M}$ = 12.0 | $\overline{M}$ = 73.2 |
| Gender: males | 4.4 | 7.9 | 11.3 | 74.7 |
| females | 5.1 | 10.0 | 12.6 | 71.6 |
| Race: white | 2.8 | 8.7 | 13.3 | 74.0 |
| black | 9.3 | 9.8 | 9.8 | 69.4 |
| Hispanic | 7.5 | 8.5 | 8.0 | 75.5 |
| Asian | 4.2 | 16.7 | 8.3 | 70.8 |
| Location: urban | 7.4 | 8.8 | 10.2 | 72.3 |
| suburban | 3.1 | 9.4 | 12.9 | 73.7 |
| rural | .0 | 14.3 | 14.3 | 81.0 |
| Level: 5th grade | 9.1 | 7.5 | 17.6 | 64.2 |
| 8th grade | 6.8 | 8.9 | 12.2 | 72.2 |
| 11th grade | 2.6 | 12.9 | 8.8 | 75.6 |
| no earth science | 2.3 | 14.0 | 3.9 | 79.8 |
| earth science | 2.4 | 12.6 | 11.7 | 73.3 |
| college | .9 | 5.3 | 8.4 | 82.7 |
| no earth science | .0 | 2.1 | 12.5 | 83.3 |
| H.S. earth science | 1.8 | 1.8 | 10.5 | 80.7 |
| univ earth science | 3.5 | 1.2 | 5.9 | 83.5 |
| both earth science | .0 | 8.8 | 5.9 | 85.3 |
| trade school | 2.2 | 7.6 | 13.0 | 75.0 |

Question 4.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 8.8 | $\bar{M}$ = 3.9 | $\bar{M}$ = 19.6 | $\bar{M}$ = 66.8 |
| Gender: males | 6.2 | 2.8 | 17.5 | 72.6 |
| females | 11.7 | 4.9 | 21.7 | 61.1 |
| Race: white | 3.7 | 8.7 | 18.2 | 73.6 |
| black | 17.6 | 9.8 | 19.7 | 58.5 |
| Hispanic | 18.9 | 8.5 | 23.1 | 51.4 |
| Asian | .0 | 16.7 | 29.2 | 70.8 |
| Location: urban | 16.4 | 8.8 | 21.7 | 57.2 |
| suburban | 3.7 | 9.4 | 18.1 | 74.1 |
| rural | 2.4 | 2.4 | 19.0 | 71.4 |
| Level: 5th grade | 18.9 | 5.9 | 24.4 | 50.5 |
| 8th grade | 8.4 | 3.8 | 16.9 | 70.5 |
| 11th grade | 3.8 | 3.2 | 15.3 | 77.4 |
| no earth science | 4.7 | 3.1 | 18.6 | 72.9 |
| earth science | 3.4 | 2.9 | 12.6 | 81.1 |
| college | 4.0 | 3.1 | 19.9 | 71.7 |
| no earth science | 4.2 | .0 | 25.0 | 70.8 |
| H.S. earth science | 5.3 | 5.3 | 21.1 | 66.7 |
| univ earth science | 3.5 | 3.5 | 15.3 | 75.3 |
| both earth science | 2.9 | 2.9 | 23.5 | 70.6 |
| trade school | 7.6 | 1.1 | 22.8 | 66.3 |

Question 5.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 5.2 | $\bar{M}$ = 5.3 | $\bar{M}$ = 6.3 | $\bar{M}$ = 82.4 |
| Gender: males | 4.2 | 3.7 | 7.3 | 83.6 |
| females | 6.3 | 7.0 | 5.3 | 81.2 |
| Race: white | 1.8 | 2.1 | 6.1 | 88.9 |
| black | 13.5 | 16.1 | 5.7 | 64.2 |
| Hispanic | 9.0 | 6.6 | 7.1 | 77.4 |
| Asian | .0 | 4.2 | 8.3 | 87.5 |
| Location: urban | 10.0 | 9.4 | 5.9 | 74.2 |
| suburban | 2.1 | 2.4 | 6.3 | 88.3 |
| rural | .0 | 2.4 | 11.9 | 85.7 |
| Level: 5th grade | 11.1 | 11.7 | 7.5 | 69.4 |
| 8th grade | 5.1 | 4.2 | 5.1 | 85.7 |
| 11th grade | 3.5 | 3.5 | 6.8 | 85.9 |
| no earth science | 4.7 | 4.7 | 2.3 | 88.4 |
| earth science | 2.9 | 2.9 | 9.2 | 84.5 |
| college | 1.8 | 2.7 | 7.1 | 87.6 |
| no earth science | .0 | .0 | 2.1 | 97.9 |
| H.S. earth science | 1.8 | 1.8 | 10.5 | 84.2 |
| univ earth science | 2.4 | 4.7 | 8.2 | 83.5 |
| both earth science | 2.9 | .0 | 5.9 | 91.2 |
| trade school | .0 | .0 | 2.2 | 94.6 |

Question 6.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 7.4 | $\bar{M}$ = 18.5 | $\bar{M}$ = 58.6 | $\bar{M}$ = 14.6 |
| Gender: males | 6.3 | 18.8 | 60.8 | 13.1 |
| females | 8.5 | 18.0 | 56.5 | 16.3 |
| Race: white | 4.1 | 13.8 | 68.8 | 12.3 |
| black | 8.8 | 28.5 | 42.5 | 19.2 |
| Hispanic | 15.6 | 24.1 | 39.6 | 20.8 |
| Asian | 16.7 | 25.0 | 45.8 | 12.5 |
| Location: urban | 10.7 | 24.0 | 46.9 | 18.0 |
| suburban | 5.4 | 14.6 | 66.5 | 12.4 |
| rural | .0 | 14.3 | 73.8 | 9.5 |
| Level: 5th grade | 16.3 | 21.8 | 42.3 | 18.6 |
| 8th grade | 9.3 | 22.8 | 57.0 | 10.1 |
| 11th grade | 3.5 | 20.6 | 61.2 | 14.4 |
| no earth science | 5.4 | 20.2 | 60.5 | 13.2 |
| earth science | 2.4 | 20.9 | 61.2 | 15.5 |
| college | .0 | 10.2 | 73.5 | 15.5 |
| no earth science | - | 4.2 | 72.9 | 22.9 |
| H.S. earth science | - | 10.5 | 70.2 | 17.5 |
| univ earth science | - | 14.1 | 75.3 | 9.4 |
| both earth science | - | 8.8 | 73.5 | 17.6 |
| trade school | 6.5 | 10.9 | 69.6 | 10.9 |

Question 7.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 6.1 | $\bar{M}$ = 48.1 | $\bar{M}$ = 34.3 | $\bar{M}$ = 10.1 |
| Gender: males | 3.7 | 50.6 | 35.0 | 9.1 |
| females | 8.7 | 45.5 | 33.4 | 11.2 |
| Race: white | 4.2 | 54.7 | 33.9 | 5.8 |
| black | 10.9 | 36.3 | 35.8 | 15.5 |
| Hispanic | 9.0 | 39.2 | 32.1 | 18.9 |
| Asian | 8.3 | 37.5 | 45.8 | 8.3 |
| Location: urban | 9.0 | 42.6 | 31.4 | 15.6 |
| suburban | 4.3 | 50.2 | 37.7 | 6.7 |
| rural | .0 | 76.2 | 21.4 | .0 |
| Level: 5th grade | 14.0 | 30.0 | 33.9 | 20.5 |
| 8th grade | 6.8 | 39.2 | 44.3 | 9.3 |
| 11th grade | 2.9 | 54.1 | 34.7 | 7.9 |
| no earth science | 3.1 | 53.5 | 35.7 | 7.0 |
| earth science | 2.9 | 54.4 | 34.0 | 8.7 |
| college | 1.3 | 69.5 | 26.1 | 1.8 |
| no earth science | .0 | 75.0 | 22.9 | 2.1 |
| H.S. earth science | .0 | 71.9 | 26.3 | 1.8 |
| univ earth science | 2.4 | 63.5 | 29.4 | 2.4 |
| both earth science | 2.9 | 73.5 | 20.6 | .0 |
| trade school | 1.1 | 55.4 | 30.4 | 6.5 |

Question 8.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 70.7 | $\overline{M}$ = 9.5 | $\overline{M}$ = 15.7 | $\overline{M}$ = 3.6 |
| Gender: males | 79.7 | 6.6 | 10.4 | 2.4 |
| females | 61.5 | 12.4 | 21.1 | 4.9 |
| Race: white | 80.9 | 6.1 | 10.7 | 2.0 |
| black | 49.7 | 18.1 | 25.9 | 5.7 |
| Hispanic | 53.3 | 14.2 | 25.0 | 7.1 |
| Asian | 79.2 | 4.2 | 8.3 | 4.2 |
| Location: urban | 56.4 | 14.5 | 23.4 | 5.1 |
| suburban | 81.0 | 5.8 | 10.5 | 2.4 |
| rural | 76.2 | 7.1 | 11.9 | 4.8 |
| Level: 5th grade | 65.8 | 10.7 | 16.6 | 6.5 |
| 8th grade | 68.4 | 11.4 | 14.3 | 5.9 |
| 11th grade | 74.4 | 7.1 | 16.8 | 1.5 |
| no earth science | 69.0 | 10.1 | 20.2 | .8 |
| earth science | 77.7 | 5.3 | 14.6 | 1.9 |
| college | 71.2 | 9.3 | 16.8 | 1.8 |
| no earth science | 68.8 | 4.2 | 22.9 | 4.2 |
| H.S. earth science | 82.5 | 5.3 | 8.8 | 1.8 |
| univ earth science | 64.7 | 17.6 | 15.3 | 1.2 |
| both earth science | 76.5 | 2.9 | 20.6 | .0 |
| trade school | 79.3 | 8.7 | 9.8 | 1.1 |

Question 9.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 30.3 | $\overline{M}$ = 52.9 | $\overline{M}$ = 5.5 | $\overline{M}$ = 9.9 |
| Gender: males | 32.7 | 50.9 | 5.9 | 9.7 |
| females | 28.0 | 55.0 | 6.1 | 10.0 |
| Race: white | 35.6 | 54.0 | 3.0 | 6.3 |
| black | 22.3 | 50.3 | 10.4 | 15.0 |
| Hispanic | 21.2 | 50.5 | 10.8 | 16.5 |
| Asian | 25.0 | 58.3 | 4.2 | 12.5 |
| Location: urban | 27.7 | 48.6 | 8.0 | 14.8 |
| suburban | 32.6 | 55.9 | 3.3 | 7.0 |
| rural | 26.2 | 61.9 | 9.5 | .0 |
| Level: 5th grade | 20.2 | 52.1 | 8.1 | 18.2 |
| 8th grade | 22.8 | 57.4 | 8.0 | 11.0 |
| 11th grade | 35.6 | 55.0 | 4.1 | 4.7 |
| no earth science | 36.4 | 51.9 | 4.7 | 5.4 |
| earth science | 34.5 | 57.3 | 3.9 | 4.4 |
| college | 41.2 | 46.5 | 2.2 | 8.8 |
| no earth science | 41.7 | 43.8 | 4.2 | 10.4 |
| H.S. earth science | 54.4 | 38.6 | .0 | 5.3 |
| univ earth science | 31.8 | 50.6 | 3.5 | 11.8 |
| both earth science | 38.2 | 55.9 | .0 | 5.9 |
| trade school | 35.9 | 54.3 | 4.3 | 2.2 |

Question 10.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 1.8 | $\bar{M}$ = 35.9 | $\bar{M}$ = 42.1 | $\bar{M}$ = 19.5 |
| Gender: males | 1.0 | 38.6 | 44.7 | 15.1 |
| females | 2.7 | 33.3 | 39.4 | 24.1 |
| Race: white | .8 | 32.8 | 51.8 | 14.0 |
| black | 5.2 | 39.4 | 21.8 | 33.2 |
| Hispanic | 1.9 | 45.8 | 24.5 | 27.8 |
| Asian | .0 | 20.8 | 54.2 | 25.0 |
| Location: urban | 3.1 | 39.5 | 29.5 | 27.5 |
| suburban | .7 | 34.2 | 50.4 | 14.2 |
| rural | .0 | 21.4 | 61.9 | 16.7 |
| Level: 5th grade | 4.6 | 43.6 | 20.5 | 30.3 |
| 8th grade | 1.3 | 38.8 | 40.9 | 19.0 |
| 11th grade | .9 | 34.7 | 46.8 | 17.6 |
| no earth science | .0 | 41.1 | 41.9 | 17.1 |
| earth science | 1.0 | 31.1 | 50.5 | 17.5 |
| college | .4 | 27.4 | 58.8 | 12.8 |
| no earth science | .0 | 25.0 | 64.6 | 10.4 |
| H.S. earth science | .0 | 35.1 | 54.4 | 10.5 |
| univ earth science | 1.2 | 27.1 | 56.5 | 14.1 |
| both earth science | .0 | 20.6 | 67.6 | 11.8 |
| trade school | 1.1 | 25.0 | 60.9 | 9.8 |

Question 11.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 2.9 | $\bar{M}$ = 41.5 | $\bar{M}$ = 9.1 | $\bar{M}$ = 45.7 |
| Gender: males | 3.7 | 37.1 | 10.9 | 47.5 |
| females | 2.0 | 46.5 | 7.0 | 43.8 |
| Race: white | 2.4 | 32.9 | 9.0 | 54.9 |
| black | 3.1 | 60.6 | 8.8 | 26.9 |
| Hispanic | 4.2 | 56.1 | 9.4 | 29.2 |
| Asian | .0 | 41.7 | 4.2 | 54.2 |
| Location: urban | 3.5 | 52.0 | 11.3 | 32.8 |
| suburban | 2.4 | 34.4 | 7.6 | 54.9 |
| rural | 2.4 | 33.3 | 7.1 | 57.1 |
| Level: 5th grade | 5.5 | 50.8 | 11.7 | 30.9 |
| 8th grade | 3.4 | 47.3 | 7.2 | 42.2 |
| 11th grade | .9 | 36.8 | 7.1 | 55.3 |
| no earth science | .8 | 38.8 | 8.5 | 51.9 |
| earth science | 1.0 | 36.4 | 5.8 | 56.8 |
| college | 1.8 | 35.0 | 9.3 | 53.5 |
| no earth science | .0 | 39.6 | 12.5 | 47.9 |
| H.S. earth science | 1.8 | 40.4 | 14.0 | 43.9 |
| univ earth science | 1.2 | 29.4 | 5.9 | 62.4 |
| both earth science | 5.9 | 35.3 | 5.9 | 52.9 |
| trade school | 2.2 | 32.6 | 10.9 | 52.2 |

Question 12.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 23.6 | $\bar{M}$ = 24.1 | $\bar{M}$ = 23.6 | $\bar{M}$ = 28.3 |
| Gender: males | 32.3 | 19.0 | 23.2 | 25.1 |
| females | 14.8 | 29.0 | 23.9 | 31.7 |
| Race: white | 24.5 | 21.3 | 26.9 | 26.6 |
| black | 20.7 | 30.6 | 16.6 | 31.6 |
| Hispanic | 23.1 | 28.8 | 18.9 | 29.2 |
| Asian | 25.0 | 8.3 | 16.7 | 50.0 |
| Location: urban | 23.4 | 29.7 | 16.2 | 30.5 |
| suburban | 23.8 | 19.3 | 28.3 | 28.1 |
| rural | 28.6 | 26.2 | 35.7 | 7.1 |
| Level: 5th grade | 22.5 | 22.8 | 24.4 | 30.0 |
| 8th grade | 19.8 | 22.8 | 24.1 | 32.9 |
| 11th grade | 25.6 | 25.0 | 23.2 | 26.2 |
| no earth science | 21.7 | 20.9 | 20.9 | 36.4 |
| earth science | 28.2 | 26.7 | 25.2 | 19.9 |
| college | 23.5 | 24.3 | 23.9 | 27.4 |
| no earth science | 16.7 | 29.2 | 31.3 | 22.9 |
| H.S. earth science | 24.6 | 21.1 | 21.1 | 29.8 |
| univ earth science | 25.9 | 27.1 | 21.2 | 25.9 |
| both earth science | 26.5 | 17.6 | 26.5 | 29.4 |
| trade school | 31.5 | 26.1 | 22.8 | 18.5 |

Question 13.

| | a | b | c | d |
|---|---|---|---|---|
| | $\bar{M}$ = 5.6 | $\bar{M}$ = 3.7 | $\bar{M}$ = 15.4 | $\bar{M}$ = 73.9 |
| Gender: males | 3.4 | 4.1 | 15.4 | 75.2 |
| females | 8.0 | 3.4 | 15.3 | 72.8 |
| Race: white | 5.1 | 1.8 | 15.9 | 76.3 |
| black | 7.8 | 9.8 | 14.5 | 66.8 |
| Hispanic | 4.7 | 4.7 | 13.7 | 74.1 |
| Asian | 4.2 | .0 | 16.7 | 79.2 |
| Location: urban | 5.9 | 5.9 | 13.7 | 73.0 |
| suburban | 5.7 | 2.4 | 17.2 | 73.7 |
| rural | 2.4 | .0 | 4.8 | 92.9 |
| Level: 5th grade | 9.1 | 9.8 | 17.6 | 61.6 |
| 8th grade | 3.8 | 2.5 | 18.1 | 74.7 |
| 11th grade | 5.9 | 1.5 | 14.4 | 77.9 |
| no earth science | 6.2 | .8 | 11.6 | 80.6 |
| earth science | 5.8 | 1.9 | 16.0 | 76.2 |
| college | 4.4 | .0 | 15.5 | 79.6 |
| no earth science | 6.3 | - | 27.1 | 66.7 |
| H.S. earth science | 5.3 | - | 12.3 | 82.5 |
| univ earth science | 2.4 | - | 10.6 | 85.9 |
| both earth science | 5.9 | - | 14.7 | 79.4 |
| trade school | 1.1 | 4.3 | 4.3 | 87.0 |

Question 14.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 9.9 | $\overline{M}$ = 37.3 | $\overline{M}$ = 33.6 | $\overline{M}$ = 17.8 |
| Gender: males | 6.5 | 37.4 | 35.0 | 19.3 |
| females | 13.4 | 37.2 | 32.1 | 16.3 |
| Race: white | 6.2 | 41.9 | 31.0 | 19.5 |
| black | 20.7 | 25.9 | 39.4 | 13.5 |
| Hispanic | 13.2 | 33.5 | 37.7 | 13.2 |
| Asian | 4.2 | 33.3 | 29.2 | 33.3 |
| Location: urban | 15.4 | 32.2 | 37.3 | 14.1 |
| suburban | 6.3 | 41.4 | 30.8 | 20.5 |
| rural | 4.8 | 35.7 | 38.1 | 16.7 |
| Level: 5th grade | 19.2 | 27.7 | 38.1 | 13.0 |
| 8th grade | 8.0 | 35.9 | 38.4 | 17.7 |
| 11th grade | 6.5 | 40.6 | 29.4 | 22.6 |
| no earth science | 7.8 | 40.3 | 27.1 | 24.0 |
| earth science | 5.3 | 40.8 | 30.6 | 22.3 |
| college | 7.5 | 47.8 | 27.0 | 17.3 |
| no earth science | 4.2 | 54.2 | 25.0 | 14.6 |
| H.S. earth science | 7.0 | 49.1 | 17.5 | 26.3 |
| univ earth science | 10.6 | 41.2 | 34.1 | 14.1 |
| both earth science | 5.9 | 52.9 | 26.5 | 14.7 |
| trade school | 2.5 | 35.9 | 39.1 | 17.4 |

Question 15.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 44.4 | $\overline{M}$ = 3.5 | $\overline{M}$ = 47.0 | $\overline{M}$ = 3.9 |
| Gender: males | 41.0 | 3.6 | 50.1 | 4.1 |
| females | 48.0 | 3.6 | 43.8 | 3.7 |
| Race: white | 40.7 | 2.8 | 53.2 | 2.4 |
| black | 46.1 | 6.2 | 37.3 | 8.8 |
| Hispanic | 53.8 | 4.2 | 36.3 | 4.2 |
| Asian | 50.0 | .0 | 41.7 | 8.3 |
| Location: urban | 48.0 | 4.7 | 40.4 | 5.7 |
| suburban | 43.2 | 3.0 | 50.4 | 2.5 |
| rural | 26.2 | .0 | 66.7 | 4.8 |
| Level: 5th grade | 54.4 | 4.2 | 32.2 | 7.2 |
| 8th grade | 50.6 | 4.6 | 39.7 | 3.8 |
| 11th grade | 39.1 | 2.1 | 55.9 | 2.6 |
| no earth science | 44.2 | 1.6 | 51.2 | 2.3 |
| earth science | 36.4 | 2.4 | 58.3 | 2.9 |
| college | 29.6 | 3.5 | 64.6 | 1.8 |
| no earth science | 35.4 | 2.1 | 56.3 | 4.2 |
| H.S. earth science | 38.6 | 5.3 | 56.1 | .0 |
| univ earth science | 24.7 | 3.5 | 69.4 | 2.4 |
| both earth science | 17.6 | 2.9 | 79.4 | .0 |
| trade school | 51.1 | 3.3 | 40.2 | 3.3 |

<u>Question 16</u>.

| | a | b | c | d | e |
|---|---|---|---|---|---|
| | $\overline{M}$= 32.8 | $\overline{M}$= 20.4 | $\overline{M}$= 25.0 | $\overline{M}$= 16.1 | $\overline{M}$= 4.7 |
| Gender: males | 24.6 | 24.8 | 29.0 | 18.3 | 2.4 |
| females | 41.3 | 15.6 | 20.9 | 13.9 | 7.1 |
| Race: white | 30.6 | 23.3 | 27.4 | 16.3 | 1.4 |
| black | 42.0 | 12.4 | 19.2 | 11.9 | 14.0 |
| Hispanic | 32.5 | 16.0 | 24.1 | 17.5 | 8.5 |
| Asian | 12.5 | 29.2 | 12.5 | 41.7 | .0 |
| Location: urban | 40.8 | 14.1 | 22.1 | 12.9 | 9.0 |
| suburban | 27.7 | 24.1 | 26.8 | 19.3 | 1.3 |
| rural | 26.2 | 28.6 | 38.1 | 2.4 | 4.8 |
| Level: 5th grade | 34.9 | 16.3 | 17.9 | 17.9 | 11.4 |
| 8th grade | 29.5 | 8.4 | 20.3 | 37.1 | 4.6 |
| 11th grade | 17.6 | 35.0 | 36.8 | 7.6 | 2.4 |
| no earth science | 16.3 | 52.7 | 17.1 | 9.3 | 3.9 |
| earth science | 18.4 | 23.8 | 49.5 | 6.3 | 1.5 |
| college | 67.3 | 8.0 | 17.3 | 6.2 | .9 |
| no earth science | 56.3 | 10.4 | 22.9 | 6.3 | 2.1 |
| H.S. earth science | 56.1 | 8.8 | 28.1 | 7.0 | .0 |
| univ earth science | 80.0 | 4.7 | 7.1 | 7.1 | 1.2 |
| both earth science | 70.6 | 11.8 | 14.7 | 2.9 | .0 |
| trade school | 5.4 | 40.2 | 38.0 | 12.0 | 1.1 |

<u>Question 17</u>.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 61.9 | $\overline{M}$ = 32.6 | $\overline{M}$ = 2.2 | $\overline{M}$ = 1.9 |
| Gender: males | 62.2 | 31.6 | 2.4 | 2.3 |
| females | 61.6 | 33.8 | 2.0 | 1.5 |
| Race: white | 65.5 | 30.0 | 2.0 | 1.2 |
| black | 56.5 | 36.8 | 3.1 | 3.1 |
| Hispanic | 54.7 | 38.2 | 2.4 | 3.3 |
| Asian | 79.2 | 16.7 | .0 | .0 |
| Location: urban | 56.8 | 37.3 | 2.5 | 2.7 |
| suburban | 65.8 | 30.2 | 1.6 | 1.3 |
| rural | 64.3 | 21.4 | 9.5 | 2.4 |
| Level: 5th grade | 59.0 | 31.9 | 3.9 | 3.6 |
| 8th grade | 59.9 | 38.4 | .8 | .8 |
| 11th grade | 60.9 | 34.7 | 1.5 | 2.1 |
| no earth science | 69.0 | 27.1 | .8 | 2.3 |
| earth science | 56.3 | 38.8 | 1.9 | 1.9 |
| college | 72.6 | 23.9 | 1.8 | .9 |
| no earth science | 66.7 | 31.1 | .0 | 2.1 |
| H.S. earth science | 73.7 | 21.1 | 1.8 | 1.8 |
| univ earth science | 76.5 | 20.0 | 3.5 | .0 |
| both earth science | 67.6 | 29.4 | .0 | .0 |
| trade school | 55.4 | 34.8 | 4.3 | 1.1 |

Question 18.

| | a | b | c | d |
|---|---|---|---|---|
| | $\overline{M}$ = 51.3 | $\overline{M}$ = 10.9 | $\overline{M}$ = 25.6 | $\overline{M}$ = 10.0 |
| Gender: males | 47.8 | 9.7 | 27.6 | 12.0 |
| females | 54.8 | 12.1 | 23.9 | 8.0 |
| Race: white | 54.0 | 9.2 | 26.6 | 8.7 |
| black | 50.3 | 10.4 | 30.1 | 6.7 |
| Hispanic | 42.5 | 17.0 | 18.9 | 17.9 |
| Asian | 50.0 | 12.5 | 33.3 | 4.2 |
| Location: urban | 48.8 | 11.9 | 25.0 | 11.3 |
| suburban | 53.2 | 9.7 | 26.5 | 9.3 |
| rural | 50.0 | 19.0 | 23.8 | 7.1 |
| Level: 5th grade | 51.8 | 14.3 | 17.3 | 12.7 |
| 8th grade | 43.9 | 12.2 | 30.4 | 11.8 |
| 11th grade | 52.1 | 8.2 | 30.6 | 8.2 |
| no earth science | 51.9 | 10.1 | 31.0 | 7.0 |
| earth science | 52.4 | 6.8 | 30.1 | 9.2 |
| college | 56.6 | 8.0 | 28.3 | 6.6 |
| no earth science | 64.6 | 6.3 | 18.8 | 10.4 |
| H.S. earth science | 70.2 | 3.5 | 19.3 | 7.0 |
| univ earth science | 44.7 | 10.6 | 38.8 | 4.7 |
| both earth science | 52.9 | 11.8 | 29.4 | 5.9 |
| trade school | 55.4 | 12.0 | 16.3 | 12.0 |

APPENDIX D

APPENDIX D

SUMMARY TABLES FOR THE ANALYSES OF VARIANCE

Analysis of Variance for Misconceptions by Gender

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 1 | 32.0257 | 32.0257 | 8.1641 | .0043 |
| Within groups | 1204 | 4723.0058 | 3.9228 | | |
| Total | 1205 | 4755.0315 | | | |

Analysis of Variance for Misconceptions by Race

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 2 | 68.7725 | 34.3862 | 8.9092 | .0001 |
| Within groups | 1161 | 4481.0239 | 3.8596 | | |
| Total | 1163 | 4549.7964 | | | |

Analysis of Variance for Misconceptions by Educational Level

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 4 | 70.3054 | 17.5763 | 4.4879 | .0013 |
| Within groups | 1197 | 4687.9650 | 3.9164 | | |
| Total | 1201 | 4758.2704 | | | |

Analysis of Variance for Misconceptions by Location

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 1 | 51.0292 | 51.0292 | 13.0410 | .0003 |
| Within groups | 1155 | 4519.4911 | 3.9130 | | |
| Total | 1156 | 4570.5203 | | | |

Analysis of Variance for Misconceptions by Course

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 3 | 22.2304 | 7.4101 | 1.7857 | .1486 |
| Within groups | 634 | 2630.9170 | 4.1497 | | |
| Total | 637 | 2653.1473 | | | |

Analysis of Variance for Misconceptions by Level and Course

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Main effects | 4 | 18.647 | 4.662 | 1.153 | 0.331 |
| Level | 1 | 1.116 | 1.116 | 0.276 | 0.600 |
| Courses | 3 | 12.912 | 4.304 | 1.064 | 0.364 |
| 2-way Interactions | 3 | 29.489 | 9.830 | 2.430 | 0.064 |
| Level Courses | 3 | 29.489 | 9.830 | 2.430 | 0.064 |
| Explained | 7 | 48.136 | 6.87 | 1.700 | 0.106 |
| Residual | 533 | 2236.563 | 4.044 | | |
| Total | 560 | 2284.699 | 4.080 | | |

Analysis of Variance for Misconceptions by Grade

| Source | D. F. | Sum of Squares | Mean Squares | F Ratio | F Prob. |
|---|---|---|---|---|---|
| Between groups | 4 | 40.2967 | 10.0742 | 2.5611 | .0371 |
| Within groups | 1173 | 4613.9886 | 3.9335 | | |
| Total | 1177 | 4654.2852 | | | |

APPENDIX E

APPENDIX E

THE INSTRUMENT

EARTH AND SPACE SCIENCE QUESTIONNAIRE

This questionnaire is part of a study to help find some common misconceptions in the earth sciences. Please mark what you believe to be the most correct answer for each question.

1. Summer is warmer than winter, because in summer:
   a. the sky has fewer clouds.
   b. the earth is nearer the sun.
   c. the earth is better insulated.
   d. the sun is higher in the sky.

2. Each day during the summer months, the amount of daylight:
   a. is more than the day before.
   b. is less than the day before.
   c. is the same as the day before.
   d. has nothing to do with the day before.

3. We can know in advance if there is going to be a very cold winter by:
   a. seeing how cold it was in the last winter.
   b. seeing how hot it was in the last summer.
   c. looking at the thickness of fur on some animals in the fall.
   d. cold winters <u>cannot</u> be accurately predicted by any of these methods.

4. We have day and night because:
   a. the sun goes around the earth.
   b. the moon goes around the earth.
   c. the earth goes around the sun.
   d. the earth spins on its axis.

5. We can use the sun to tell time, because at 12:00 noon, the sun is:
   a. in the eastern sky.
   b. in the western sky.
   c. in the southern sky.
   d. directly overhead (straight up).

6. In May, June, and July, the sun sets:
   a. in the north.
   b. in the north-west.
   c. in the west.
   d. in the south-west.

7. The different shapes (or phases) of the moon are caused by:
   a. weather on the earth.
   b. the shadow of the earth falling on the moon.
   c. the lighted half of the moon sometimes facing away from us.
   d. the large dark craters that are on the moon.

8. The moon shines because it:
   a. reflects sunlight.
   b. makes its own light like the sun.
   c. is like a star, just bigger.
   d. is so very hot that it glows.

9. When we have a full moon, people that same night in Australia:
   a. will also have a full moon.
   b. will have a different phase of the moon.
   c. won't be able to see the moon at all because of clouds.
   d. will have a full moon, but only for half the night.

10. It takes about one ______ for the moon to go around the earth one time.
    a. hour
    b. day
    c. month
    d. year

11. Venus, Mars and Jupiter are planets. We can often see them at night:
    a. but only after midnight.
    b. but only with a telescope or a pair of binoculars.
    c. because every night they are in the same place in the sky.
    d. because they are often brighter than the brightest stars.

12. Falling or shooting stars are really:
    a. rocks that are falling down to the earth.
    b. stars that are falling down to the earth.
    c. the same as asteroids.
    d. the same as comets.

13. Earthquakes can be accurately predicted by:
    a. observing stars and planets.
    b. listening for loud thunder.
    c. observing the behavior of wild animals.
    d. earthquakes <u>cannot</u> be accurately predicted by any of these methods.

14. The terrible floods that occur along a river:
    a. occur only once every 100 years.
    b. can be caused by man.
    c. occur only when snow melts in the spring.
    d. are worst during a full moon.

15. If a crystal can scratch glass, then:
    a. it is a diamond.
    b. it is <u>not</u> a diamond.
    c. it may be a diamond.
    d. it probably is <u>not</u> a diamond.

16. Right now, the direction, north, is:
    a. toward the front of this room.
    b. toward the back of this room.
    c. toward my left.
    d. toward my right.
    e. straight up.

17. The dinosaurs:
    a. lived long before cave-men.
    b. lived at the same time as cave-men.
    c. are still living someplace on earth.
    d. never lived anywhere on earth.

18. It is possible that in the near future Chicago could be severely damaged by:
    a. either a tornado or an earthquake.
    b. <u>neither</u> a tornado nor an earthquake.
    c. a tornado, but <u>not</u> an earthquake.
    d. an earthquake, but <u>not</u> a tornado.

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STUDENT INFORMATION:

19. Gender: a. male b. female

20. Race: a. white b. black c. Hispanic d. Asian e. other

21. Grade: a. elementary b. middle c. high school d. adult/college

22. City of residence: a. urban b. suburban c. rural

23. Last grade received in science: a. A b. B c. C d. D e. F

24. Earth science courses taken: a. high school b. college c. both d. neither

APPROVAL SHEET

The dissertation submitted by Kenneth J. Schoon has been read and approved by the following committee:

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The final copies have been examined by the director of the dissertation and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the dissertation is now given final approval by the Committee with reference to content and form.

The dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Aug 19, 1988
Date

Diane Schiller
Director's Signature