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Middle school science teachers' conceptions of the nature of scientific knowledge

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MIDDLE SCHOOL SCIENCE TEACHERS' CONCEPTIONS OF THE NATURE OF SCIENTIFIC KNOWLEDGE

by

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TOMLINSON, JOHN GARRETT, Ed. D. Middle School Science Teachers' Conceptions of the Nature of Scientific Knowledge. (1992) Directed by Dr. H. Svi Shapiro. 178 pp.

The purpose of this interpretive inquiry study was to ascertain the conceptions of the nature of scientific knowledge of middle school science teachers. Initially, a model of the nature of scientific knowledge was developed from the literature. Scientific knowledge is characterized as humanistic, social, historical, based on specific beliefs, observation based, a result of inquiry, composed of knowledge structures, and unique. The model served as a comprehensive framework against which to compare teachers' conceptions of the nature of scientific knowledge.

The study involved six successful middle school science teachers from urban and suburban/rural school districts. Each subject participated in two unstructured interviews with the researcher.

Results indicate that the teachers possessed a somewhat idealistic view of scientists, a limited conception of the role of scientific communities in the production of knowledge, a confusion of science and technology, a conception of a standardized methodology in science, a positivist perspective of knowledge, and a realist/pluralistic realist view of knowledge. In addition, subjects confused the functions of laws and theories, possessed a popular conception of scientific facts, viewed historical knowledge as cumulative, and had difficulty relating the basic assumptions of science as well as other ways of knowing. Therefore, the study found that the subjects possessed a less than adequate view of the nature of scientific knowledge.

The study concludes that these middle school science teachers were poorly prepared to present to their students an adequate view of the nature of scientific knowledge. Thus, increased emphasis on the nature of scientific knowledge in teacher preservice and inservice training is needed. Recommended changes include academic work/teacher training in the history, philosophy, and sociology of science and the integration of the

dimensions of the nature of scientific knowledge with pedagogy as well as curriculum materials. In addition, an internship at a research laboratory for preservice and inservice teachers is recommended.

INTRODUCTION: PERSONAL PROLOGUE AND PREFACE

Personal Prologue

I am a science educator. A significant part of my being is connected to the discipline of science. Even my relationships with family and friends are influenced by my science self-view. My training in science has influenced how I perceive the natural world around me. I am constantly observing with astonishment the intricacies and complexities of nature. It is humbling to realize how much there is to know and how little is known about the natural world. Science provided me with a mental framework to attempt to understand the natural world. Yet, I began to question that mental framework that I had learned through schooling and educational experiences. This dissertation was motivated by that questioning process in which I began to learn a different perspective of science as a way of knowing.

My interest in science began as a child with the wonderment of the natural world. The "why" and "how" questions began to emerge as I attempted to relate my being to the natural setting in which I was positioned. In school, I began to learn answers to my questions and my curiosity grew. I attempted to understand all the many concepts in the forms of facts, theories and laws of the science discipline, although not really comprehending the personal significance of learning the information. I experienced many successes with "knowing" about science and was encouraged by several significant individuals to pursue science as a career. Not realizing it, science was beginning to become more and more a part of my being and began to influence my world view.

In undergraduate school, the complexities of the natural world began to make an impression on me. The zoology, botany, physics, and chemistry courses all promoted an intricate natural world view that transformed my high school visions into a new view of the structural reality of nature. I was astonished by the amount that humankind knew about the natural world and began to feel comfortable with the conceived certainness portrayed by scientific knowledge. It all seemed very objective based on the absoluteness of observational data and proved by the logic of scientific methodology. It was an intriguing world in which to be involved.

However, in graduate school, a transformation began to occur. It began when I read Thomas Kuhn's book, The Structure of Scientific Revolutions. Gradually a new vision began to form about this world of science that I had felt so comfortable being a participant. I began to wonder about the certainness and absoluteness of knowing in science. I thought about my feeling of the superiority of science as a way of knowing. I began to realize that science had been reified in my training to the extent that the humanness of it was not apparent. Motivated by Kuhn's work, I sought out other works on the subject. Now instead of reading about the subject matter in science, I began to read about the scientific enterprise. Immediately, I realized I had moved into the realm of the philosophy, history, and sociology of science. A completely different view of the world of science in which I previously felt so contented began to emerge. It was an uncomfortable transformation in which I learned how vulnerable our scientific knowledge really is. I believe that so much of humans' identity is interwoven with their visions of the natural world that there is a tendency to "want" our knowledge of it to be certain. However, as history has shown, our "knowledge" of today may become the falsehoods of tomorrow.

Because of this re-awakening of my science world view, I began to reflect on the science education of students. Do students misunderstand science as I once did seeing it in terms of reification and certainty? I researched the question in the literature and discovered my fear was substantiated. The very schooling process of which I am a part was producing students who do not fully understand the nature of scientific knowledge particularly from a historical, philosophical, and sociological perspective. The literature (American Association for the Advancement of Science, 1989; Elliott & Nagel, 1987; Horner & Rubba, 1978; Kuhn, 1970; Padilla, 1983; Rubba, Horner, & Smith, 1981; Tyson & Woodard, 1989; Yager, 1983) advocated that the textbook represents the "truth" about the natural world for students, and it legitimized a science world view of certainty. My concern moved to the classroom teacher who is the key to any change in students' visions. As with students, the literature (Behnke, 1961; Blakely, 1987; Ogunniyi, 1982; Rowe, 1976) confirmed my suspicions. As I had been trained, teachers likewise were being enculturated into a science world view that science is a positivist, factual way of knowing and, in turn, they were portraying science in that way to students. From this very personal concern for science education, I wanted to learn more about the teacher views of scientific knowledge. I wanted to spend time with teachers discussing in detail their conceptions of the nature of scientific knowledge.

Thus, the topic and methodology for this dissertation was born. I decided to talk with teachers about their conceptions of scientific knowledge through an unstructured interview. It would provide me with the framework as well as the flexibility to probe their subjective realities. However, first I needed an understanding of this concept "scientific knowledge." From an exhaustive review of the literature, I constructed a "model" of this entity to compare teachers' responses. It took me well over a year to complete this model. It was very difficult because of the numerous viewpoints of the historical, philosophical, and sociological nature of scientific knowledge. I had to make decisions on which ideas to incorporate in my model, and I found myself reexamining many times the current model as I would read a newly acquired book or article on the subject. However, I am currently satisfied with my constructed model.

I do not concede any special validity to the model, only that the contextual choices made were based on the extensive reading of the topic. It was a subjective procedure, but choices had to be made as in any construction of a model. I know that in the future as I further explore this topic my ideas may change, but that is the nature of learning. I can only say presently that it is the best I can do, and I am willing to defend it as a credible model.

I thoroughly enjoyed the many interactions with the subjects. They enthusiastically discussed their views with me and wanted to learn my viewpoint. I could not help but perceive a thankfulness in the subjects that someone wanted to listen to what they had to say. Many times they struggled with an answer or exhibited "structured silences" as they searched for an answer. Numerous times they expressed the realization that they had not ever thought about many of the questions I asked. It became obvious that many of the concepts of the nature of scientific knowledge were very taken-for-granted by the participant-teachers. The terms were learned in their training but they were never analyzed thoroughly. It was at times uncomfortable for them to admit they did not know an answer or understand some very basic concepts of their discipline. For example, David remarked in his frustration, "That's pretty sad for a science teacher not to know that". However, all the subjects wanted to know more about my research and after the completion of the dissertation, I will visit with them to discuss their viewpoints in relation to the model. I owe that to them as fellow human beings who are searching for an adequate science world view. The teacher-participants inspired me during the years of writing the dissertation. After an interview, I was always energized by their interest and enthusiasm. I felt that I truly had a topic of importance to the science education community.

The most difficult part of the dissertation was the analysis of the subjects' written narratives. I wanted to portray as accurately as possible the subjects' views. I owed that endeavor to them for trusting me with their personal conceptions of scientific knowledge. It was in writing the interpretive narratives that I constantly had to be aware of my subjective mental frameworks that would be imposed on the data. I struggled with the analysis always reading the written narratives many times to enhance an adequate analysis. For some reason, I always would wonder if the narratives would be interpreted in the same way by someone else. However, the frameworks of analysis are the dimensions of the model of scientific knowledge. They are outlined and obvious to those who read them. It was the subjective decision making on "pertinent" data that I had to be constantly analyzing. I can only say that I have to the best of my ability constructed an analysis based on the data and shaped by the frameworks of the model. I am confident that my subjects would agree that my descriptions portray their conceptions of the nature of scientific knowledge.

I believe this study will make a contribution to the science education community because of its depth. Only in the detailed nature of the interviews did the many meanings of scientific terminology and concepts become evident. I believe my recommendations for the improvement of the deficiencies in science teacher world-views would improve their conceptions of the nature of scientific knowledge.

As human beings we have a tendency to believe we can find the truth about nature. We have expended a large amount of energy and resources in an attempt to know about the natural world around us. We are frustrated at times by how little we know and the tentativeness of our knowledge. We must accept that we are limited knowledge seekers and the sociological, historical, theoretical, and philosophical aspects of scientific inquiry influence the resulting knowledge. It is in an in-depth study of scientific knowledge that an appreciation of its tentativeness and lack of absolute validity can be appreciated. It is uncomfortable to realize we don't "know" for certain, but this realization must be part of our struggle to comprehend the natural world. It is in our limitations as human beings that strength can be found to continue our search for understanding. "To know" is tentative. Scientific knowledge is not the truth but human's attempt to create personal understanding. The Greek philosopher Zenophanes (Magee, 1985) says it best by explaining:

> The gods did not reveal, from the beginning,
> All things to us, but in the course of time
> Through seeking we may learn and know things better.
> But as for certain truth, no man has known it,
> Nor shall he know it, neither of the gods
> Nor yet of all the things of which I speak.
> For even if by chance he were to utter
> The final truth, he would himself not know it:
> For all is but a woven web of guesses. (p. 24)

Preface

This study is a portrayal of the conceptions of six middle school science teachers about the nature of scientific knowledge. An attempt was made to reveal the subjective realities of the participants in an effort to make explicit the obvious as well as tacit meanings conceived about scientific knowledge. The importance of teachers in conveying an adequate vision to students of the dynamic nature of scientific knowledge cannot be overemphasized. Only by understanding teachers' conceptions in an in-depth manner can strategies be taken to improve deficiencies in their comprehension of the nature of scientific knowledge. The term "nature of scientific knowledge" is a very complex entity which involves historical, sociological, humanistic, and philosophical interactions. The study attempts to bring all of those elements together by the creation of a model of the nature of scientific knowledge. The eight dimensions of the model describe the complexities of these elements and their interrelationships. In addition, the model served as an interpretive framework against which to compare subjects' views about the nature of scientific knowledge. The implications of this study can have dramatic effects on the manner in which science teachers are currently trained.

Chapter One explains the nature and significance of the problem as well as reviews the literature on the topics of students' and teachers' conceptions of the nature of scientific knowledge. An operational definition of the nature of scientific knowledge as well as an explanation of the meaning of an "adequate" understanding of the nature of scientific knowledge are provided to assist the reader in understanding the terminology. Furthermore, scientific literacy and its relationship to an adequate understanding of the nature of scientific knowledge is examined. A description of the research studies on students' and teachers' understanding of scientific knowledge is given. Finally, the importance of the classroom teacher to curricular changes is outlined, and an explanation is provided of the importance of middle school science instruction.

In Chapter Two, a detailed description of a model of the nature of scientific knowledge based on the literature is given. Initially, the model is portrayed in an outline form with descriptor phrases followed by brief explanations. The remainder of the chapter is composed of detailed descriptions of each of the eight dimensions of the model.

A depiction of the study's methodology is provided in Chapter Three. The introduction describes the deficiencies of previous studies on the nature of scientific knowledge and the rationale for the use of the interpretive inquiry methodology in the study. The nature of interpretive inquiry as a methodology is given to assist the reader in an understanding of its basis and its goal of a particular understanding. The limitations and strengths of interpretive inquiry as well as the rationale of the generalizability of the study are outlined. Unstructured interviews as "a conversation with a purpose" are described to assist the reader in a comprehension of that particular methodology. The procedure of the study is outlined depicting the selection of the subjects, the initial conference, the interview format, and the analysis of the subjects' narratives. Finally, subject profiles are given to provide the reader with an understanding of the biographical and professional backgrounds of the six subjects.

Chapter Four describes the participating middle school science teachers' conceptions of the importance of science education and each dimension of the model of the nature of scientific knowledge as well as outlines subjects' conceptions of the influences of their views on their teaching methodologies. This chapter was the result of an in-depth analysis of the written narratives of each subject's interview. Through the use of subjects' quotes, the description freezes instances in the interviews to analyze both their explicit as well as implicit meanings. It is in this chapter that "what is said" is given and then "what is meant" is described. The chapter attempts to depict the nature of scientific knowledge as viewed by the six teacher-participants.

Lastly, Chapter Five summarizes the major findings of the study and portrays the implications of the study's findings on the training of science teachers. In addition, recommendations are proposed on strategies to improve science teachers' conceptions as well as for further research into this area.

In summary, it was with deep personal concern that I undertook this study. The concern was for the students in our schools as well as the teachers in the "everydayness" of their profession. In addition, there was a concern for my personal understanding of a very complex issue - the nature of scientific knowledge. I strived for a disciplined study coupled with an openness to provide the depth I needed to ascertain an understanding of the subjective realities of the teacher-participants. It has been a personally rewarding journey into an exciting world of scientific knowledge and teacher world views. I realize the difficulties of attempting a personally meaningful study and producing "knowledge" from it that can be objectified to the rest of the science education community. In final analysis, the value of this study lies in the success it has in combining both of these goals.

CHAPTER I

SCIENTIFIC LITERACY, STUDENTS, TEACHERS, AND THE NATURE OF SCIENTIFIC KNOWLEDGE

Introduction

Scientific literacy is widely stated as a goal of science education. As the world becomes increasingly scientifically oriented, individuals need an adequate understanding of science. Scientific illiterates are strangers in their own society. Being ignorant of science, they are not able to comprehend the debates of scientific issues, much less influence them. Although there are many definitions of "scientific literacy," one widely accepted dimension is the adequate understanding of the nature of scientific knowledge (American Association for the Advancement of Science, 1989; Association for Science Education, 1981; Bybee, 1986; McCormick, 1989; National Assessment of of Educational Progress, 1989; National Science Teachers Association, 1982; Showalter, Cox, Holobinko, Thompson, & Oriedo, 1974). Many science educators advocate an increased emphasis on the nature of science and scientific knowledge in science instruction and curriculum development (Abimbola, 1983; Aikenhead, 1986a, Bybee, 1986; Clough, 1989b; Gallagher, 1984; Hodson, 1988).

In response to the growing consensus on the importance of students' comprehension of the nature of scientific knowledge, three new national curriculum development projects as well as a national assessment instrument are including this dimension as a fundamental part of their reform recommendations. "Project 2061: Science For All Americans," a project of the American Association for the Advancement of Science (AAAS), is currently developing curriculum models that include methods of scientific inquiry, the essence of the scientific enterprise, and the scientific perspective (AAAS, 1989). The Biological Sciences Curriculum Study (BSCS) is designing a science program specifically for middle school students titled "Science and Technology: Investigating Human Dimensions" that includes curriculum emphases of the nature of science and scientific explanation (BSCS, 1990). The National Science Teachers Association (NSTA) has initiated a major science curriculum reform program, "Scope, Sequence, and Coordination of Secondary School Science" in which students will investigate the basic ideas of the nature of scientific knowledge (NSTA, 1990). In addition, the 1989-90 National Assessment of Educational Progress (NAEP) measurement of students' knowledge of science expanded its previous efforts to include the nature of science (NAEP, 1989).

Locally, North Carolina is a curriculum development center for National Science Teachers Association's Scope, Sequence & Coordination project. The "North Carolina Project For Reform In Science Education" is developing a middle school curriculum framework in which an important strand is the historical perspective that emphasizes an adequate understanding of the operation of the scientific enterprise (North Carolina Project for Reform in Science Education, 1991). In addition, the state science curriculum of North Carolina is being revised to include as one of its strands the nature of science.

The increased emphasis on the epistemological nature of science in assessment and curriculum development is hoped to improve students' distorted notions about this fundamental dimension of scientific literacy. Studies show that students confuse the functions of models, laws, and theories (Aikenhead, 1987), use terms like scientific method, science, and technology in contradictory ways (Fleming, 1987; Ryan, 1987), and think science produces indisputable, absolute truths (Fleming, 1986; Rubba, Horner & Smith, 1981). Students prescribe to the following popular view of scientific knowledge: "Science knowledge is proven knowledge.... Personal opinion or preferences and speculative imagining have no place in science. Science is objective. Scientific knowledge is reliable knowledge because it is objectively proven knowledge." In addition, students apparently do not understand the aims of science, its processes, its human dimensions, nor its interactions with society.

Students' fundamental misconceptions about the nature of scientific knowledge must result, in part, from the type of science instruction they receive in schools. Through the use of textbooks and traditional instructional methodologies, school science portrays scientists as idealized and depersonalized pursuers of the truth about an objective reality using a particular infallible step-by-step scientific method. Projecting an inductivist-positivist image of science, schools advocate that knowledge is induced from generalizations based on unbiased observations (Abimbola, 1983; Clough, 1989a). The emphasis of school science on vocabulary and concepts reifies knowledge discounting the human element in its creation. Through the use of "cookbook" type laboratory exercises, hypotheses are viewed as simple guesses and theories are believed to be proven by objective direct observations and easy yes/no analysis (Hodson, 1988). Scientific laws are taught to students as validated, established theories. Schwab (1960) characterizes such instruction in science as the "rhetoric of conclusions." Traditional classroom methods "treat only the outcomes, the conclusions of enquiry, divorced from the data which support them and the conceptual frames which define and limit their validity" (Schwab, p. 8). Lacking in school science is any discussion of other ways of knowing as well as the scientific community's activities in the dissemination and validation of scientific knowledge.

Thus, current pedagogical methods distort the nature of scientific knowledge by providing a simplistic view of a very complex humanistic enterprise. The result of the continued usage of traditional instructional techniques and curriculum materials will have far reaching consequences to the acquisition by students of an important dimension of scientific literacy. The key to any improvement in students' conceptions of the nature of scientific knowledge either through new instructional techniques or new curricular materials is the science teacher.

The Problem, Its Nature, And Its Significance

The most important element in the instructional process as well as the primary arbitrator of the science curriculum is the science teacher. The science teacher mirrors a view of the nature of scientific knowledge and represents the image of science for students. Conceptions of the nature of scientific knowledge will influence the language used, the topics that are emphasized, the investigative procedures employed, the evaluation methods implemented, the use of textbook/resource materials, and the resulting student interactions. These elements of instruction compose the teaching style which is one of the most important factors influencing students' view of the nature of scientific knowledge (Rubba & Horner, 1981). The assertion is that science teachers' conceptions of the nature of scientific knowledge influence their teaching practices which in turn affect students' views of the scientific enterprise.

Unfortunately, numerous research reports reveal that science teachers possess many of the same fundamental misconceptions about the nature of scientific knowledge as students (Behnke, 1961; Billeh & Malik, 1977; Blakely, 1987; Carey & Stauss, 1968, 1970; Hodson, 1988; Kimball, 1967-68; Miller, 1963; Rowe, 1976; Schmidt, 1967-68). For example, many science teachers confuse science and technology, possess an inductivist-positivist perspective of science, subscribe to the belief of a step-by-step scientific method that portrays a direct relationship between observation and theory, and promote a naive realist position. These distorted notions of the nature of scientific knowledge do not seem to be related to the number of years of teaching experience, college grade point average nor the number of college science courses (Billeh & Hasan, 1975; Carey and Stauss, 1970; Kimball, 1967-68). These misnotions are reflected in their teaching styles and perpetuate students' misconceptions about the nature of scientific knowledge.

Therefore, it appears that an obstacle to students achieving a widely accepted dimension of scientific literacy, an adequate understanding of the nature of scientific knowledge, is the science teacher. Since the middle school level of education represents a critical time in a student's development of attitudes toward science, an understanding of middle school science teachers' views about the nature of scientific knowledge is very important. Any misconceptions learned by students during the middle school years will be especially difficult to correct at the high school level.

It is the responsibility of science educators to present an adequate view of scientific knowledge to students. Because the teacher is at the focus of the curricular recommendations to improve students' views of the nature of scientific knowledge, it is imperative to recognize the importance of adequate conceptions of teachers in achieving any desired goals. Only when the many dimensions of teachers' views of the nature of scientific knowledge are analyzed can science educators begin to address the problems and design methods to correct the situation through the preservice or inservice training of teachers. As science education enters a new decade with an increased nationwide emphasis on this very important dimension of scientific literacy, the science education profession needs to promote an adequate understanding of the nature of scientific knowledge among its practitioners.

The Nature of Scientific Knowledge - An Operational Definition

Science is a quest for understanding of the natural world, and the activity of the quest results in "scientific knowledge." Although the nature of scientific knowledge may be viewed as a part of a larger concept of the "nature of science", the term "nature of scientific knowledge" is defined in this research study in such a comprehensive manner that it incorporates most of the widely accepted dimensions of the "nature of science" concept. Thus, discussions of relevant literature will include references to the nature of science as well as to the nature of scientific knowledge. It was important in analyzing scientific knowledge not only to examine the products (facts, theories, and laws), but the processes that produce the resultant knowledge. Therefore, in this research project, the term "nature of scientific knowledge" describes the human dimensions, social nature, historical elements, inquiry processes, basic beliefs, and uniquenesses that are involved in the production of such knowledge as well as the nature of the resulting products. In Chapter Two, a detailed description of each dimension of a conceptual model of the nature of scientific knowledge is presented. Any reference in the research study to an "adequate" understanding of the nature of scientific knowledge refers to a comprehension of the dimensions of the conceptual model.

Scientific Literacy and the Importance of Science Education

The National Science Teachers Association (NSTA) has emphasized that the primary goal of science instruction is to increase the scientific literacy of students (NSTA, 1982; NSTA, 1987; NSTA, 1990). The world will change radically in the future, and science as well as technology will be at the focal point of that change - producing, forming and reacting to it. It is essential that individuals understand the nature of scientific knowledge because science permeates all realms of human activity and affects the quality of life.

Scholars have attempted to describe the characteristics of a scientifically literate person. The literature reveals that the scientifically literate individual:

1. Understands and appreciates the diversity and unity of the natural world (American Association for the Advancement of Science, 1989; McCormick, 1989; Rothman, 1989).

2. Comprehends the nature of science as a human enterprise with both great potential and limitations as well as understands the historical dimensions of science. (American Association for the Advancement of Science, 1989; Bybee, 1986; Kimball, 1967-68; Lederman, 1985; McCormick, 1989; Rothman, 1989; Rubba & Andersen, 1978; Showalter, Cox, Holobinko, Thompson, & Oriedo, 1974; Voelker, 1982).

3. Understands the nature of scientific knowledge, the investigative procedures, and applies key scientific constructs such as laws, hypotheses, facts, and theories accurately (American Association for the Advancement of Science, 1989; Lederman, 1986; McCormick, 1989; Rothman, 1989; Rubba & Andersen, 1978; Showalter et al., 1974).

4. Utilizes the processes of science and scientific ways of thinking in solving problems and decision making in everyday life (American Association for the Advancement of Science, 1989; Haney, 1964; Lederman, 1986; McCormick, 1989; Rothman, 1989; Showalter et al., 1974).

5. Possesses feelings and values consistent with the essence of science (Rubba & Andersen, 1978).

6. Comprehends the role of science in society and its interrelationships with technology (Kyle, Jr., 1984; Rubba & Andersen, 1978; Showalter et al., 1974).

The dimensions of scientific literacy are incorporated in the numerous stated goals of science education. A National Science Foundation (NSF) research study, Project Synthesis, interpreted data from three NSF studies as well as the National Assessment of Educational Progress study and formulated four "goal clusters" which summarize the primary aims of science education as indicated by the existing literature. The clusters indicate learning objectives in four classifications of relevance for (a) the individual, (b) society, (c) academic preparation, and (d) career selection (Kahl & Harms, 1981).

The first goal cluster relates science education to the personal needs of the individual. The emphasis of this goal cluster is the preparation of individuals to use science for the improvement and management of their lives in an increasingly scientific world (Kahl & Harms, 1981). These goals include the knowledge a person needs in order to be a responsible consumer and the ability to recognize and comprehend how science affects one's life. Individuals need to possess the inquiry and critical thinking skills to understand

and interpret information in a systematic way to make informed, responsible decisions (Aldridge & Johnston, 1984; Bybee, 1984; National Science Teachers Association, 1987; Norris, 1985; Rothman, 1989; Siegal, 1985; Steen, 1989). Ultimately, the purpose of science education is to prepare individuals to lead personally responsible and fulfilling lives by liberating their human intellect (American Association for the Advancement of Science, 1989).

The second goal cluster relates to the needs of society and emphasizes science education as an avenue to produce responsible citizens who are able to deal intelligently with complex science related issues of society such as pollution or nuclear energy (Aikenhead, 1986a; Aldridge & Johnston, 1984; Bybee, Carlson, & McCormack, 1984). Citizens need to understand the nature of science and its potential to not only solve societal problems, but to create new ones. Thus, individuals must possess the initiative to understand public policy on scientific issues and the skills to influence it (Kahl & Harms, 1981; Koballa, Jr., 1984; McCormick, 1989; Voelker, 1982). A sense of appreciation and custodianship of the natural world should be fostered (Kahl & Harms, 1981). Other goals in the literature that relate to this Project Synthesis goal cluster state the importance of science education to maintaining and improving nationalistic goals such as the economy (Bybee et al., 1984; Connelly, 1969; Mullis & Jenkins, 1988), security (Aldridge and Johnston, 1984), productivity (McCormick, 1989), and citizenship participation (Bybee, 1986; McCormick, 1989; Connelly, 1969; Mullis & Jenkins, 1988).

The third goal cluster advocated by Project Synthesis includes the science education goals that relate to academic preparation. The opportunity should be available to those individuals who desire to professionally and academically advance in acquiring scientific knowledge. The goal relates to the acquisition of the necessary science courses that must be completed to further a study of science. (Goodlad, 1984; Kahl & Harms, 1981;

McCormick, 1989). Science education should produce the next generation of scientists (Aikenhead, 1986a; Bybee et. al., 1984; Harms, 1981; McCormick, 1989).

The last goal cluster involves career education awareness. Although related to the previous goal cluster, the career awareness cluster includes any careers related to the scientific field from scientists to lab technicians. These goals emphasize the availability of careers as well as the extent of required academic preparation. Also, students should be cognizant of famous scientists and their contributions as well as the human factor in the scientific enterprise (Campbell, 1985; Kahl & Harms, 1981; Mackay, 1971).

Thus, the term "scientific literacy" contains many dimensions, and these dimensions are interwoven in the numerous goals of science education. One dimension that is widely accepted as being a fundamental element of scientific literacy as well as a very important goal in science education is the adequate understanding of the nature of scientific knowledge. It is this dimension that permeates all comprehensions of science and provides individuals with a firm basis to understand the complexities of the scientific enterprise.

The Importance of an Adequate Understanding of the Nature of Scientific Knowledge

Although an understanding of the nature and functions of the products of science (facts, theories, and laws) is important, a comprehensive view of the social, historical, regulatory, humanistic, and investigative perspectives of knowledge production provides an individual with a complete world view of science. Personal and social decisions are made not on the content of science learned, but on an understanding of the character, processes and limits of the scientific enterprise (Aikenhead, 1987; Fleming, 1986). Latour and Woolgar (1986) state:

> Science ... generates too much hope and too much fear. If the public could be helped to understand how scientific knowledge is generated and could understand that it is comprehensible and no more extraordinary than any other field of endeavor, they would not expect more of scientists

> than they are capable of delivering, nor would not fear
> scientist as much as they do (p. 13).

An authentic view of the nature of scientific knowledge creates the realization that science cannot produce easy solutions to complex problems, the so called "technological fix." The myth of "scientism", the excessive faith in the rationality and objectivity, would be discouraged (Aikenhead, 1986a).

Furthermore, for individuals who understand the humanistic and tentative nature of knowledge, confusion is avoided when new information contradicts traditional scientific principles or when two research projects interpret the same data differently producing contradicting results (Connelly, 1969; Crowell, 1989; Hickman, 1984). Cynicism about science can be avoided if individuals understood the conditional nature of scientific facts, theories, and laws. The tentative reliability of science is understood when major restructuring of knowledge occurs especially in the current age in which knowledge possesses such a short "half-life" (Benjamin, 1989).

Thus, understanding the nature of scientific knowledge promotes confidence to question statements of science, to be open to new answers, and to critically analyze scientific decisions that influence the well-being of our society. Furthermore, a basic understanding of knowledge production yields insights into the interactions between the scientific community and society. It provides a deeper understanding and personal reflection of the complexity of the natural world and the immense difficulty of understanding it.

Students' Views of the Nature of Scientific Knowledge

Most research studies conclude that students have not attained an adequate understanding of the nature of scientific knowledge. Student conceptions of science are often as mystical as realistic (Aikenhead, 1986a). The majority of the tests to access student understanding are objective measures using multiple choice answers or a Likert scale. A few of the measures allow for written responses to questions or explanations to answers.

The Test on Understanding Science (TOUS) was developed by Cooley and Klopfer (1961) and consists of 60 multiple choice questions dealing with understandings of the scientific enterprise, scientists, and aims/methods of science. MacKay (1971) used TOUS to measure the comprehension of science of over 1200 seventh-tenth grade students and found pupils lacking an understanding of the dynamic, ongoing nature of science. Students confused the functions and distinctions of models, theories, and laws as well as the relationship of scientific facts and truth. Students were also unclear about the difference between science and technology. Jungwirth (1973) used one part of TOUS, "Scientists as People," and studied 613 ninth graders, 610 tenth graders and 213 twelfth graders in Israel. He discovered misconceptions about the role, motivations, and characteristics of scientists.

A recent study of 10,800 high school students in Canada by Aikenhead, Fleming, and Ryan (1987) used an instrument called Views On Science, Technology, and Society (VOSTS) in which students agreed, disagreed, or could not respond to 46 statements and were required to write an explanation of their choice of an answer. VOSTS examined the characteristics of scientific knowledge, scientists, and the interactions of science, technology and society. In examining the argumentative student explanations, the investigators found that students used terms like scientific method, facts, the tentativeness of knowledge in many and contradictory ways. Students were uninformed on the external influences on scientific knowledge, the authentic motivation of generating science knowledge, the realistic view of the scientific inquiry, and the basis of principles, models, and classification schemes. In general, they conceived of a scientific method that entailed following prescribed procedures meticulously. Students viewed scientific facts in many ways including as proven entities. Students did confuse science with technology and the authors referred to the combination as "technoscience" (Aikenhead, 1987; Ryan, 1987).

Considered as one of the best measures of students' understanding of science on a national basis is the National Assessment of Educational Progress (NAEP) science assessment which samples 9-, 13-, and 17-year olds. The test requires students to answer multiple-choice questions on areas of content, context (scientific, societal, personal and technological), and cognitive areas. Based on the 1976-77 assessment which sampled 17,345 nine-year olds, 25,653 thirteen-year-olds, and 31,436 seventeen-year-olds, Welch (1981) reports that 70% of the students understood the significance of observation in science, but less than half were cognizant of errors that are inherent in the measurement process. Less than 60% of the students knew that science knowledge is based on specific assumptions and only 25% and 32% (nine- and thirteen-year-olds respectively) realized that all science concepts are not thoroughly understood. Welch (1981) concludes that students seem to conceive science as something done by others rather than a process that could be incorporated into their ways of thinking. The 1986 NAEP assessment which sampled a total of 6,932 nine-year-olds, 6,200 thirteen-year-olds, and 3,868 seventeen-year-olds supports the previous findings with students' knowledge of science and their integration abilities being very limited (Mullis & Jenkins, 1988).

Other inquires into students' understanding of the nature of scientific knowledge reveal similar deficiencies. The 1989 International Assessment of Mathematics and Science (including the United States and four other countries as well as four Canadian provinces) found that only 42% of the sampled American 13-year-old students understood scientific procedures and data analysis (Lapointe, Mead, & Phillips, 1989). Horner and Rubba (1978) conducted a survey at a mid-western high school in the United States and found that 30% believed that scientific research produces indisputable, absolute truth as well as exhibited the belief that theories mature into laws. A study by Fleming (1986) revealed that students believed that facts are equivalent to the truth, and scientists are viewed as the "keepers of the truth" (p. 208).

Furthermore, Rubba, Horner, and Smith (1981) surveyed 40 seventh and 62 eighth graders using a Likert scale questionnaire that asked questions about scientific laws/theories and their relation to truth. They found that the surveyed students did not understand science "well enough to appreciate the tentative nature of scientific knowledge" nor that "scientific laws and scientific theories are two distinct types of explanations" (p. 225). Other reports reveal that students generally do not possess an adequate understanding of the nature of scientific knowledge (Cawthron & Rowell, 1978; Cooley & Klopfer, 1963; Lerner & Bennetta, 1988; Mead & Metraux, 1957; Miller, 1963; Mitias, 1970).

Some studies do reveal encouraging findings about students' conceptions of the nature of scientific knowledge. The 1976-77 National Assessment of Educational Progress did find that 80% of students tested believed that theories change (Welch, 1981). Aikenhead (1987) found that 75% of students knew the impreciseness and human character of classification schemes as well as most students believed scientific knowledge is tentative. A study of 409 biology students by Lederman (1986) using the Nature of Scientific Knowledge Scale that uses 48 statements in a Likert scale response format revealed that sampled students' conceptions of the nature of science were adequate.

Although there are some contradictions, at least most of the research studies indicate that substantial numbers of students possess misconceptions about the nature of scientific knowledge. They believe that science supplies right answers, the application of a "scientific method" yields objective valid data, models/classification schemes represent realities in nature, basic knowledge is unchanging, theories evolve into laws, and science and technology are synonymous.

The Importance of the Classroom Teacher

The significance of the classroom teacher to the learning process as well as execution of the curriculum is extensively supported in the literature. Teacher practices such as modes of presentation, verbal/nonverbal behaviors, language usage, task selection, classroom management, and instructional style determine to a large degree the quality and level of students' learning (Abimbola, 1983; Harms, 1981; Lunetta & Penick, 1983; Skymansky & Penick, 1981; Wiggins, 1989). Because students learn many behaviors by imitation and identification, the role model created by the teacher is very influential. The science teacher is the image of science for students. Watson (1983) states that "the view of science in the classroom is created by the teacher and mirrors the views of the teacher" (p. 51).

Specifically, studies by Benson (1984), Lederman (1985, 1986), and Zeider and Lederman (1987) substantiate that certain teaching practices (frequent inquiry-oriented questioning, problem solving, sequential probing, relevancy of studies, and personable student-teacher interactions) positively influence students' conceptions of the nature of scientific knowledge. Furthermore, teachers' epistemological conceptions of science are a factor in determining personal positions on the selection of content and implementation of instructional methods which influence students' views. Dibbs (1982) found a positive relationship between teachers' beliefs in a particular philosophy of science and their teaching styles which in turn affect students' understandings. Dibbs states:

> Pupils' views about the philosophy of science are influenced by the way in which they are taught science even if their teacher does not attempt to do so explicitly. The teaching style used implies that the teacher holds a certain philosophy, and this implicit philosophy can have effects upon the pupils. Pupils taught in different ways exhibit a different pattern of responses on specially designed measures for science understanding. (p. 226)

Benson's (1984) inquiry into the conceptions of biology teachers supports Dibbs' study by finding that teachers strongly influenced students by their particular views of biology.

Furthermore, the language teachers use in instruction can affect students' conceptions of the nature of scientific knowledge. Munby (1976) emphasizes that "the language in which science instruction is given is significant for the understanding it can convey about the nature of science" (p. 115). Zeidler and Lederman's (1987) study of 18 biology teachers "concluded that the ordinary language teachers use to communicate science content does provide the context in which students formulate their own conceptions of the nature of science" (pp. 6-7). For example, a realist perspective views scientific knowledge as real, true, and having its own reality. Scientific descriptions are viewed as fixed, objective and empirical truths. An alternative perspective of scientific knowledge is the instrumentalist view in which scientific statements are products of human imagination used to make inferences and construct models to explain phenomena. It views knowledge as changing, utilitarian, and tentative. In a comparison of the instrumentalist and realist language used by biology teachers, Zeidler and Lederman's (1987) study found that teachers' views of the nature of scientific knowledge as expressed in their language is persuasive.

In addition, the teacher is the ultimate mediator, interpreter and clarifier between the curriculum and the student. It is teacher characteristics that are more important than a particular set of curriculum materials. Since the teacher is at the center of many recommendations to improve deficiencies in students' understanding of the nature of scientific knowledge, it is imperative to realize that the teacher is the critical factor in achieving any desired goals. The knowledge, philosophy and instructional style of the teacher must be in agreement with the curricular objectives and methods for the materials to be successful (Bates, 1978; Harms, 1981). Schwab (1960) states, "If the structure of teaching and learning is alien to the structure of what we propose to teach, the outcome will inevitably be a corruption of that content" (p. 15). Herron (1971) advocates:

> By the intellectual milieu he [the teacher] fosters,
> by the conceptual contexts he engenders in the minds
> of his students, indeed, by virtue of the topics he
> emphasizes (and tests for) and those he does not, he
> is in a position to either amplify or short-circuit
> the purposes of those who developed the course materials. (p. 204)

Specifically referring to curriculum development to improve students' understanding of the nature of science, Carey and Stauss (1970) emphasize that:

> If the teacher's understanding and philosophy of science is not congruent with the current interpretation of the nature of science; if the objectives that he establishes are not congruous with the dynamic spirit of science, then the instructional outcomes will not be representative of science in spite of all the efforts that may be expended by those charged with the development of relevant curricular materials. (p. 368)

Thus, the classroom teacher has a pivotal role in any attempt through curriculum reform as well as better instructional methodologies to improve students' understanding of the nature of scientific knowledge. Teachers' views of the nature of scientific knowledge influence explicitly as well as implicitly teaching practices, language used, selection of materials, and implementation of curriculum. Any deficiencies in teachers' conceptions must be addressed and rectified before students' understandings can be improved.

Teachers' Understandings of the Nature of Scientific Knowledge

If students are to acquire an adequate comprehension of the nature of scientific knowledge, teachers need to possess an adequate understanding in order to instill its essential qualities in students. However, most researchers indicate that inservice and preservice science teachers, in general, do not possess an adequate understanding of the nature of science (Behnke, 1961; Billeh & Malik, 1977; Blakely, 1987; Carey & Stauss, 1968, 1970; Hodson, 1988; Kimball, 1967-68; Miller, 1963; Rowe, 1976; Schmidt, 1967-68). Schmidt (1967-68) commented that "some secondary science teachers understand science no better than students they may be assigned to teach." (p. 365). Hodson (1988) discloses that a 1979 Association for Science Education report in the United Kingdom states that:

> Most science teachers, who are themselves products of a science education that places a high premium on scientific knowledge and pays lip service to the history and philosophy of science, share ... a scant understanding of the nature of scientific knowledge. (p.21)

Prospective science teachers have been the object of several studies. Carey and Stauss (1968) used the Wisconsin Inventory of Science Processes (WISP), a test of 93 statements on the assumptions, activities and products of science, in conjunction with an essay question, "What is your concept of the nature of science?", to measure the understanding of prospective science teachers in a science methods class. Although results of the study indicated the majority recognized the human element in science, a minority confused science and technology, and there was an indication of a lack of an adequate concept of the nature of scientific knowledge. Ogunniyi (1982) evaluated the understanding of the nature of science of 53 prospective science teachers by their use of language to describe science. The measure administered was the Language of Science Test which consists of 64 statements based on the language of science concepts held by selected philosophers. The results indicated that most subjects conceived laws and theories as verifiable and true, thought science terms such as atom, electron, and molecule were empirical concepts, and generally did not possess an adequate notion of the nature of scientific knowledge.

Several studies compared the understanding of the nature of science between practicing teachers and students. Miller (1963) used the Test on Understanding Science (TOUS) to compare levels of understanding of science teachers to secondary students. Miller found that 38% of the advanced eleventh and twelfth grade students scored above 50% of teachers. Miller's study was replicated by Schmidt (1967-68), and the results indicated that 47% of the students scored above 25% of the teachers and 9% above 50% of the teachers. Behnke (1961) used a survey instrument with statements about the scientific enterprise to analyze the opinions of 621 science teachers. The most surprising finding by Behnke was that 51% of science teachers agreed strongly that scientific knowledge was unchangeable and fixed. Behnke concludes that "much of the misunderstandings ... were related to a lack of understanding of the nature of science" (p. 200). Carey and Stauss (1970) surveyed 31 experienced science teachers with the WISP instrument and their findings supported previous studies that science teachers do not possess an adequate understanding of the nature of scientific knowledge.

In more recent studies, Rowe (1976) investigated the conceptions about laws and theories of 50 randomly selected middle/junior high school science teachers using an opinionnaire that required responses indicating agreement, disagreement, uncertainty or confusion with a series of statements. The results indicated that the sampled teachers' views of laws and theories were contradictory and inconsistent. Blakely (1987) used TOUS to sample 91 middle school teachers' understanding of the nature of science. Blakely concluded that at least 25% of the science teachers:

> Confuse science and technology; misunderstand how scientists cooperate with one another;... fail to discriminate among laws, theories, and hypotheses; and are unsure of the purpose of scientific experiments and the aims of science. (p. 354)

However, other studies have found that in comparing mean scores of teachers to the mean scores of students, teachers' scores were higher than students (Broadhurst, 1967; Welch & Pella, 1968). Lederman (1985, 1986) administered the Nature of Scientific Knowledge Scale to high school biology teachers and concluded that participating teachers possessed an adequate conception of the nature of science.

Some studies have attempted to determine the relationships of teachers' understanding of the nature of scientific knowledge to some academic/teaching experience variables. Carey and Stauss (1970) investigated teachers' understanding in relation to the variables of teaching experience, college grade point average, science credit hours and high school science courses. In the sample of 31 science teachers, they found little relationship between the variables and teachers' conceptions of the nature of science. In a previous study, Carey and Stauss (1968) also found no relationship to academic variables (number and grades of science courses taken) and an understanding of science using the WISP instrument. Blakely (1987) found no significant differences in the scores on TOUS of 91 middle school teachers based on the number of methods classes taken in preservice training or the possession of middle school certification. Billeh and Hasan (1975), Billeh and Malik (1977) and Kimball (1967-68) found in their research studies that teaching experience does not have a significant affect on teachers' understanding of the nature of scientific knowledge. Therefore, it appears that conceptions of the nature of scientific knowledge are formed before, during or by the end of preservice training and remain virtually unchanged by teaching experience.

Thus, preservice and inservice teachers do not possess an adequate understanding of the nature of scientific knowledge based on the majority of studies. There exists a confusion of science and technology, an inductivist-positivist perspective of science, and a belief in the stability of scientific knowledge. Even in a comparison with the students they are teaching, studies indicate the teachers' understanding is not much greater, and in some instances, less than some of their students. Academic and experience variables do not seem to relate to levels of understanding of the nature of scientific knowledge. Therefore, it cannot be assumed that when science educators discuss the dimensions of the nature of scientific knowledge that they fully understand those concepts.

Middle School Science: Its Importance

The middle school is an administrative structure that usually encompasses grades 6-8 or 6-9 and the student age group of 11-14 years old. The middle school years represent the time students are forming attitudes about themselves in relation to school and in relation to science. Modes of behavior, patterns of thought, and basic attitudes are being established in the early adolescent (Pratt, 1981; Padilla, 1983; Yager, Aldridge & Penick, 1983; Smith, 1983). It is in middle school that students begin to make decisions about their future science study. Simpson (1978) and Voelker (1982) assert that by the ninth grade, students have established their attitudes about science. If middle school students develop a negative attitude about science, it influences future performance and views about the nature of science and its usefulness. Any failure students experience in middle school may convince individuals that they are incapable of learning or understanding science. Furthermore, if students learn an unrealistic view of the nature of scientific knowledge in middle school years, it is even more difficult to resolve misconceptions later in the schooling process.

Therefore, it is important that particular attention be given during the middle school years to establish positive attitudes toward science and a realistic view of the nature of scientific knowledge. It is an ideal place in the schooling process to institute changes in the present content oriented science instruction because (a) learners are at the point in their intellectual development to begin to understand the complex nature of knowledge production and (b) the middle school science curriculum is integrated, interdisciplinary, and exploratory in nature (Thier, 1984).

Also, middle school teachers tend not to be single subject specialists (i.e. biology, physics, chemistry) and would be less content oriented. Classroom instruction could emphasize science processes and inquiry to explore science questions instead of an emphasis on the preparation for the next science course. Promoting the use of science skills (observing, hypothesizing, collecting data, and experimenting) would provide the middle school student with the opportunity to be theorists and to understand a realistic perspective of the production of science knowledge (Padilla, 1983). A multidimensional approach to science could be implemented using practical applications and everyday experiences including issues in society as well as the historical aspects of scientific thought.

Thus, the middle school represents a critical period for students in their development of attitudes and concepts about the nature of scientific knowledge. In addition, the middle school is an excellent place in the schooling process to institute changes in science education from the content driven curriculum to one modeled after a realistic view of the nature of scientific enterprise.

Summary

Scientific literacy is a widely accepted goal of science education. An important dimension of scientific literacy is an adequate understanding of the nature of scientific knowledge. An adequate epistemological comprehension of science provides an understanding of the social, historical, regulatory, humanistic and investigative perspectives of knowledge production as well as the functions of the products of science. However, most research studies reveal that students do not have an adequate understanding of the nature of scientific knowledge. Traditional instructional methodologies and curriculum materials currently being used distort the dynamic nature of knowledge production.

Thus, there is an increased emphasis on the epistemological aspects of science in the science education community as evidenced by three national science curriculum reform efforts currently being implemented in which the nature of scientific knowledge is an important part of their recommendations. The most important element in the implementation of any curricular reforms or improved instructional techniques is the science teacher. However, the science teacher seems to be an obstacle to any improvement of students' conceptions because most research studies reveal that preservice and inservice science teachers do not possess an adequate view of the nature of scientific knowledge.

Because the teacher is at the focus of any curricular recommendations to improve students' views of the nature of scientific knowledge, it is imperative to recognize the importance of adequate conceptions of teachers in achieving any desired goals. Only when these dimensions of teachers' conceptions of the nature of scientific knowledge are thoroughly analyzed can science educators begin to recognize the causes and intricacies of any misconceptions as well as the barriers to the classroom implementation of adequate epistemological views. Strategies can then be developed to correct any misconceptions of the nature of scientific knowledge by the preservice and inservice training of teachers. The science education community must promote an epistemologically adequate view of science among its practitioners especially as science education enters a new decade of an increased nationwide emphasis on this very important dimension of scientific literacy.

CHAPTER II

A MODEL OF THE NATURE OF SCIENTIFIC KNOWLEDGE

Introduction

To provide a basis of comparison for the study of teachers' conceptions of the nature of scientific knowledge, a model of the nature of scientific knowledge was developed through a review of the literature. It will serve as a comprehensive statement against which to identify deviations of conceptions revealed by teachers. There are many possibilities of such a model, but a combination of models by Welch (1984), Kimball (1967-68), Rubba and Andersen (1978), American Association for the Advancement of Science (1989), and Showalter, Cox, Holobinko, Thompson, and Oriedo (1974) supported by pertinent commentary from the literature provided a basis for a portrayal of the nature of scientific knowledge.

No claim is made that the dimensions described in the model outline the nature of scientific knowledge. There is disagreement among scientists and philosophers about the elements of scientific knowledge. An attempt was made to outline the most widely accepted constituents of scientific knowledge found in the literature. The model consists of descriptor phrases followed by a brief explanation. After the model outline, each dimension of the model is described in detail.

Model Outline

The model consists of eight dimensions. The nature of scientific knowledge is such that it is:

1. Humanistic - The production of knowledge is a human activity characterized by human limitations, strengths, and weaknesses. The fundamental human entity in scientific knowledge production is the scientist. Scientists exhibit a full range of altruistic to biased behaviors. Thus, there is no simple, accurate characterization

of scientists' abilities and traits. Scientists are motivated by professional and personal reasons as well as human curiosity. The resultant knowledge demonstrates that scientists as human beings are imperfect knowledge seekers.

2. Social - Scientists interact through scientific communities that use a shared framework of beliefs about the natural world to determine the acceptability of problems, investigative methods, and results. In addition, the community of scientists regulates professional credentialing, codes of conduct, communication systems, and standards of agreement. Through debate and consensus, scientific communities are the exclusive arbitrators of the authenticity of knowledge. Science as a social institution influences and is influenced by other institutions in the funding, directions and purposes of scientific research. Furthermore, science and technology interrelate but are not synonymous having very different social roles. Scientific knowledge itself is amoral. Moral judgements can only be made on the applications of that knowledge.

3. Historical - Within a paradigm structure or research program, scientific knowledge develops cumulatively. However, from a total historical perspective, scientific knowledge has evolved through revolutionary eras of complete shifts of beliefs about the natural world. Scientific progress produces subsequent paradigms that are more effective than previous ones at solving and generating new experimental problems. The revolutionary history of scientific knowledge demonstrates the uncertainty and tentativeness of that knowledge.

4. Based on Specific Beliefs About the Natural World - The production of scientific knowledge is based on the beliefs that the natural world is understandable, causal, orderly, consistent, and predictable.

5. Observation Based - Scientific knowledge results from inquiry that is based on the act of observing, directly or indirectly, natural phenomena. Scientific observation is not a simple process but is a complex human activity involving selection schemata and filtration mechanisms influenced by the experiences, expectations, language and paradigmatic beliefs of scientists. To minimize human selection and filtration effects, the scientific community subjects observational evidence to stringent independent tests. However, theory precedes observation as well as its validation. Therefore, all scientific observation is as tentative as the theory on which it is based.

6. A Result of Inquiry - Scientific knowledge is produced by a dynamic interaction between scientists using many methods of inquiry and the natural world. Induction, falsification, and hypothetic-deductive models of scientific inquiry all suffer from the problematic aspects of the act of observing, the finiteness of observational evidence, their basis on past experience, and logic invalidity. The revisionist view of inquiry rejects formal logic systems and sense data as the ultimate epistemological authorities and recognizes the theory-ladenness of scientific inquiry in observation, methodology, factual relativism, and the resulting knowledge structures. There is no one scientific method, but many modes of scientific inquiry that vary according to the scientist, the discipline, the investigative problem, reliance on historical data, and the use of applicable theoretical structures. Scientific inquiry produces knowledge that is probabilistic, fallible and tentative.

7. Composed of Knowledge Structures - Facts, theories, and laws are the knowledge structures of science. They attempt to explain or describe natural phenomena in as simple and comprehensive manner as possible in many cases using mathematical language to state relationships in a precise way. These knowledge structures form a structural reality that may or may not correspond to the absolute natural reality. Scientific facts are understandings of scientists based on many repeatable observations of some natural phenomena. Different than the common-sense understanding of the word fact, scientific facts are dependent on theory, tentative, and devoid of absolute truthfulness. Theories and laws result from the testing of hypotheses. Hypotheses are attempts to explain or describe an observation that can be tested by experimentation. A theory strives to explain a broad range of phenomena whereas a law describes relationships between repeatable, observable events. A scientific law and theory are two different knowledge structures. Laws describe relationships whereas theories explain reasons for the relationships. Therefore, theories do not become laws and vice versa. Scientific models are mental, mathematical, or physical depictions of laws and theories that strive to express in a simple way the structure or behavior of entities. Facts, theories and laws form a structural paradigm of nature for the scientific community. However, these knowledge structures are not the truth in the absolute sense, but are incomplete, probabilistic, and tentative.

8. Unique - Scientific knowledge is just one of many ways of knowing. Although some processes of knowing scientifically overlap with other modes of knowing, there are several distinguishing characteristics of scientific knowledge. These include its testability, predictive power, consistency, replication, communal review, and revisionary nature. Some problems lie outside the realm of scientific inquiry, and thus, science is unable to answer all questions.

These eight dimensions do not have discrete borders that separate them, but they are interrelated in many ways. For example, the humanistic, social, and historic dimensions influence and inform each other as well as the entire realm of scientific inquiry and observation. The resulting knowledge structures reflect human limitations, historical advances, and the social interaction of decision-making. These facts, theories, and laws in turn constitute a paradigm of nature used by scientific communities to inform and limit future research efforts.

Description of the Model's Dimensions

Each dimension of the model of scientific knowledge is described below in detail to assist in an understanding of the brief explanations that follow the descriptor phases in the model outline.

The Humanistic Dimension

The production of scientific knowledge is first and foremost a human enterprise. Any interpretation of the natural world emerges and develops in the human mind, and thus, knowing scientifically must be put into a human context. To understand the human quality of science, it is necessary to comprehend the nature of the "agent" in knowledge production - the scientist. The concept "scientist" in the epistemological model is defined as an individual who has received professional training in the system of natural scientific knowledge and is, on a daily basis, actively engaged in research activity investigating the natural world. The human characteristics of scientists affect the credibility and reliability of the resultant knowledge. Comprehending scientific knowledge requires knowing about the human qualities of scientists.

Many sources including school science curriculum materials portray an idealized version of the characteristics of scientists. Scientists are described as objective, emotionally neutral, rational possessing superior reasoning abilities, open-minded, invested with superior intelligence, truthful, and communal in sharing knowledge (Carin & Sund, 1975; Cawthron & Rowell, 1978; Cronin, 1989; Cross, 1990; Diederich, 1967; Haney, 1964; Mahoney, 1976, 1979). However, studies of scientists reveal individuals exhibiting characteristics contrary to the image of the model scientist (Cole, 1985; Cole & Cole, 1973; Kuhn, 1970; Mahoney, 1976, 1979; Mahoney & DeMonbreum, 1979; Mahoney & Kimper, 1976; Mitroff, 1974; Roe, 1961). These strengths, weaknesses and limitations of being human permeate and shape the resultant scientific knowledge.

A widespread assertion portrays the scientist as objective and emotionally neutral in his scientific investigations. Mahoney (1979) states that the scientist is characterized as "a dispassionate creature allegedly capable of suppressing personal biases in the interest of objective inquiry" (p. 351). However, the representation of the scientist as objective has been strongly challenged (Chalmers, 1976, 1990; Cole, 1985; Herron, 1971; Kuhn, 1970; Mahoney, 1976; Robinson, 1969; Welch, 1984). The effects of paradigmatic beliefs, professional schooling, and expectations of scientists on objectivity in observing phenomena will be discussed in detail in fifth model dimension titled "Observation and the Production of Scientific Knowledge."

Another attribute portrayed in the ideal version of scientists is that scientists do not exhibit emotionality in their professional work. Roe (1961) explains that reported descriptions of scientists "describe their cold, detached, impassive, unconcerned observation of phenomena which have no emotional meaning for them" (p. 456). Mitroff (1974) challenged this assertion by the results of his study of 42 geoscientists in America that disclosed "vividly the inner and often extreme emotions that are connected with the doing of science" (pp. 70-71). Mahoney (1976) provides the strongest statement of the scientists' emotionality and its affect of scientific investigation by stating that "the scientist is probably the most passionate of professionals; his theoretical and personal biases often color his alleged 'openness' to the data" (p. 6).

Furthermore, far from being stoic, scientists often exhibit unrestrained jubilation and excitement with positive experimental results or new discoveries. Likewise, not unusual among scientists are feelings of disappointment and depression. Experimental anomalies cause agony and frustration that may result in professional self-doubts. Scientists are often emotionally attached to their scientific work and sometimes suffer direct attacks or bitter disputes involving their conceptual perspectives (Mahoney, 1979; Kuhn, 1970).

Emotional objectivity may be an admirable goal for a scientist, but its realizability is not possible. The subjective nature of scientists is explained by Mahoney (1979) who states, "The scientist cannot be devoid of emotions; human beings necessarily display certain behavior patterns which are characteristic of the species" (p. 364). In fact, most scientists are motivated by their deep emotional association with their profession. Thus, scientists are subjective human beings that are affected by a wide range of emotions and that emotionality may affect the epistemological credibility of their work.

Moreover, the conception that scientists possess superior reasoning abilities and rationality have been called into question. A study in which the logical abilities of 15 ministers were compared to 15 physicists and 15 psychologists, the scientists performed no better than the other subjects (Mahoney & DeMonbreum, 1977). Logical thinking skills are certainly helpful to the scientist, but they are not wholly sufficient. Mahoney (1979) states that "much of scientific thinking is 'psycho-logic' rather than formally rational" (p. 364). Thinking processes contrary to formal logic have marked numerous scientific discoveries. Copernicus' placement of the sun at the center of the universe was more a "bold leap of faith, an act of imagination" (Hansgen, 1991, p. 691) based on aesthetic and philosophical reasons than the logic of contemporary scientific ideas. Thus, scientists should not be stereotyped as possessing superior logical and reasoning abilities.

In addition, scientists exhibit a full range of creativity in their work. This creativity involves human strategies such as speculation, fantasizing, brainstorming, and imagining. The invention of scientific concepts and the subsequent testing of these ideas are " as creative as writing poetry, composing music, or designing skyscrapers" (American Association for the Advancement of Science, 1989, p. 27).

Open-mindedness is a characteristic that is often used to describe scientists. Open-mindedness involves the withholding of judgement until enough evidence is available, being open to all data relevant to a theory or hypothesis, and the readiness to alter an opinion when justified by the data. Studies (Mahoney, 1979) have revealed that there is a variance along a continuum in the "withholding of judgement" dimension of open-mindedness among scientists. Scientists range from those who will not make conclusions unless there is a large amount of supporting data to those who on very little data formulate extensive generalizations and enterprising models.

Furthermore, the open-mindedness corollary of scientists' receptivity to all relevant data can be challenged by a review of historical evidence. For instance, Copernicus, Newton, Mendel, Darwin, and Einstein each experienced the narrow-mindedness of their peers even to the extent of the prevention of the publication of their opinions. Mahoney (1979) advocates that such intolerance to new, relevant data is present currently by the prejudiced way in which scientific journal articles are reviewed.

Related to the issue of scientists' openness to relevant data, is the characteristic of the willingness of a scientist to change an opinion when justified by the data. Mahoney (1979) states that "eminent researchers have often displayed dogmatic faith in their theories, even in the face of strong falsifying data" (p. 359). There appears to be differential levels of dogmatism among scientists depending on their status in the scientific community (Mitroff, 1974). Considering that a scientists' life's work may be devoted to the promotion and development of a particular theory, it is not unexpected that such inflexibility be exhibited. Thus, scientists may be very persistent in their opinion despite the introduction of formidable contrary evidence.

In addition, the stereotypical scientist is portrayed as an individual with superior intelligence. Whereas it is evident that only the brightest applicants are admitted to graduate school, does superior intelligence predict degrees of scientific contribution? Mahoney (1979) and Cole and Cole (1973) reveal that, using standard measures of IQ, studies have not found a convincing relationship between contributions to science and IQ. Zuckerman (1970) probably summarizes a more accurate view of the scientist in regard to intelligence by stating, "motivation and endurance seem to count for at least as much as intelligence in producing superior scientific work" (p.241). Therefore, scientists need not possess superior intelligence and the level of intelligence does not necessarily affect the level of significant contribution to scientific knowledge.

Honesty and integrity are model traits of the idealized scientist. While it is realistic to state that the majority of scientists strive toward truthfulness, the misrepresentation and fabrication of data or results do exist. Historically, Galileo falsified some figures on gravity (Cohen, 1957), and Newton manipulated data in order to correspond to his models (Westfall, 1973). In modern times, Mahoney (1979) states that "the misreporting of research, the discarding of discrepant subjects, and similar misdemeanors, can readily find their way into the most righteous of laboratories" (p. 361). A national survey of physicists, biologists, psychologists, and sociologists (Mahoney & Kimper, 1976) found that 42% of the subjects were cognizant of at least a single case in which experimental data had been falsified. Thus, scientists are not unsusceptible to distorting experimental data and results.

Furthermore, scientists are portrayed as individuals who openly share their continual work and knowledge in a cooperative manner with other scientists. Included in this corollary is the assumption that scientists are more interested in advancing scientific knowledge than personal honors and prestige. With the abundance of scientific papers and journals the appearance of a communal sharing of information would appear to be obvious. However, the extensive publication of articles may be motivated by less generous reasons. Typically, scientists are driven by a intense desire to gain credibility and recognition. A priority contest results in which scientists or research teams race to be the first to advocate a new discovery, innovation, theory, or technique. Scientists are very cautious in reporting unfinished work and revealing potential answers. Thus, the outcome in some cases is one of competitiveness instead of cooperation to the point of being secretive. Throughout history and in present times, science has witnessed many bitter disputes about the priority issue of discoveries (Mahoney, 1979). Recently, two scientists, Dr. Robert Gallo and Dr. Luc Montagnier, have participated in a seven-year dispute about which one deserves the credit for discovering the AIDS virus (Thompson, 1991).

However, most of the factors that motivate scientists are not contrary to the progress of scientific knowledge. Incentives for scientists include (a) the publication of articles, (b) receiving research grants or monetary awards, (c) being cited in other scientific journals, (d) receipt of distinguished awards, and (e) invitations to advance professionally. Because of the importance of recognition in gaining financial support, scientists devote most of their time to researching and writing papers.

Moreover, human curiosity has to be considered as an important motivating force in scientific inquiry (Aikenhead, 1987; Haney, 1964; Kuhn, 1970; Welch, 1984). Kuhn sees the scientist as a "puzzle-solver," and the challenge of the puzzle is a significant motivating factor for the scientist. Scientists tend to want to understand a novel natural phenomena that cannot be explained by existing knowledge.

Thus, as human beings, scientists exhibit the full range of altruistic to biased behavior patterns similar to fellow members of the human race. There is no single personality description of the scientist just like there is no distinct model that describes all human beings. Like other members of the human species, scientists react, behave, reason, and sense based on past and present experiences. As human beings, scientists are somewhat inadequate of grasping the actualities of the natural world in its absolute terms. The human element permeates scientific knowledge production and is a component that penetrates all dimensions of any epistemological model of science.

Therefore, scientific inquiry is a human journey. The human qualities and behavioral patterns of scientists affect scientific knowledge production. As a knower, "homo scientus" (Mahoney, 1976) will always be an imperfect knowledge seeker. The human constituent of the nature of scientific knowledge must not be neglected, and that most important factor should not be characterized in a simplistic, idealized manner.

The Social Nature of Scientific Knowledge

The production of scientific knowledge is a complex social activity that involves groups of scientists called scientific communities operating under a shared framework of beliefs/values, rites of passage, codes of conduct, communication systems, and standards of agreement. Scientific knowledge is public knowledge and is like a language. It is intrinsically the common property of a group of people. To understand the nature of scientific knowledge, the group dynamics that create, shape, and use the knowledge need to be recognized.

A typical scientific community consists of practitioners of a particular specialization. Members of the community have completed comparable educational training in similar scientific literature about their speciality. Usually each community has a subject matter of its own marked by the boundaries of its technical literature. Practitioners within a community view themselves as having the responsibility for the development of their subject matter as well as the professional training of their successors (Kuhn, 1970).

Such scientific communities can exist in several different levels. All natural scientists would be the most global community whereas specific professional groups (botanists, zoologists, physicists, etc.) are scientific communities. Communities may be an assemblage of scientists of similar techniques such as protein chemists, radio astronomers, high-energy physicists, or organic chemists. These communities are further subdivided into groups of scientists that conduct detailed research into very specific areas of their discipline such as the neuroendrocrinologists that study only "releasing factors of a peptide nature" that affect brain control (Latour & Woolgar, 1986). Typical communities at this level have approximately one hundred members each. It is in these communities of scientists that the production and validation of scientific knowledge occurs.

Like other social institutions, a scientific community is stratified with a division of labor. The fellowship of scientists is generally hierarchically divided which affords approximate categorization by responsibilities. The lowest category includes the technicians, instrument specialists, or graduate research assistant whose primary work usually includes the unimaginative day-to-day operation of experimental equipment to generate data. Next is an extensive group of experimentalists whose job is very similar to the technicians in grinding out data, but they usually have a greater responsibility in organizing and directing research. The next level consists of a heterogeneous grouping of indistinguished scientists whose major work emphasis is conceptual and can be classified as theoreticians. They plan experimental designs and interpret research data. The theoreticians share their responsibilities with the top echelon of the community - the famed scientists. This top group includes usually older, well published members who are recognized as the "experts" of the discipline. The top two categories of scientists share communal responsibilities of judging the worth of potential research, serving on editorial boards, advising on fund allocations, maintaining positive public relations and protecting the history of their discipline (Mahoney, 1979).

Kuhn (1970) refers to the entire body of views about the "reality" of the natural world shared by a scientific community as a "paradigm" or a "disciplinary matrix." These beliefs are in the form of the structures of science: facts, theories, and laws. The paradigm describes the entities that exist in nature as well as the behavior of those entities. For example, a component of the disciplinary matrix is "symbolic generalizations", such as F=ma or "action equals reaction," which are used and accepted by members of the scientific community without question.

Furthermore, a particular paradigm is accepted by a community of scientists on a consensus basis and serves as a template to measure and evaluate all scientific activity. Adherence to a paradigm allows members of a scientific community comprehensiveness in professional communication through a shared language and relative harmony in professional opinions. In the face of opposition of the accepted paradigm, the scientific community provides encouragement and support usually resulting in stubborn resistance of contradictory views. Such paradigms require great loyalty by scientists and operating under a particular paradigm affects individual scientists and their scientific endeavors in a number of ways (Kuhn, 1970).

A scientific community requires of an individual a set of credentials to be accepted into its speciality. A person not only has to be endorsed by established members but has to have completed professional training that embodies principles of the accepted paradigm. In the schooling process, the scientific subject matter which is the tested and shared possessions of the community is learned and applied to problems to facilitate understanding of accepted consequential happenings in nature (Kuhn, 1970). In such learning, the language of science becomes part of an individual's vocabulary and permeates all phases of the work of the scientist from problem formation to validating conclusions. Kuhn (1970) emphasizes that "as one is given words together with concrete examples of how they function in use; nature and words are learned together" (p. 191). Thus, scientists learn a subject matter whose boundaries have been established by a community of professionals among whom they were trained, with whom they must work, and from whom they must receive recognition (Kuhn, 1970).

Therefore, the centrality of language in the training of scientists as well as communication within a scientific community cannot be minimized. Language is a social mechanism of interfacing with other human beings. To be social knowledge, scientific knowledge has to be linguistically encoded. In order for scientific ideas to be questioned, altered, and shared by other scientists, a shared background of agreed upon meanings to words is necessary. The accepted paradigm of nature supplies these meanings. Thus, the way in which scientists organize and discuss the natural world is based on and limited by language (Kuhn, 1970).

Since a scientific community's paradigm outlines the current accepted view of the natural world, it serves a criterion for determining "valid" problems to study and their importance. In particular, a paradigm defines the problem and assures that a problem has a solution. To a large degree, these problems are the only ones a scientific community will regard as "scientific" and urge fellow scientists to pursue. Problems that do not meet the criteria of the accepted paradigm will be rejected as meaningless, metaphysical or too problematic (Kuhn, 1970; Herron, 1971). Thus, a particular paradigm of nature guides a group's research efforts.

Also, commitment to a science community's paradigm restricts and regulates the investigative procedures and instrumentation. To be "legitimate," the scientific methods used must obey the accepted "rules of the game." These rules include application of accepted scientific facts, laws and theories as well as preferred types of instruments and procedures for their use. Striving to solve a problem defined by existing knowledge, scientists know what they want to achieve and design the investigative instruments accordingly. In using the accepted methods and instrumentation, the paradigm provides a scientist with assumptions that particular findings will result (Kuhn, 1970).

Once a possible solution to an accepted problem is found, it is not ultimately the personal decision of an individual scientist or a team of scientists to the "validity" of the finding. It is the responsibility of the scientist or scientists to communicate, formally and informally, the findings of the experiment to the relevant scientific community and persuade other scientists of the correctness of the experimental results. Scientific opinions do not become "knowledge" until it has been reviewed and received approval by the consensus of a scientific community.

Therefore, scientists strive for recognition through publication in order for their work to be acknowledged, replicated or expanded. They invest a great deal of energy into persuasive publication (Latour & Woolgar, 1986; Mahoney, 1979). It is thus not surprising that there are over 70,000 scientific journals with a new article being published every 35 seconds (Hurd, 1990; Mahoney, 1979). Scientists strive to publish their work as extensively and quickly as possible. Scientific activity can be viewed as "an exchange of social recognition for information" (Hagstrom, 1965, p. 13).

Moreover, the publication process itself is an important social component of the scientific enterprise involving individuals' interactions in reviewing and approving or rejecting articles that will affect the fate of ideas. Without communication to the professional community, ideas will seldom gain recognition or acceptance. The social dynamics of the publication process can either promote or discourage ambitious scientists as well as emerging scientific research trends.

However, scientists need each other in order to increase their production of knowledge as well as confirm its acceptability (Latour & Woolgar, 1986). Not only does most experimental work involve teams of scientists, but peer approval and feedback are very important in motivating fruitful investigative endeavors. A scientific community provides an arena for such approval or feedback through professional meetings and publications.

Thus, in essence to be knowledge, the proposed solution has to be certified by the practitioners of the trade. Scientific communities are the exclusive arbitrators of the authenticity of scientific knowledge. Latour and Woolgar (1986) state that "scientific activity is not 'about nature', it is a fierce fight to construct reality" (p. 243). The "reality" of nature is the result of these communal debates not its cause. In other words, during the debate about the meaning of experimental results, no scientists can resolve the controversy by revealing that nature told them the answer. Rather, as Clough (1989b) states:

> They must present their evidence for what they think nature is, and the controversy continues until there is a collective decision reached on what the evidence means. However, once the controversy is resolved the reason for the decision is not ascribed to the consensus reached by the participants, but rather is attributed to the independent existence of nature. (p. 10)

The result is that the construction of scientific knowledge appears to be unconstructed by anyone.

Once an idea becomes an accepted part of the corpus of knowledge, its history of social construction fades away and the circumstances of its subjective production become less and less significant. It is viewed as noncontroversial, objective, taken-for-granted, and becomes part of the tacit knowledge of the scientist. Only if later evidence points to the knowledge as being "wrong" are the social factors of its creation resurrected. The accepted information is embodied in textbooks or daily scientific activity and perhaps forms the basis of new instrumentation. It becomes part of the accepted paradigm of nature. The community of scientists strongly supports the concept and contests attacks against its validity. The new "knowledge" is used to judge the worth of experimental questions, procedures, or even research projects. Opposing views are rejected and viewed as nonscientific or nonexistent. The new "fact" of nature exists solely because of the continuing support of a community of believers (Feyerabend, 1975).

Furthermore, science cannot be seen as an isolated social institution. It interacts with other social institutions such as government, education, business, and military. These institutions influence the funding, direction, and purposes of the scientific community.

Due to these influences, research in the natural sciences is becoming more socially than theory driven. Science is subjected to the usual conflicts of class, government and business interests not so much in its efforts to preserve and transmit knowledge but in its role of modifying and expanding knowledge (Aikenhead, 1986a; Fleming, 1987).

Moreover, it is in these interactions with other social institutions that the distinct role of science and technology begins to become unclear. However, the social role of science is to extend or modify knowledge about natural phenomena without regard to its practical applications. On the other hand, technology's social role can be viewed as the development and enhancement of practical methods and procedures to respond to human needs. Seeing technology as just applied science implies that the aim of technology is to discover practical applications of scientific research. Fleming (1987) emphasizes that technology is not just applied science. In other words, technology does not depend on science, but possesses its own resources and is itself an identifiable cultural institution. Science does not necessarily limit technological possibilities just as conversely a significant advancement in science produces corresponding progress in technology. Therefore, "technologists apply technology, just as scientists apply science" (Fleming, 1987, p. 165). However, there is an interrelationship between science and technology in that scientific discoveries do influence technological advances just as technological instrumentation affects the progress of science. In addition, scientific knowledge itself is amoral. It is in the applications of scientific and technological knowledge that moral judgements have to be made.

Thus, the social system of science implemented by the interactions of scientists through scientific communities determines the validity of problems, investigative techniques, and experimental results based on a communal view of the natural world. This natural paradigm of the scientific community that is taught to aspiring scientists and practiced by the status quo restricts views of the natural world and permeates the production of knowledge. Scientific knowledge is shaped by the beliefs and attitudes of its practitioners and reflects the history, power structure and political climate of the supportive community. The "reality" of nature is socially constructed being the result of interactions between scientists rather than the purpose of communal activity. The epistemological aspects of acceptability cannot be divorced from the sociological concept of decision-making. Therefore, scientific knowledge production is a social phenomenon.

The Historical Aspect of Scientific Knowledge

Throughout time humans have attempted to understand the natural world and thus scientific knowledge has a history. There have existed many models for the structure and complexity of the natural world. Each one of the historical models of nature have been examined carefully by contemporary scientists concerning its perceived validity. These past views of nature have been discarded, modified or maintained withstanding challenges to their perceived authenticity. Yesterday's revolution in thought is today's common sense, and today's knowledge may evolve into tomorrow's discarded ideas. Scientific knowledge is continually in a state of examination and change.

Historical study provides a method of examining the manner in which scientific knowledge has developed. Neither the ahistorical inductivist's view of the confirmation of theories by observational data nor the Popperian perspective of falsification of theories provide an adequate portrayal of the development of science (Chalmers, 1976). Rather Thomas Kuhn (1970) better describes the evolution of science by a careful examination of its history. He outlines a revolutionary view of the development of scientific knowledge using a sociological perspective.

Operating under an accepted paradigm of nature, scientists do not question the assumptions of the paradigm, but they further define and articulate the structures and bases of the current paradigm. Kuhn (1970) refers to such "puzzle-solving" activity within the scientific communities as "normal science." It is the period of time when paradigmatic knowledge is extended by attempting to increase the match between theoretical predictions and experimental results.

In doing so, scientists will experience difficulties and encounter apparent puzzles that resist solving using the prevailing beliefs about nature. Kuhn (1970) points out that there will always be unsolved puzzles within a paradigm. However, an anomaly will become threatening to the paradigm if it contradicts paradigmatic fundamentals, and it persistently resists removal despite the continued efforts of the community of scientists. Due to the failure to remove the anomaly and possible gradual buildup of other anomalous events, the accepted paradigm begins to possess a diminished capacity to solve or generate problems for its practitioners and is less able to support its vigorous research tradition. Thus, in Kuhn's (1970) perspective, the periods of normal science become interrupted by intervals of crisis or breakdown in the current paradigm.

Moreover, attempts by scientists to solve the anomaly or anomalies become increasingly more radical and the previous rules of investigative activity are relaxed. Special efforts in investigating the anomaly may cause the profession to consider a new array of commitments as well as a new set of principles of investigative procedures. Professional insecurity heightens, and scientists begin to doubt as well as openly question the reigning paradigm. The crisis intensifies when a rival paradigm emerges. The new paradigm will be much different and incompatible with the previous one. Scientists examine competing articulations and are willing to try alternative investigative procedures to attempt to understand the debate over fundamentals. This period of crisis in paradigmatic beliefs resulting in a debate of competing views is called by Kuhn (1970) as "extraordinary science."

Eventually, the period of extraordinary science may end by a consensus of scientists accepting an alternative paradigm of nature and abandoning the original, problematic paradigm. The decision to reject a paradigm is always accompanied by the acceptance of another rival paradigm. Such extraordinary shifts of paradigms are referred to by Kuhn (1970) as "scientific revolutions". He explains that "they are the tradition-shattering complements to the tradition-bound activity of normal science" (Kuhn, 1970, p. 6). The new paradigm would explain as much of the anomalous areas as possible and create new problems for research. The new paradigm is not just a change in a theory, but a radical shift or "gestalt switch" in the scientific community's natural world view.

With the onset of a new paradigm, there is a reconstruction and reevaluation of the knowledge structures of science - facts, theories, and laws. In essence, the world of scientific investigation has changed. Scientists design new instruments, research new problems, and make new observations. A period of normal science resumes until a new crisis develops followed by an revolution in paradigms. This revisionary process in the collective theoretical and methodological beliefs is far from a cumulative process (Kuhn, 1970, Herron, 1971).

However, the historical development of science is usually viewed as a cumulative process. Scientists are seen as contributing one or more pieces to the puzzle of a view of nature, and these pieces are added up to make the science of today. This cumulative perspective is typical of inductivists' account of science. In other words, scientific knowledge continuously grows as increasingly numerous observations are made which permits the formulation of new concepts, the refinement of previous ones, and the discovery of new relationships between phenomena (Chalmers, 1976). Textbooks portray scientific progress as cumulative because they explain only the portion of a scientists' past achievements that appear to be contributory to the premises and solutions of the textbook's current paradigmatic problems. Past scientists are portrayed as working on the same set of problems under the same paradigmatic conditions as todays' scientists. Contrary to this perspective, earlier scientists pursued their own problems with their own instrumentation within the contemporary paradigmatic beliefs which were quite different than today's model of the natural world (Kuhn, 1970).

The "development-by-accumulation" viewpoint is challenged by the revolutionary idea of scientific development as described by Kuhn (1970) when viewed in a long-range historical perspective. Kuhn emphasizes that the cumulative view ignores the role of paradigms in influencing observation and experiment. The basis for the revolutionary perspective is that history illustrates that there have been bodies of belief that are incompatible with the current principles in science. These discarded views of the behavior of the natural world exist as evidence that science has not grown by accumulation. Therefore, the evolution of science can be viewed as "a succession of tradition-bound periods punctuated by noncumulative breaks" (Kuhn, 1970, p. 208).

Only during periods of normal science is scientific inquiry cumulative because its aim is the further articulation of the currently accepted paradigm. It is based on several past scientific discoveries of the paradigm that the scientific community asserts as providing the basis of future research efforts. Periods of normal science are usually very successful in the expansion of the scope and precision of the paradigmatic knowledge. The knowledge gained during periods of normal science builds upon itself. Ironically, it is in the detailed, precise investigative activity of normal science that anomalies begin to appear and subsequently may cause a paradigmatic shift in the scientific community (Kuhn, 1970).

Furthermore, the criterion for scientific progress as seem in the Kuhnian perspective is problem-solving ability. The revolution of paradigms involves the probability of a better fit between experimental results and theory of the successful paradigm. The most significant claim made by the supporters of the new paradigm is that they can answer problems that led the previous paradigm to crisis.

Thus, the development of scientific knowledge is the result of the continuous effort by the community of scientists to fit theoretical predictions with experimental findings. Scientific knowledge progresses cumulatively only within periods of normal science. However, there will always be the possibility that a new theory will better explain observations and new laws will enhance descriptions of phenomenal relationships. The consequence is a revolution in the view of the natural world which produces reevaluation of the knowledge produced under the tenets of the previous paradigm. The history of science demonstrates that the scientific enterprise can never irrevocably commit itself to any fact, law or theory no matter how valid it appears in the current paradigm of nature. Therefore, scientific knowledge has a revolutionary history that demonstrates its epistemological uncertainty and tentativeness.

Specific Beliefs About the Natural World

The production of scientific knowledge is based on certain beliefs or assumptions about the natural world. Scientists believe in the existence of a real world, an absolute reality, that can be examined and comprehended through careful research. By using human intelligence with the assistance of investigative procedures and instruments, it is believed the structure of the natural world can be revealed (American Association for the Advancement of Science, 1989; Kimball, 1967-68; Welch, 1984).

Furthermore, scientists believe that nature is not inconsistent in behavior. Consistency in nature occurs in relation to time, scale, and place. The current discoveries are applicable to explaining natural phenomena in the past as well as the future. Nature behaves on a small scale as it does on a large scale, and natural events are not unique to any single part of the universe (American Association for the Advancement of Science, 1989; Aikenhead, 1975; Kimball, 1967-68; Welch, 1984).

Moreover, it is believed that events in nature have explainable causes, and there is an orderliness in nature. Thus, the causes of natural phenomena can be described by systems of explanations that apply everywhere in nature. By understanding these relationships, predictions can be made about the behavior of natural occurrences. (Hodson, 1988; Kimball, 1967-68; Welch, 1984; Aikenhead, 1975).

Therefore, based on these very fundamental beliefs, scientists conduct their daily investigative activity of problem solving. The resulting scientific knowledge rests on the foundation of these assumptions.

Observation and the Production of Scientific Knowledge

An important step in the production of scientific knowledge is the observation of natural phenomena. Playing a basic role in scientific inquiry, observation not only leads to the formation of questions, but observation set in a testable framework also is vital to the determination of acceptable answers. However, it is important to understand the contextual nature of the act of observing and formulating observation statements.

Scientists can explore the natural world by actively observing a wide range of conditions or from observing the selected conditions of a contrived experiment in the laboratory. Such observations are made directly by using the human senses, indirectly by using magnifying glasses, microscopes, etc. as extensions of the human senses, or by devices that extend the capabilities of human senses such as neutrino detectors (Norris, 1985). Because of the importance of evidence in science, great significance is placed on the development of observing methods and instruments (American Association for the Advancement of Science, 1989).

However, human beings are not perfect instruments of observation, and thus, there are no purely objective observations. Observation is linked to human sensation of stimuli and perception. "Sensation" refers to the stimulation of the sense organs, and "perception" refers to the mental interpretations of the sensations. The act of observing involves the human processes of sensation selection and perceptual filtration (Harris, 1979). From the vast array of incoming stimuli, an individual chooses to attend to only a few relevant ones and ignores the irrelevant ones. The selection of "relevant" stimuli is not at random but is based on some sort of experiential schemata. Furthermore, there are filtration mechanisms that intercede between the act of sensing and perception. For example, several observers may receive identical images of an object on their respective retinas of their eyes, but they will not necessarily have the same perceptional experience. These filtration mechanisms consist of the experiences, knowledge, and expectations of the observer. In science, two filtration mechanisms are particularly important to understand - linguistic systems and paradigmatic theoretical beliefs (Chalmers, 1976).

Initially, the act of observing is complicated by a dependency on the use of a language symbol system. Humans experience many sensations, but language tends to filter out sensations that cannot be related using familiar linguistic terms. Thus, the act of perceiving and the act of expressing an observation statement are one function. Furthermore, communication of an observation can only occur through the use of words that have agreed upon meanings. In the scientific enterprise, the precise meanings of words are defined by an accepted paradigm (Feyerabend, 1975). For example, the word "force" has a precise meaning derived from a theory in physics. In science, observation statements are necessarily formulated in the language of some theory that provides distinct conceptual schemes for words. Thus, clearly structured theories are a prerequisite for precise observation statements. In other words, theory precedes observation in science (Chalmers, 1976).

Therefore, the perceptional schema of scientists is based largely on the selected paradigm of the natural world they choose to utilize. This perspective creates a filtration mechanism for scientists that determines what observations are relevant to an investigation. However, preselection is a necessary characteristic of scientific observation. Cole (1985) states that "researchers have to focus before they can see which means they have to decide where to look" (p. 98). Otherwise, there would be no basis for determining relevant observations. Such observational schemata based on a paradigm are acquired by scientists through their training and association with other scientists when they learn methods of observation as well as the descriptions of the observable entities in nature. Thus, what scientists perceive and expect through observation is influenced by a conceptual framework composed of paradigmatic experiences and knowledge (Cole, 1985; Mahoney, 1979).

Even sophisticated instrumentation does not produce objective observational information. The theoretical basis of the design and operation of an instrument was once controversial among scientists. Blachelard (Latour & Woolgar, 1986) refers to such instrumentation as "reified theory." Such scientific apparatus, called "inscription devices" by Latour and Woolgar, produce pictures, charts, diagrams, and figures. These inscriptions that are used as scientific evidence are far from being objective or independent of theoretical influence.

Furthermore, support for the theory-ladenness of scientific observation is revealed through any historical analysis of science (Abimbola, 1983; Kuhn, 1970; Mahoney, 1976). Alter the paradigm, and different observational data will result. For example, "valid" observations of falling objects on the earth based on the Ptolemaic geocentric view of the solar system became erroneous under the Copernican paradigm where the earth spins on its axis. Thus, observations are not unsusceptible to revision, and there can be no permanent boundaries established on what entities are in fact observable.

Moreover, not only does "what" is observed depend on the linguistic and paradigmatic lens used to view it, but any inferences drawn from the observation is influenced even further by the scientist's paradigm of nature. Observations can describe what is sensed directly or indirectly, but they do not explain anything. In science, an observation has no meaning until it is explained (Aikenhead & Fleming, 1975). Scientists' inferences from observations determine how they construct the structure of the natural world.

In addition, the social nature of scientific observation should not be minimized. Scientific observations must be communicated as observation statements to the scientific community in order to become relevant to the discipline. Thus, different from personal/private observations, scientific observations formulated in paradigmatic language are public entities which can be utilized and examined. The scientific community interacts to determine the contributory nature of observations (Chalmers, 1976). Aikenhead and Fleming (1975) state that "in science, an observation is not an observation unless a group of scientists agrees with it" (p. 904).

However, the theoretical, experiential, and linguistic elements of observation have not been overlooked by scientists. It is because of these elements that scientists have required that investigative observation be done in standardized conditions following routine procedures. Scientific observational techniques involve the use of measurement and controlled experimentation. Scientists actively engage with the natural world to check for the reality of an observed phenomena. Acceptable observation statements are those that have survived the most stringent independent tests levelled against them by the community of scientists. The use of quantification and instrumentation reduces the subjectivity of observation. However, these methods do not eliminate the subjective nature of human perception, but just minimize its effects (Chalmers, 1990).

Thus, observation is not a simple process, but a human activity that is permeated by selection schemata and filtration mechanisms composed of shared beliefs in a paradigm and an observational language. Much different than the inductivist-positivist perspective of unbiased observations yielding a secure basis for science, observations are not flawless or beyond the question of doubt. Theory must precede observation as well as the validation of observation statements, making the resulting scientific knowledge as fallible as any theory on which it is based. Because of the fallibility of theories, the guidance they provide to the determination of which observations are relevant may be misleading and might result in important observations being missed. Therefore, it is important to understand the theory-ladenness of the act of observing and the subsequent tentative conclusions drawn from those observations that result in scientific knowledge.

Scientific Knowledge as a Result of Inquiry

Scientific knowledge is produced through inquiry. It is through experimentation that scientists strive to substantiate and expand the tenets of the accepted paradigm of nature by rigorous testing of theoretical predictions. In addition, it is the replication of the experimental results by members in a scientific community that determine the contributory nature of any findings to the body of knowledge. The popular view of scientific inquiry is that scientific knowledge is based on objective, proven facts from which theories and laws are derived inductively.

This view of science became prevalent during the seventeenth century Scientific Revolution due to scientists like Galileo and Newton. The concept was promoted by Frances Bacon who stressed that to understand nature, humans need to observe and investigate natural phenomena instead of depending on the previous explanations of the ancient philosophers such as Aristotle. It was stressed that experience through observation was the source of scientific knowledge (Chalmers, 1976). There are many problems with the belief that scientific inquiry is grounded in the truth of inductive logic, involves proved empirical facts of experience independent of theory from which theories and laws are derived, and is determinant in the survivability of theories and laws. To understand these problematic areas, a brief review of the historical philosophical thought about scientific inquiry is helpful.

Frances Bacon advocated a logical system of scientific inquiry through the inductive method called empiricism-inductivism, and Bertrand Russell, along with Alfred Whitehead, blended symbolic logic systems with the empiricist's viewpoint to form logical positivism (Abimbola, 1983). Both philosophies insist that science begins with unprejudiced observation of natural phenomena. Their tenets insist that observation statements can be justified by direct use of the investigator's senses. Other observers can verify the truthfulness of the observation statements by use of their senses. Singular observation statements describe a particular observation at a certain time and place. Scientific laws and theories are broad generalized statements about natural phenomena. The inductivist claims that it is legitimate to formulate a generalization from a finite number of singular observation statements providing there are a large number of observations and a variety of observations under numerous conditions (Chalmers, 1976; Mahoney, 1976).

However, there are several problematic aspects to this inductive basis of scientific inquiry. In addition to the theory-ladenness of observation, inductive arguments are not logically valid arguments. Moreover, the demand for numerous observations under a variety of circumstances can be called into question as well as justifications based on past experience (Mahoney, 1976).

To address some of these problems of induction, the logical empiricists, a present philosophy of science, focus on the confirmation of universal statements through testing of predictions. This philosophy is based on the works of Carnap, Hempel, Nagel and others (Abimbola, 1983). It is committed to the use of the empirical sciences and symbolic logic in the examination of the predictive and explanative nature of theories and laws. The logical empiricists insist that it is induction that is used to derive hypotheses (logic of discovery), but deductive reasoning is used to formulate predictions and explanations (logic of proof) (Abimbola, 1983; Chalmers, 1976). This is the basis of the hypothetico-deductive model of scientific inquiry. The hypothesis is the starting point from which predictions of behavior can be deduced, and if the behavior does indeed occur, the hypothesis is confirmed. If the predicted events do not happen and the soundness of the deductive logic is certain, then the hypothesis must be revised (Abimbola, 1983; Chalmers, 1976).

However, the origin of the hypothesis by inductive reasoning in the hypothetico-deductive model has been questioned by Hanson, Polanyi, and others (Mahoney, 1976). They argue that the formation of hypothesis is much less rational than depicted and that hypotheses can originate in a variety of ways from lucky guesses to accidents, dreams as well as logical reasoning. Furthermore, in the hypothetico-deductive model, induction is not eliminated from the confirmation of the hypothesis. In other words, the hypothesis holds true once, twice, three, four,..."n" times, and then a claim can be made that it will always hold which is inductive logic. However, it cannot be known for certain that it will always hold, because the hypothesis has been tested only a limited number of times. In other words, it can only be argued that the statement will hold because it has always held. Thus, the hypothetic-deductive model does not eliminate the problems of inductive reasoning (Chalmers, 1976).

Furthermore, the positivists and logical empiricists advocate that scientific knowledge is based on a pure empirical factual data base. They advocate that the "facts" of experience form the origin of theories, force consensus, and are the final determinant of accuracy. However, there are no "pure" factual data because they acquire their meanings only in a conceptual framework which is a particular paradigm of nature. Thus, the production of data presupposes some conceptual construct. In other words, rather than reflecting data, theories may be thought of as generating data. Since facts are dependent on theory, they are relative, not absolute and may change in the future as theoretical assumptions change. Thus, factual evidence serve as devices that attempt to describe the real natural world rather than a firm basis for knowledge (Chalmers, 1990; Mahoney, 1976).

One method out of the induction problem as well as the other aforementioned problems as a basis of scientific proof is to claim that formulation and confirmation of theories and laws is probabilistic. In other words, the generalizations inductively derived through a number of observations cannot be guaranteed to be perfectly true, but there is a high degree of probability that they are true. The larger the instances of observation, the more probable the conclusion. Likewise, the greater the number of confirming instances indicate a degree of probability that an hypothesis will hold true. However, the result is still an universal statement based on a finite number of observations (Chalmers, 1976).

Another way to avoid the problems of induction is to deny that induction is the basis of scientific inquiry. Karl Popper (Chalmers, 1976) does just that in his falsification theory of scientific research. He admits that observation is theory-laden and that observational data cannot absolutely establish the truthfulness of a theory or law. Furthermore, he stresses that the true test of an hypothesis is not being able to confirm it through testing, but that it is stated in such a way that would allow some event to falsify it. Thus, different from the verificationists who need many similar observations to "prove" a theory or hypothesis, the falsificationists need only one disconfirming observation to refute a generalization (Chalmers, 1976).

However, theories are insulated from complete falsification by the "Duhem-Quine" thesis. It states that "any theory can be permanently saved from refutation by internal revisions and adjustments" (Mahoney, 1976, p. 140). The tenet is illustrated in the history of science and seems to be currently practiced. Theories are adjustable in their predictions, and scientists are more likely to modify a theory than to outright renounce it. Thus, the acceptance or the rejection of theories based on data is not as straightforward as it appears.

Therefore, neither the inductivist's claim that theories and laws result from drawing conclusions inductively from observation or the falsificationist's belief of the refutation of hypotheses based on observation adequately characterize scientific inquiry. Another new revisional model of scientific inquiry was created by an in-depth analysis of the history of science. It is based on the philosophical thought of Bronowski (1965), Feyerabend (1988), Kuhn (1970), and Toulin (1953). The basic tenets of this "revisionist" philosophy of scientific inquiry are as follows:

1. Formal logic systems and sense data as the ultimate authorities in the validity of scientific knowledge are rejected. The ultimate decision of the truthfulness of knowledge rests with the scientific communities.

2. Paradigmatic beliefs determine to a large extent what is perceived of phenomena and thus, observation is very theory-ladened.

3. There are no absolute, immutable facts, but facts are relative to their conceptual frameworks, and as paradigms change, facts will change.

4. Theory does not arrive out of data, but theory is prerequisite for data.

5. Scientific inquiry operates within an accepted paradigm that determines the validity of problems, instrumentation, functional models, and methods of inference.

6. Conjecture, paradigmatic beliefs and tacit knowledge all interact in scientific inquiry.

7. Scientific inquiry is characterized as continuous research with ongoing criticism.

8. Scientific knowledge is not ultimately true, but is fallible and tentative (Abimbola, 1983; Mahoney, 1976).

Thus, the new view of scientific inquiry rejects the idea that scientific knowledge is securely grounded in inductive logic systems and the facts of unbiased observational evidence. The natural reality produced by scientists is "more like the clay models of a sculptor than the steel girders of an architect" (Mahoney, 1976, p. 134).

Specifically, what is the nature of scientific inquiry? It would seem that an accurate description of the nature of scientific inquiry would be found in the writings of the individuals actively engaged in the process; the scientists. However, scientific papers, the printed communications of scientists in professional publications, distort the processes of science. Such papers misrepresent the thought processes that originate and accompany the work reported in the papers (Latour & Woolgar, 1986; Medawar, 1964). They fail to describe erroneous trails, hunches that did not materialize, or mistakes in the experimental process. According to Knorr-Cetina (1981):

> It is clear ... that once the selections of the laboratory have been crystallized into a scientific result, the contingencies and contextual selections from which it was composed can no longer be differentiated. In fact, the scientists themselves actually decontextualize the products of their work when they turn them into "findings," "reported" in the scientific paper (p. 47).

In addition, the format of scientific papers (introduction, literature review, methods, results, and discussion) promotes the perception of an inductive view of the process of experimentation. In other words, theoretical generalizations will result from objective, unbiased observations and declarations of fact. Also, the pressure to publish may cause scientists to only describe successful studies, to only investigate the easily evaluated questions, and to misrepresent the procedures or results to satisfy journalistic requirements (Mahoney, 1976).

Furthermore, misrepresentations of scientific investigations are confounded by textbooks that portray scientific inquiry as involving a specific process called the "scientific method." This model of inquiry is usually outlined as a step-by-step procedure that scientists follow. The steps are usually outlined as :

1. Make an observation and identify the problem
2. Collect information about the problem
3. Form a hypothesis
4. Test the hypothesis
5. Collect and analyze the experimental data
6. Form a conclusion (Clough, 1989b; Hill, Shaw, Jones, & Carter, 1990)

This typical textbook description of a step-by-step "scientific method" is characterized by Connelly (1969) as a "fairy tale on enquiry" (p. 110). The processes of discovery are too complex to be generalized into a simplistic step-by-step model (Feyerabend, 1975; Halpin & Swab, 1990; Herron, 1971; Hodson, 1988; Hurd, 1986; Toulmin, 1985). Such a description misrepresents the dynamic nature of the interactions between the scientist, the experimental problem, and relevant subject matter. In Science for All Americans by the American Association for the Advancement of Science (1989), the authors state:

> Scientists differ greatly from one another in what phenomena they investigate and in how they go about their work; in the reliance they place on historical data or on experimental findings and on qualitative or quantitative methods; in their recourse to fundamental principles; and in how they draw on the findings of other sciences. (p. 26)

Because the many sciences have different areas of concern as well as different goals, they require different types of evidence and utilize a variety of theoretical structures. Thus, they employ many different procedures of investigation.

Furthermore, a review of the history of science illustrates that many past ideas of science have arisen in a very disorderly way. Any adherence to a specific method of science would have eliminated many of past theoretical conceptions that are now considered as a basis of science. Feyerabend (1975) advocates that there are no general methodological rules which at times should not be broken. If any tenet is cited as being fundamental for scientific inquiry, a review of the history of science will disclose incidents where the rule was not obeyed. Feyerabend explains that scientific progress would be hindered seriously if scientists followed a definite method. The only rule in science, according to Feyerabend, is "anything goes."

Whatever the methodology used, the important issue is that the experiment is conducted according to a standardized procedure that can be replicated by members of the scientific community. It is in the experimental setting that variables can be held constant or manipulated to provide observations of phenomenal regularities. Such experimental intervention into natural phenomena is necessary to provide relevant information. However, regularities in data obtained in artificially constructed experiments do not necessarily indicate valid explanations for natural phenomena occurring outside experimental situations. In the natural world, phenomena result from a combination of many diverse processes juxtaposed in a complex manner. The scientific experiment is designed only to facilitate the production and observation of some phenomena that is relevant (Chalmers, 1990).

While it is conceded that observations, empirical data, experimental design, and justification of results are all formulated in theory, once the experiment is activated, it is the nature of the world that produces a result. Chalmers (1990) states, "It is the fact that experimental outcomes are determined by the workings of the world ... that provides the possibility of testing theories against the world" (p. 72). Significant results are often ambiguous, very hard to obtain, and not infallible. However, the history of science has shown that significant results can result from experimentation based on many methods of inquiry.

Thus, scientific inquiry involves a dynamic interaction between the natural world, the humanity of the scientist, paradigmatic theoretical assumptions and many investigative methods. Induction cannot be justified as providing the absolute proof of the truthfulness of knowledge due to its finite number of observational evidence, its basis on past experience, the problematic nature of observation, and its logical inability to derive a proof. Falsification and the hypothetico-deductive models of scientific inquiry suffer from the same problematic aspects as induction. The ultimate epistemological authority for the validity of knowledge arriving from scientific inquiry is not formal logic systems or sense data, but the consensus of scientific communities. There is not one but many scientific methods of investigating natural phenomena. The evaluation of the validity of theories and laws is not a simple straightforward process of inquiry, but involves theory modification more frequently than theory rejection. Understanding scientific inquiry illustrates that there are no experimental tests that can judge a theory's or law's absolute truthfulness. Scientific inquiry produces knowledge that is fallible, probabilistic, and tentative.

The Structures of Scientific Knowledge

Through the many methods of inquiry, the resulting scientific knowledge is expressed in the form of facts, theories, and laws. These "structures" of knowledge form the basis for a view of the natural world detailing its composition and in turn drawing their validity and meaning from an accepted paradigm. Due to facts, theories, and laws, it is possible for scientists to communicate in a shared language as well as make predictions and propose explanations.

The structures of scientific knowledge attempt to describe and explain natural phenomena in as simple and broad terms as possible (Kimball, 1967-68; Rubba & Andersen, 1978; Welch, 1984). This principle of parsimony states that "science should be conservative in stating the implications of its data; that the data should be interpreted in the simplest manner possible" (Lachman, 1960, p.53). The result are facts, theories, and laws that express specificity and with clear expression versus vagueness and generality. Science strives to generate the least number of comprehensive concepts to describe or explain the largest number of natural observations (Rubba & Andersen, 1978). The facts, theories, and laws devised by the separate disciplines of science contribute to the overall body of knowledge which is interrelated and concordant.

Furthermore, facts, theories, and laws in science are usually expressed whenever possible in the language of mathematics. Mathematics allows definitions of quantities, properties and relationships in a very concise and precise manner. Systems of mathematics are very helpful in data organization as well as communicating information based on data (Lachman, 1960).

Scientific knowledge structures and reality.

The popular view of the structures of scientific knowledge is that they relate the truth about the natural world. What is the relationship between these knowledge structures and the reality of nature? The "realist" position advocates that there is a very direct relationship between the knowledge structures of science and "what the world is really like." In other words, facts, theories, and laws have a direct ontological relationship to the real natural world similar to common-sense objects of perception. Scientists discover these truths about a natural world that is just waiting to be revealed. Inductivists and logical positivists as realists state that truth about the natural world can be derived through valid inductive processes. Criticism of this perspective relate to the logical invalidity of induction and the theory dependence of observation (Aikenhead, 1987; Latour & Woolgar, 1986).

Recognizing the many problems of the realist position, the "instrumentalist" advocates a distinct separation between scientific concepts relating to direct observation and others relating to theory. Entities that can be directly observed describe the real world, but theoretical descriptions of entities not directly observable do not. The theoretical entities are just useful instruments to promote calculations and to order perceptional information. They do not have an ontological status that connects them to reality nor an existential status. Thus, neutrons, electrons, and quarks do not exist in the natural world whereas planets, stars, and rocks do. The naive instrumentalist believes it is not the purpose of science to establish entities beyond observation because there is no sure method to connect the unobservable to the observable. The main criticism of the naive instrumentalist perspective is the distinction between the observable and theory. All observation statements are theory-laden and thus fallible. Thus, their viewpoint is based on a distinction that is not present (Aikenhead, 1987; Chalmers, 1976).

In contrast to the instrumentalist and realist positions, the "radical instrumentalist" or "pluralistic realist" (Chalmers, 1976) advocates that such a boundary between observational language and theoretical language is nonexistent. Emphasis is placed on the distinction between conceptual systems such as facts, theories, and laws that are changeable, human products and the real natural world. The external natural world is real, but so are facts, theories and laws that are continuously produced and adjusted by real scientific inquiry. In other words, there is an absolute natural reality and a "structural reality," scientifically speaking, of facts, theories, and laws. They are two distinct realities that are linked by scientific inquiry.

The radical instrumentalist or pluralistic realist denies that there exists a direct link between the structures of science and the real natural world. The entities described in facts, theories, and laws may or may not exist in nature, but to insist that they exist in the real world is a mistake since the structures of science are not derived from objective sense data, but are constructed from theory dependent observation statements. Even though scientific inquiry strives to understand the relationship between scientific knowledge structures and the real world, there is no absolute test of their truthfulness. If confirmation of theoretical predictions occur during experimentation, it has not been demonstrated that the entity exists in nature. It only demonstrates that the predicted result was obtained in the artificial reality of the experimental set-up. Thus, the knowledge structures that compose the structural reality of scientists are tentative describing entities that may or may not exist. They cannot provide epistemological certainty about the absolute reality of the natural world, and by their very nature, they are provisional (Chalmers, 1976).

In support of the radical instrumentalist or pluralistic realist position of the separation of an external natural world and a structural reality of knowledge structures is the historical record of science in which the scientific structural reality has changed as opposed to the absolute natural reality. For example, upon the acceptance of the heliocentric view of the solar system, the rotation of the earth as opposed to a stationary earth position became the common-sense view of the world. The earth did not begin turning on its axis with Copernicanism. Furthermore, the radical instrumentalist position makes sense of the effort of science to derive knowledge structures that are simple and coherent. Such coherency and simplicity allow scientific inquiry to be very precise and productive. It is not nature that is simple, but only the knowledge structures that humans produce. (Chalmers, 1976)

Thus, the structures of scientific knowledge are explanative and descriptive constructions that constitute a structural reality for the scientists. They are not final statements of truth, but are conditional and never proven in the absolute sense. Scientific facts, theories, and laws have discrete and special functions as knowledge structures. A discussion of each will assist in an understanding of their similarities and differences.

Scientific fact.

In the everyday usage of the word, a fact is defined as an entity that has an actual existence or occurrence that is viewed as possessing an objective reality. Facts are presented as independent of opinion or belief and as a result, they are unsusceptible to modification or change under any circumstances. There seems to be no debate about the existence of a fact. It is taken for granted about its truthfulness and used to support other facts (California Department of Education, 1990; Latour & Woolgar, 1986). It is believed that laws and theories can be refuted or confirmed by the facts of observation and experimentation. Thus, facts seem to be the epistemological authority on which other knowledge structures are based.

However, an examination of the construction and features of a scientific fact will illustrate a different perspective. A fact is a statement that has lost most of its conditional modalities. It is the aim of the laboratory to decrease the number of modalities of a statement and to add more "factuality" to the statement. Statements are thus loaded with associative investigative documents and qualifying modalities that create an evaluation of the statement. The object of scientists is to persuade their colleagues to drop the modalities and accept as well as use the statement as a matter of fact. Most statements remain with their qualifying modalities, and some are discarded never to be considered again. However, some statements possessing a large amount of supporting evidence are borrowed as well as used extensively by the scientific community. Their fact-like status becomes greater as they lose qualifying modalities. It eventually loses most of its modalities and becomes part of the larger body of knowledge. Thus, a qualified statement about an object becomes an existential, objective object in the structural reality of the scientist as more and more reality is attributed to the object. Once the controversy ends in the scientific community, the statement becomes a fact and its methods of subjective construction are forgotten (Latour & Woolgar, 1986).

However, three modalities that a scientific fact always keeps are its theory-ladenness, its tentativeness and its lack of absolute truthfulness. It is in this way that the scientific view of a fact and the common, everyday usage of the word "fact" are very different. Specifically, a scientific fact can be thought of as an understanding based on many repeatable experimental observations done within a theoretical framework. Facts acquire their meaning only within a conceptual framework, thus they are relative. Since there is no absolute test of the validity of the scientific evidence, scientific facts do not "prove" a theory or law. Scientific inquiry does not result in infallible ideas and thus, does not serve as a proof. The word "proof" should be limited to strict logical derivations or abstract mathematics.

Furthermore, there are no "bare" facts, but scientific facts achieve their meanings only in a paradigmatic theoretical context. That theoretical context generates the basis for scientific inquiry that produces facts. Thus, facts can be viewed as the products of theory, not its predecessor. Since the facts of science are based on the current theoretical paradigm, they are always subject to change based on new evidence (California Department of Education, 1990; Feyerabend, 1975). The idea of the mutability of facts supports the notion that progress in science is not by factual accumulation. The history of science demonstrates the rejection of alleged immutable "facts" that were replaced by newer ones. Mahoney (1976) explains, "Our 'facts' are just as fickle as our theories. Todays facts are yesterday's science fiction and tomorrow's myths" (p. 18).

Thus, factual relativism places scientific facts in a very different perspective than the common-sense usage of the word "fact." Facts change when their theoretical basis changes. Facts do not "prove" theories or laws since there is no absolute test of the validity of scientific evidence. Factual relativism demonstrates that facts are not the firm, immutable epistemological building blocks of truth as perceived by the nonscientist, but are changeable, pragmatic constructions that provide a possible correspondence to an absolute natural reality.

Scientific hypothesis.

In order to develop an understanding of the last two scientific knowledge structures, theories and laws, a comprehension of the nature of a scientific hypothesis is helpful. A hypothesis attempts to explain an observation and serves as a foundation for experimentation. It is a very important mental tool of a scientist. Serving as a supposition or an educated guess, an hypothesis is used to make a prediction implying a cause and effect relationship. Then through experimentation, a phenomenon is observed and a comparison is made with the prediction. If the hypothesis is very close to the prediction, the researcher has an useful explanation of the event (Aikenhead & Fleming, 1975).

Throughout the history of science, hypotheses have led to important discoveries. Some hypotheses, although wrong, are very productive. However, the majority of incorrect hypotheses prove unfruitful. When an hypothesis seems correct after experimentation, the researcher limits claims of discovery to the specific conditions of the experiment and continues further investigation. This "working hypothesis" is scrutinized under further experimentation and new avenues of investigation applying the new hypothesis may result. If an hypothesis explains many facets of a natural phenomena after many subsequent investigations, it might eventually become a conceptual scheme of understanding which is a theory. In addition, if a working hypothesis about the relationships of observable events subsequently are accepted by the scientific community, it might become a scientific law. However, it must be remembered that there is not a simple, direct connection between hypotheses through observation and theories/laws due to the mediation of paradigmatic beliefs.

Scientific theory.

A theory attempts to explain a group of observations that reflects on some property of the natural world. Whereas an hypothesis strives to explain a narrow range of events, a theory organizes and explains a broad range of phenomena. Hypotheses are derived from a theoretical basis and if through continuous testing, the hypotheses are sustained, the theory is strengthened. If many hypotheses based on the theory are confirmed by a preponderance of evidence, the theory will gain the acceptance by the scientific community. Thus, theories gain credibility and consistency through the testing of hypotheses. Theories strive to explain cause and effect relationships about previously observed phenomena, create new experimental investigations, and predict future natural behaviors (Aikenhead & Fleming, 1975; California Department of Education, 1990; Lerner and Bennetta, 1988; Lachman, 1960).

Theories are never proven to be true or false in the absolute sense. They are tentative changing with new observations and their usefulness. Theories are tools used by the scientific community to attempt to explain the behavior of perceived natural entities. No theory explains all events applicable to it. The more useful a theory is, the better the theory is. If a theory begins to make invalid predictions concerning new observations, its usefulness suffers and a new search for a more valid theory begins. When a theory is replaced, it is not proved false. It has just become not useful (Aikenhead & Fleming, 1975).

Theories can be of two basic types: (a) theories that provide an intellectual framework for understanding and prediction of a specific type of natural phenomena as well as a direction for new investigations and (b) great key theories that informs a whole science that brings many discrete findings together into a systematic science such as the theory of evolution. Theories unify science so extensively that only in the theoretical context can concepts be understood and contributions be evaluated (Lerner & Bennetta, 1988).

Scientific law.

A scientific law describes relationships between observable events that have been observed to occur over and over again. In addition, laws can be used to predict the occurrence of relationships between certain phenomena. An example of a law in science is Boyle's Law which states "that the volume of a gas varies inversely with the pressure applied to it, other conditions remaining constant"(Lachman, 1960, p. 28). Such lawful relationships are often expressed in a mathematical form or by formulae. Laws in science do not explain the reasons for such relationships between existing properties. Theories attempt to explain such relationships. Laws describe, theories explain. In the case above, the kinetic theory of gases was created to explain the relationship between volume and pressure (Horner & Rubba, 1979). In some instances, laws are advanced before theories are generated to explain them. For example, the law of gravity has existed for a long time and currently, there is no single, accepted theory to explain it.

Since laws and theories are entirely different types of knowledge statements, theories do not become laws. No matter how much testing of a theory occurs, it will not develop into a law. There is not a maturational relationship between the two knowledge structures. Laws are derived from hypotheses that receive enough acceptability from the scientific community to be accepted. Also, laws and related theories do not have to appear similar. For example, Boyle's Law does not mention "molecules" that are mentioned in the kinetic theory of gases that strives to explains molecular interactions (Horner & Rubba, 1979).

Furthermore, no law is considered absolute or unchanging. Current scientific laws are viewed more valid by scientists than alternative ones. When observations are made that cannot be described by a current law, the law is changed or new laws are adopted. Just as with theories, laws are based on observational and experimental evidence and are subject to the limitations and influences of those human operations.

Scientific model.

To assist in the understanding of scientific theories and laws, scientists create models. Models are mental, mathematical, or physical depictions that strive to illustrate in a simple way the structure or behavior of entities that are described in theories and laws. Models cannot be expected to represent exactly the theoretical or lawful entity or phenomenon. They are limited in their usefulness due to scale, qualitative differences, and simplicity. Thus, models can be conceived as pragmatic representations of theories and laws (Aikenhead & Fleming, 1975; American Association for the Advancement of Science, 1989).

The Uniqueness of Scientific Knowledge as a Way of Knowing

Scientific knowledge is just one of several ways of knowing or domains of meaning. Other modes of knowing include mathematics, history, politics, religion, philosophy, technology, and aesthetics. Some authors (Burke, 1985; Feyerabend, 1975; Mahoney, 1976) advocate that science cannot be distinguished from other ways of knowing. Mahoney (1976) compares science to religion in that science also involves worship of a knowledge base, ritualistic behavior, a precise dogma, a hierarchy of participants and entrance requirements for its participants. Burke (1985) explains that science is like magical rituals and religious beliefs because each contains a cosmogony that explains existential questions, a structure to explain cause and effect relationships, languages only known to the participants who have been admitted after passing rigid tests, and a procedural methodology. Feyerabend (1975) takes even a more radical stance with his denunciation of an universal scientific method by advocating that science cannot be differentiated from myths, politics, art, or even fairy tales.

However, even though science overlaps with other ways of knowing, science does possess some distinctive characteristics. The main differentiations of scientific knowledge from the other ways of knowing is attributable to its testability, predictive power, consistency, replication, communal review, and revisionary nature. An idea to be scientific must be able to be tested yielding experimental or observational evidence to judge its validity against alternative explanations. It is the predictive power of scientific explanations that allow them to be judged against other explanations. A scientific explanation must agree with all observational data better than alternative ideas, and must illustrate a cause and effect relationship. Furthermore, any researcher can replicate a scientific investigation and verify or reject the results. A scientific finding must be communicated openly and fully to members of the scientific community to be deemed contributory. In the public arena of peer review, scientific knowledge is tested and debated about its validity before it becomes accepted knowledge (American Association for the Advancement of Science, 1989; California Department of Education, 1990; Showalter, Cox, Holobinko, Thompson & Oriedo, 1974).

In addition, the revisionary nature of scientific knowledge distinguishes it from other types of knowledge. When discrepancies arise in the observed results of inquiry and the predicted results, the specific knowledge scheme is called into question. If subsequent examination of a particular knowledge structure reveal many discrepancies, revision and reformulation of the knowledge structure will occur. Thus, scientific knowledge is always tentative and self-correcting. (Herron, 1971, Showalter et al., 1979).

Thus, scientific knowledge is only one way in which humans attempt to understand their surroundings. Other modes of knowing create knowledge in their own particular way. They have different aims, methods of accumulating and validating data, ways of decision-making, and a set of assumptions all of which generate a different kind of knowledge. Many questions cannot be studied in a scientific mode of knowledge production and lie outside the realm of science. Therefore, science is unable to answer all questions. Is science the best way of knowing? Scientific knowledge provides a very complex picture of the natural world, but that is not the proof that it portrays the most accurate paradigm of nature.

Summary

A model of the nature of scientific knowledge was created based on previous models and a review of the literature. Scientific knowledge is humanistic, social, historical, based on specific beliefs, observation based, a result of inquiry, composed of structures, and has attributes of uniqueness. Scientific inquiry is a human enterprise affected by qualities and behavorial patterns of scientists. These human characteristics affect the credibility of the resultant knowledge. In addition, scientific knowledge is shaped by its social nature and is affected by the power structure and political climate of the supportive scientific community. The epistemological aspects of its acceptability cannot be divorced from the sociological concept of decision making. Scientific observation is not a simple process, but is permeated by theory and the limitations of language. There is no one scientific method but many approaches to scientific inquiry which results in the knowledge structures of science - facts, theories, and laws. An understanding of the dynamic processes of scientific inquiry demonstrates that science cannot produce final statements of the truth. All scientific knowledge is probabilistic and tentative never being proved in the absolute sense. Even though scientific knowledge has unique attributes such as its testability, predictive power and communal review, science cannot answer all questions. It is just one way of knowing.

CHAPTER III

METHODOLOGY

Introduction

The majority of studies on students' or teachers' conceptions of the nature of scientific knowledge have used quantitative measures. Instruments using a Likert scale to monitor responses to statements about the nature of science and scientific knowledge include the Nature of Science Scale (Kimball, 1967-68), Test on The Social Aspects of Science (Korth, 1968), Wisconsin Inventory of Science Processes (Scientific Literacy Center, 1967), Welch Science Process Inventory (Welch & Pella, 1968), and Nature of Scientific Knowledge Scale (Rubba, 1976). Cooley and Klopfer (1961) devised a measure titled Test on Understanding Science which includes multiple choice questions.

To better understand respondent answers to questions concerning the nature of scientific knowledge, Aikenhead, Fleming, and Ryan (1987) designed a measure called Views on Science-Technology-Society (VOSTS). The test asks respondents to react to a statement by marking agree, disagree, or could not respond and then to write a short paragraph explaining their choice. In this way, researchers are able to gain an insight into the reasoning and thought patterns that informs respondents' answers. In a study of 10,800 high school seniors using VOSTS, Aikenhead, Fleming, and Ryan (1987) discovered that in many cases a number of respondents marked agree and disagree to particular questions, but at the same time gave similar justifications for their answers. These findings raise significant concerns about the measures using the Likert scale adequately measuring participants' conceptions of the nature of scientific knowledge.

Furthermore, from the analysis of the written justifications in VOSTS, Aikenhead, Fleming, and Ryan (1987) indicated a need to examine carefully the meanings of the words and ideas individuals used. What were individuals' conceptions of terms such as scientists, scientific method, fact, law, theory, technology, or science? The qualitative data of VOSTS support the need for this research study into the conceptions of the nature of scientific knowledge by an in-depth probing of the language and thought patterns of participants through interpretive inquiry using unstructured interviews.

The Nature of Interpretive Inquiry

Interpretive inquiry strives to make sense of and understand the conceptions of individuals through face-to-face interactions to gain an inner perspective of their personal world views. The meanings people impose on reality influences the way they think and behave. The best way to discern individuals' conceptions is to watch, discuss, listen and participate with them in their struggle to relate their world views. Interpretive inquiry is based on a phenomenological paradigm that there is subjective reality constructed primarily through an individual's experiences in the world. This personal reality which includes a tacit, taken-for-granted world can only be understood through the intersubjective involvement with another human being (Barritt & Beekman 1983; Firestone, 1987; Shapiro, 1983). The emphasis is on interpretation and description while the ultimate goal of interpretative inquiry is a particular understanding (Rist, 1982; Shymansky, 1984). In this case, the particular understanding is middle school science teachers' conceptions of the nature of scientific knowledge.

In interpretive inquiry, the researcher is the instrument and the interpretation of the data arises out of the experiences of the investigator (Eisner, 1981; Smith, 1982). Since the researcher plays an active role in the creation of the understandings of the investigation, the subjectivity of the researcher is recognized. The perceptions and personal understandings that the investigator brings to the study influence the selection of questions, episodes, statements, and descriptions as well as the ultimate interpretation.

However, it is the subjectivity of the researcher that presents some dangers in interpretive inquiry studies. Different from quantitative studies, there are numerous ways to conceptualize and define the relevant parameters of the data . In addition, there are no reliability or validity quantifications of the instrument or statistical analysis of the data to determine "significance." It is the researcher that provides the only means of knowing about the subjects and the ultimate interpretation of the data. In this particular study, the researcher has struggled with the immense responsibility of portraying subjects' views as accurately as possible and interpreting their conceptions in an adequate manner. It is recognized by the researcher that there is always a degree of arbitrariness inherent in any attempt to categorize subjects' world views. The researcher does not assume any special validity of the participants' science world views as defined in the study other than the fact that their construction was defined by parameters of the study's model of scientific knowledge and were formulated judiciously to create a common ground for interpretation. Other limitations of interpretive inquiry studies as compared to quantitative studies relate to the absence of precision in focusing on one or a few variables and the limited number of subjects. The issue of generalizability in interpretive studies is discussed below.

The power of interpretive studies is their scope. Rich description provides the reader with a recreation of observations as well as a deep understanding of the results (Firestone, 1987; Rist, 1982; Smith, 1982). It freezes instances of the inquiry to bring them to a level of awareness and consciousness. Since such a study requires an intense, in-depth involvement of the investigator, usually interpretive inquiry studies involve a small number of subjects. The strengths of the interpretive inquiry studies are the recognition of subjectivity, detailed depictions, and the attention to perspectives evidenced by quotations and descriptions.

Moreover, generalizability is a concept relating to the belief that the findings of a study can be generalized to the universe of similar phenomena. In interpretive inquiry studies, the emphasis is on particular understandings with little possibility of absolute replication. However, this research study is predicated and supported by previous studies on individual's conceptions of the nature of scientific knowledge. In addition, interpretive inquiry studies maintain that the general resides in the particular, and what is learned from the intense analysis of individuals' subjective realities can be expanded to other settings. These subjective realities are not arbitrary ones but are constructed by the participants through experiences and associations with other human beings and cultural influences. Thus, participants' subjective realities are reflective of the culture in general (Eisner, 1981). In this particular study, the participants have experienced professional training as a science teacher which is somewhat standardized and very similar across the nation. Also, their work situations in the middle school setting is comparable to most middle schools in the nation in respect to organizational schemes, student populations and curricular content. Due to these similar educational cultural influences and sociological effects, particular subjective realities of the participants can be generalized. In learning about each individual's "consciousness of scientific knowledge," important information can be gained about the general science education culture. Moreover, the generalizability of this interpretive study lies in the intersubjectivity of the study with the audience reading it and their ability to personally relate descriptions and findings to their own situations.

Unstructured Interviews

The unstructured interview format was selected as the method of obtaining a perspective of the middle school science teachers' conceptions of the nature of scientific knowledge. The unstructured interview (also called informal interview or semi-structured interview) is seen as a "conversation with a purpose" (Burgess, 1984). As opposed to the structured interview where the subject is in a subordinate role answering predetermined questions in a particular pattern, the unstructured interview employs a thematic framework from which to form questions during the conversation. The questions can be rephrased, reordered, analyzed, and discussed. There is considerable active participation and interaction by both individuals. The investigator is a confidant who sincerely is interested in the views of the individual. Because there exists a more natural, personal relationship between the researcher and the respondent than in the formal interview setting, the conversation yields much richer, in-depth information (Burgess, 1984; Rist, 1982).

Procedure

Selection of Subjects

The study involved a total of six middle school science teachers from an urban school district of approximately 20,00 students and a suburban/rural school district of about 24,000 students. The selection of the participants began with a request of the school districts' science supervisors for a list of recommended teachers to participate in the study. Criteria outlined for recommended participants included teachers actively involved in teaching middle school science as well as certified in that field. In addition, recommended individuals must be judged as "successful" science teachers as evidenced by peer recognition, school district activities, and receipt of awards. Also, the list of requested recommended participants needed to include both sexes, different races, and a range of teaching experience. From the submitted lists of recommended teachers, the investigator chose six participants that included a range of teaching experience, both sexes, and two races. A descriptive profile of each subject is given at the end of the chapter. All subject names used in the descriptive profile as well as throughout the study are pseudonyms to insure the anonymity of the participants.

Initial Conference

After the selection of possible participants in the study, the researcher sent to each subject a letter that outlined a brief description of the research project, an invitation to participate, and a notification that a phone call would follow to ascertain a decision of involvement. The first six teachers contacted by the researcher agreed to participate in the study. During the phone conversation, a date and time for an initial conference was scheduled. The initial conference, usually lasting about thirty minutes, included a detailed discussion of the scope of the study, the time requirements, the assurance of confidentiality, and the use of the results of the study. At that time, subjects read and signed the "Consent to Act as a Human Subject" form. A date and time for the first interview session was scheduled. In addition, each subject was given the Biographical/Professional Background Questionnaire (see Appendix A) to complete and return by mail to the researcher before the first interview.

Interview Format

The interview stage of the study consisted of two interactions on different days between the researcher and each participant. The unstructured interviews were held at the subjects' homes during a time free from distractions and interruptions. All conversation was recorded on audio tape and brief notes were taken by the researcher detailing any "interpretive asides" (expressive nature, body language, and behaviors of the subject). The initial interviews began with an explanation of the aims of the interview and the freedom to seek clarification of any questions. The interviews continued with questions seeking clarification of any completed items on the Biographical/Professional Background Questionnaire. From that point, the interviews involved a discussion between the researcher and subjects about the main themes of the study - the importance of science education, the eight dimensions of the model of scientific knowledge, and the way in which the teachers' viewed their conceptions of scientific knowledge affecting their instructional methodologies. An Interview Theme and Question Guideline (see Appendix B) was used by the researcher as a reference to ensure that the same themes would be covered in all interviews. The guideline indicates the types of questions that were addressed in the interview sessions. However, during the interviews, questions were rephrased and reordered as an interview progressed. Thus, the sequence of questioning was quite different for each subject. The initial interview sessions were very successful with participants freely and enthusiastically discussing their perspective of each of the interview themes. The lengths of the initial interviews ranged from 90 minutes to three hours with the average length being two hours.

After the initial interview session with each subject, the researcher transcribed the audio tape. It was invaluable for the researcher to personally transcribe the audio tapes. It allowed not only for the content of the questions and answers to be heard again, but also permitted an examination of interview and questioning techniques used by the researcher. In this way, the researcher was able to improve in questioning and interaction strategies for subsequent interview sessions. It was discovered that reasking questions in a different way, sometimes using the language of the participant, was an effective method of checking for consistency and clarification of answers. In addition, detailed questioning was needed into the precise meanings of words to allow a complete understanding of the implicit meanings of the language used by the subjects.

Using the transcript, a careful analysis of the initial interview was done seeking out any thematic areas that were missed or areas that needed clarification. Once the analysis was finished, a date and time for the second interview was scheduled with the subjects. The time interval between the first and the second interview sessions ranged from two weeks to five months with the average length of time being nine weeks. The second interviews proved invaluable in providing the researcher with a chance to address areas that needed further explanation or clarification as well as to ask about themes for which time did not allow during the initial interview. As in the initial interview sessions, the subjects were enthusiastic and eager to talk about their views. The lengths of the second interviews ranged from 50 to 125 minutes with the average length being 76 minutes. The audio tapes of the second interviews were transcribed again by the researcher. The total transcript of all the interviews with the subjects totaled 287 pages in length taking 95 hours to transcribe.

Analysis

Analysis occurred during the interviewing process as well as subsequent to it which is typical to interpretive inquiry studies. There was constantly an interaction between collection of data and analysis; between "what is known versus what is to be learned" (Rist, 1982, p. 445).

Using the transcripts, the investigator repeatedly read the narrative of each subject striving to understand participants' assumptions, meanings of words, and conceptions. Particular attention was given to reoccurring concepts that related to the thematic framework of the interview. Any connection between the subjects' biographical data and conceptions was noted. A detailed attempt was made by the researcher to determine the conceptual "lens" through which participants viewed scientific knowledge.

Finally, the subjects' narratives were analyzed seeking unifying elements that linked the conceptions of the six participants as compared to the model of the nature of scientific knowledge and subsidiary issues of the study. Described in the next chapter, these elements supported by quotes and descriptive narrative portray the nature of scientific knowledge as conceived by the sample of middle school science teachers.

Subject Profiles

Beth

Beth is a white female, 45 years old. She has taught a total of 22 years all at the same school, and on a daily basis , she teaches eighth grade science to 104 students. As a tenured teacher, she is certified on a graduate level as a mentor teacher and in the areas of academically gifted, middle school science and social studies. Possessing an undergraduate degree in home economics, Beth continued to complete her education with the Masters of Education degree in middle school science. Beth is a regular workshop leader around the state and a presenter at state science conferences. Beth has received an Outstanding Science Teacher Award and the Distinguished Service to Science Education Award from a state science teachers' organization. Her local school district presented her with its highest science teaching award as well as the Teacher of the Year Award. She is involved extensively on a district-wide basis in inservice training particularly in cooperative learning and effective schools.

Beth became involved in teaching science when unable to secure a position as a home economics teacher. She returned to graduate school to secure her certification in science and began teaching at her present school. Her views about scientific knowledge have been influenced by college professors and interactions with science educators. She views the classroom teacher as very important commenting, "The quality of education boils down to what happens when a classroom of students sit down under the direction of that one teacher." Science is exciting to Beth because of its changing views of ourselves and the planet earth. In addition, Beth enjoys teaching science because of her love of the subject and the positive feedback of her students.

Diane

Diane is a white female, 29 years old. She has a total of eight years teaching experience having been at her present school six years. She is certified as a mentor teacher and in the areas of academically gifted, middle school science and math. As a tenured teacher, she teaches eighth grade science to 101 students daily. After receiving a Bachelor of Arts degree in education, she completed the Master of Education degree in middle school math. She received an Outstanding Science Teacher Award and the Distinguished Service to Science Teaching Award from a state science teachers' association. In addition, her school district presented her with the Teaching Excellence Award as well as the Teacher of the Year Award. Diane is also an author having published an article on affective education in a professional magazine. She is especially proud of being selected as a participant in a national research associate program serving an eight-week summer internship at a research laboratory.

Diane was influenced by two high school science teachers to pursue a science related career. Her views about the nature of scientific knowledge has been affected initially by college professors and reading science literature, but more recently by her experiences at a national laboratory. She conceives the importance of classroom teachers as "critical" because they serve as a role model, facilitator, and a motivator for students which can "make or break a kid as far as their interest in science." Science is interesting to Diane because it is "intriguing ... not boring, and it is applicable to the real world." Because of her love of learning and helping others, she wanted to become a teacher particularly at the middle school level.

David

David is a white male, 48 years old. He has a total of 20 years of teaching experience with 15 years at his present school. David teaches seventh grade science to 120 students on a daily basis. As a tenured teacher, he is certified on the "A" level as a mentor teacher and in the academically gifted and middle school science areas. He graduated from a local university with a Bachelor of Arts degree in biology with some graduate work in ecology. He has received awards from the local Jaycees as Young Educator of the Year and from the local school district as Middle School Teacher of the Year. He is actively involved in his school's leadership team and serves as science department chairperson.

In addition, David views the importance of the classroom teacher as being a positive role model for students. Science interests David because it "gives us meanings and explanations for the physical and biological relationships on the planet earth." Being influenced by his family background, military service career, and college experiences, David decided to follow a career as a science teacher.

Alice

Alice is a white female, 41 years old. She has been teaching for a total of 11 years with six of those years at her present school. As a tenured teacher, she teaches eighth grade science to 120 students on a daily basis. She is certified on the "A" level in middle school science having received a Bachelor of Science degree in education. Alice has participated in many district-wide inservice sessions from critical thinking workshops to school leadership seminars. Being active in coaching science competition teams at her school, Alice has directed teams of students to the finals of two state science competitions in recent years. She has received the Teacher of the Year Award and has been a nominee for the district-wide Teaching Excellence Award. Because of her innovative teaching techniques, Alice has received two grants to enhance her classroom science teaching.

Alice is interested in science because "all knowledge is stimulated from science." She views science as a way to "allow humanity to be free to create and through that creation give forth something of themselves." Alice believes that classroom teachers are important because they are necessary to stimulate critical thinking and "to offer ... a safe shelter for that child to be free to think." Influenced by her grandfather who was a doctor and the curiosity of her children, Alice became a teacher of science to help young people develop a desire to learn more about the natural world.

Jane

Jane is a black female, 45 years old. She has been teaching for a total of 21 years, five of which have been at her present school. She teaches science to 111 seventh grade students each school day. As a tenured teacher, she is certified on the "A" level in middle school science. She completed her Bachelor of Science degree in biology and has continued her professional development through attendance to many inservice opportunities on various science instructional methodologies. Jane was a recent nominee for the state Earth Science Teacher of the Year Award.

Furthermore, Jane is interested in science because "it attempts to explain the world around us and ... uses the knowledge gained to enhance our lives." Professional colleagues, inservice workshops, and reading the science education literature have influenced Jane's view of scientific knowledge. She views the importance of the classroom teacher as a "guide for the students in learning." Even though Jane did not enter college to be a science teacher, science was always one of her favorite subjects. She enjoys teaching science because of the excitement of the subject and the personal stimulation of helping students.

Bob

Bob is a white male, 44 years old. This year is his first year at his present school but he has been teaching for a total of 13 years. He is certified in middle and secondary science possessing a Bachelor of Science degree in science education. He has done some post-graduate work in curriculum planning and the social foundations of education. He has worked in four different school districts teaching middle and high school sciences in addition to a tenure as a central office administrator and manager in a private business. He currently teaches eighth grade science to 125 students daily. On the district level, he has recently received their top award, the Excellence in Science Teaching Award. As an avid reader of science literature, Bob is very active in his district in writing science curriculum and integrating computers in his classroom.

Bob likes science because he enjoys "knowing why things are the way they are." Being influenced by a special middle school teacher, Bob began to enjoy science and later, in the military, Bob was given the chance to teach others. In college, Bob was guided into the science education field by an influential science educator. He immensely enjoys teaching science because of his love of the subject, the challenge of testing new ideas, and the feedback of his students.

Summary

The previous results of quantitative measures of the nature of scientific knowledge have indicated a need for an in-depth probing of individuals' conceptions of this important area of science. The interpretive inquiry method of investigation was chosen for the study because of its emphasis on face-to-face interactions with individuals in an attempt to understand their subjective realities. By the use of unstructured interviews, the researcher sought to ascertain the personal meanings the subjects ascribed to their views of the nature of scientific knowledge. Although interpretive inquiry studies are limited by the lack of reliability/validity quantifications, statistical analysis, and large number of subjects, their strengths lie in the scope of the studies through rich description and recognition of subjectivity. Because the subjective realities of the participants are reflective of their cultural and socialization experiences, a particular understanding of their scientific knowledge conceptions applies to a general understanding of science teachers' world views. The methodology of this study has provided a portrayal of the views of scientific knowledge held by the sample of middle school science teachers.

CHAPTER IV

THE IMPORTANCE OF SCIENCE EDUCATION AND THE NATURE OF SCIENTIFIC KNOWLEDGE: CONCEPTIONS OF SIX MIDDLE SCHOOL SCIENCE TEACHERS

Introduction

Through the unstructured interview format, a detailed account was obtained of the teachers' conceptions of the nature of scientific knowledge. Two subsidiary issues addressed in the interviews were the importance of science education and the effect of the subjects' views of the nature of scientific knowledge on their teaching strategies. This chapter describes these conceptions in a thematic approach. Initially, teachers' conceptions of the importance of science education will be described which is followed by participants' conceptions of the eight dimensions outlined in the model of the nature of scientific knowledge. Finally, a portrayal of teachers' conceptions of the effect of their views on their instructional strategies will be given.

The Importance of Science Education

The main goal of science education is to increase the scientific literacy of students. In Chapter One, the features of scientific literacy and the main goals of science education are depicted. The two most prominent views expressed by the subjects dealt with the custodianship of the natural world and the acquisition of critical thinking/problem-solving skills as an individual as well as a citizen. The subjects viewed science education as providing students with an appreciation and understanding of the natural world in order to live in harmony with it. Recycling, natural resource conservation, energy efficiency, acid rain, and ecological relationships were mentioned as key environmental issues that students should understand. Beth stated that being literate in science is:

> Being familiar with enough basic science concepts so that you can live in this world and not do detriment to yourself or this planet as you use the resources ... in such a way that their use will benefit you as an individual and for the good of this planet.

Two subjects felt strongly enough that they felt the "survival" of the world depended on the science education of students. In discussing the problems of humanity, Bob stated that "if there is a solution, it is going to be found through science" whereas David expressed, "Our entire future is dependent upon our understanding of science."

Furthermore, the importance of students developing critical thinking and problem solving skills in science education was commented upon by every subject. These skills were viewed as necessary for intelligent decision making as an individual or as a citizen contributing to society. Alice saw science education in a personal perspective as developing "a student who can look at all sides of an issue, can see the value of a problem, can take that problem and fit it somewhere into their puzzle of life." In this manner, she believed students can learn to analyze problems, to recognize that all ideas have merit, create their own ideas, and develop confidence in their own knowledge. Jane emphasized that students have "got to be able to hear the facts on both sides and then make a decision based on what they think is best for the community or for them." Several subjects considered the critical thinking/problem solving skills inherent in scientific methodology. By studying science, Beth related, "That's what you are teaching when you teach process skills, and you teach the scientific method - a logical way of arriving at a legitimate, credible answer to a problem."

In addition, subjects mentioned future employment opportunities for students, possession of an adequate knowledge base, and affective concerns as reasons for science education. Diane emphasized that she thinks that "we need people who understand and who are capable in science, who can go out there and fill the jobs." Jane was more specific by stating that "we have to provide scientists." The acquisition of a knowledge base in science was discussed in the context of acquiring future jobs or understanding scientific issues in decision making. Finally, subjects noted that science education should develop interest, curiosity and a positive attitude toward science. Bob explained that students should understand that science is "fun to do."

However, in every case, the subjects stated that the goals of science education were not being achieved in schools. Beth attributed the reason to the lack of time and hands-on science instruction. She explained:

> You are caught between what you really feel is the right thing to do for kids, and what you really can do. It takes time to plan and we do not always have that time. That's why hands-on ... science ... doesn't get done.

Similarly, Diane viewed the failure of achieving the science education goals due to the lack of hands-on science that causes a loss of interest by students. Diane responded:

> I think you really got to get them to like it [science].... I see teachers who have their kids come in, sit down, and read a page and answer questions.... That is all they ever do and they never use any lab equipment.... I don't even think it is the majority of teachers who are teaching with the hands-on approach.

David attributed the uncaring attitudes of students about science whereas Alice believed class sizes and lack of teacher planning time contributes to the failure of achieving the science education goals. Bob viewed the reasons as the unchangeability of teachers, the curriculum, and the use of textbooks as well as the emphasis on vocabulary. Bob explained, "I think teachers are ... scared of changing what they are doing.... I think probably all of us spend more time in the textbook than we should ... and too much time on vocabulary." Jane thought societal influences on children, too many concepts to learn, textbooks, and a lack of hands-on activities create a deficiency in meeting science education goals.

Interestingly, when the question of the importance of science education was narrowed to "Why is middle school science education important?", the answers also narrowed considerably. Almost in every case the subjects mentioned that middle school science is preparation for high school science course work. David stated, "I've got to get them ready for high school." The other dominant issue involved the conception that it was the really last chance to develop an interest and a positive attitude in students about science. Diane explained that she needed to "make them [students] love science so that when they leave me, they will continue taking them [science courses] in high school." The importance of middle school science education was paramount in Beth's view who stated, "If we get more kids going into science, it is going to be the middle school that is going to make the difference." The issues of developing a custodianship of the natural world and critical thinking/problem solving skills were not mentioned in the middle school context. Thus, it appears that the subjects could be more comprehensive in their thinking of the general importance of science education. However, when applied to their particular daily situation at the middle school level, their reasoning was more practical and diminished to preparation and attitudinal aspects of science schooling.

In comparison with the conception of scientific literacy and its characteristics as well as the National Science Foundation's "goal clusters" (Kahl & Harms, 1981) as outlined in Chapter One, the subjects conceptions of the importance of science education were generally inclusive of most of the dimensions. Neglected as goals of science education by the subjects were an understanding of the scientific enterprise as a human enterprise and a cognition of scientific history. These two areas are very important for a complete understanding of the nature of scientific knowledge.

The Nature of Scientific Knowledge

Humanistic Nature of Scientific Knowledge

Teachers' conceptions of the human element in the production of scientific knowledge was ascertained by questioning about their views of the characteristics of scientists. The difficulty with this line of discussion was the different participants' conceptions of the word "scientist." The investigator began to realize the various views by examining answers to the Biographical/Professional Background Questionnaire question, "Do you see yourself as a scientist?" Five of the six subjects expressed the view that they were scientists. Cited reasons for their conceptions included their use of problem-solving strategies in experimentation, discovery techniques using the scientific method, and curiosity about the natural world. Beth stated, "A scientist is one who appreciates, observes, and attempts to understand how things work in the natural world, and I do all those things." Diane possessed two views of a scientist by viewing herself as a scientist in class in the process of investigating problems but did not see herself as a scientist professionally speaking. Diane explained, "As a profession, I do not because I am not solving/investigating problems on a daily basis." Bob was confident in not viewing himself as a scientist because he doesn't do research.

In the interviews, the issue of participants' conceptions of the word "scientist" was clarified even further. The general view of a scientist was reinforced by the subjects' responses. Jane explained:

> I have come to see that anybody who pursues an interest or studying about science is a scientist. If you are finding out about the world around you and gathering some kind of knowledge then technically you are a scientist.

Beth does not see the requirement of generating new knowledge to be a scientist. She stated, "I see a scientist as anybody that is trying to observe, learn about and interact [with the natural world] in a positive way." Beth, David, Alice, and Jane saw themselves as scientists.

Moreover, Diane viewed herself as a scientist in the classroom in the process of investigating problems, but she was careful to point out the alternate interpretation of the word "scientist" in the professional sense. Through her experience at a national laboratory, she related her view of the professional scientists as one who does research on a continual basis and produces knowledge. However, Bob distinguished between a scientist and a "student" of science. He viewed a scientist as a person who is actively engaged in research on a daily basis and creates knowledge. A "student" of science is anyone who studies science and uses it in some form of communication. Therefore, he viewed himself as a "student" of science.

The discovery of the different interpretations of the word "scientist" by the sample of teachers has significant implications for measuring individuals' conceptions of scientists by multiple choice or Likert scale measures. The different interpretations of the word "scientist" would illicit misleading answers by respondents to questions formulated with the test designers' conception of the word. To obtain an accurate measure of conceptions of a scientist by a sample, it would be necessary to explain the test's definition of the word "scientist." In the interviewing process, before the researcher continued questioning about scientists, the operational definition of a scientist was given. A scientist is an individual who has received professional training in a system of natural scientific knowledge and is, on a daily basis, actively engaged in research activity investigating the natural world.

The interviewing process continued with an examination of respondents' conceptions of the characteristics of scientists. When asked about objectivity in scientists, two subjects seemed to be unsure because their initial answer conveyed their belief in scientists being objective, but later they changed their view of scientists' objectivity. All the subjects believed that scientists strive for objectivity in research, but they viewed such objectivity can be tempered by human biases. Beth explained, "I think there has to be objectivity in science, but anytime you deal with the human element how can you be sure there is 100 percent objectivity?" Alice stated her uncertainty by commenting, "I just don't know how objective they truly are." The subjects connected any biases in scientists to the process of the interpretation of data. Alice commented:

> If you are a scientist ... and you really want to believe it [possible answer to a problem], then you are more apt to believe it. You focus on the data that has been collected by scientists who believe what you are thinking.

However, when forced to choose, most of the subjects felt that scientists were more objective than subjective. None of the subjects mentioned initially the effects of paradigmatic beliefs, language or professional schooling on the objectivity of scientists. Only after asking about these effects on scientists' objectivity did the subjects comment that those factors do affect objectivity. Beth thought that the scientist's professional training "would increase his objectivity and might help him ask the right questions." Bob was the only participant that discussed the emotional nature of scientists in relation to objectivity. He explained, "I think most scientists probably are very emotional ... and I mean most of them are emotionally attached to what they are doing." Yet, he viewed scientists as able to put their emotions aside and to objectively determine the validity of their findings.

In addition, other characteristics of scientists discussed by the subjects included reasoning abilities, intelligence, honesty, open-mindedness, and sharing knowledge. Two of the subjects believed scientists have to be very rational and possess good reasoning skills. Superior intelligence was not viewed as necessary for scientists by participants, but they viewed scientists as at least above average in intelligence. Moreover, most of the subjects believed scientists strive toward honesty in their work. However, two of the subjects did relate reading about the falsification of data by scientists. In addition, Beth was very disturbed upon learning about a group of scientists that intentionally left out a step in their methodology to prevent others from duplicating it. All but one of the subjects viewed scientists as open-minded. Beth viewed open-mindedness as a basic requirement for a scientist by advocating, "If you truly are a scientist then you will toss your theory or alter it so that it conforms to the new information." In contrast, based on her experience in a laboratory, Diane commented that scientists "were willing to listen to all points of view ... but they did not waiver at all." She continued by explaining that the scientists "were very adamant." Therefore, Diane viewed scientists as not being open-minded in the sense of accepting new ideas.

Furthermore, all the subjects viewed scientists as very willing to share their experimental findings with the scientific community. Beth stated, "The whole idea of doing it [experimentation] is to share it [the results] with the scientific community, and it is up for peer review." However, only one subject believed that the publication of experimental findings consumed most of a scientist's time. Relating her experience in a lab setting working with scientists, Beth related that "about 90% of their time is spent writing and researching papers ... to get it [experimental results] out to everybody else." All the other subjects conceived that data collection and analyzing data consumed most of a laboratory scientist's time.

When asked about the factors that motivate scientists, the predominant answers given by all the subjects dealt with intrinsic reasons. Curiosity was viewed as the primary motivating factor for scientists. Beth explained, "It is the pure desire to know on a personal level" whereas Jane was more specific by stating, "I think it is curiosity and ... that built-in motivation that hates mysteries. They just want to solve and they want to find out." In addition, a common view of scientists' motivation was the desire to help humanity. Bob advocated that they "care about the future of the world and the future of mankind." In helping humanity, the subjects saw the scientist as being able to solve problems that affect the future such as cures for diseases. Beth believed that scientists are motivated entirely by the intrinsic factors by commenting, "Scientists are doing it out of just a yearn for learning and a desire to know how the natural world works."

However, other subjects included extrinsic factors for the motivation of scientists. Diane stated:

> It is not just internal because they get satisfaction and approval from their peers. They get recognition from the people around them so it is both internal about yourself plus getting recognition from your peers.

Thus, Diane recognized the motivating factor of peer recognition which may take the form of publications, professional advancement, presentations, or awards. Based on her experience in the laboratory setting, Diane mentioned that even the number of cites in professional publications was an important motivating factor of scientists. Other external motivating factors expressed by subjects were money, project funding and prestige.

It is apparent during the interviewing process that the one specific origin of the subjects' views about scientists was through their interactions with scientists. Jane formed her conceptions of scientists by her brief interaction with a scientist whom she views as very intrinsically motivated. Jane stated, "This person is not self-seeking in trying to get recognition for herself." Diane related that she thought scientists were "super smart, intelligent persons" working mainly by themselves. After her extensive experience in a laboratory setting, her views of scientists changed drastically. Diane commented, "You don't have to be brainy. My scientist was so down to earth that he was just like the typical person you would see on the street."

In summary, it is very important to understand the conceptions of the word "scientist" by research subjects before any understanding of their conceptions of the traits of scientists can be obtained. With the exception of one subject, these science teachers considered themselves as scientists in the ways they studied and attempted to understand the natural world. In describing the characteristics of scientists, all subjects described most of the typical ideal traits of scientists. The influence of expectancy effects on objectivity was related by most of the participants. However, the subjects did not specifically recognize the effects on objectivity of paradigmatic beliefs, language and the professional schooling of scientists. They tended to believe scientists are more objective than subjective. Furthermore, most subjects conceived scientists as very open-minded, not realizing the extent of scientists' possible intolerance toward conflicting views. In addition, there was the belief that scientists openly shared their scientific findings with the scientific community. The secretive nature of scientific inquiry was not mentioned by most subjects. Finally, most subjects realized the intrinsic as well as extrinsic motivating factors of scientists, but only one subject comprehended the extensive time scientists devote to publication. In general, subjects' understanding of the human element in the production of scientific knowledge tended toward an idealistic view rather than a realistic view. They held scientists in the highest regard and were very disturbed when contradictions to their views were revealed. It was apparent that the most influential factor affecting subjects' views of scientists was their association or lack of association with scientists. By far, Diane possessed the most realistic view of scientists whereas the other five subjects, who have not had any extensive association with scientists, generally viewed scientists in a more idealistic way.

<u>The Social Nature of Scientific Knowledge</u>

Conceptions of the social nature of scientific knowledge were determined by asking the subjects about the interactions of scientists in the production and arbitration of scientific knowledge. Other issues addressed in the interviews were subjects' views of the difference between science and technology as well as the interaction of science as an institution with other social institutions.

Initially, a mutual understanding of the term "scientific community" had to be ascertained. Most of the subjects viewed a scientific community in a very broad sense. For example, Jane conceived a scientific community as "those people who are really doing some kind of research ... in any area of science." There was not any clear understanding by the subjects of the term "scientific community." Thus, to clarify the term, the researcher explained the study's operational definition. A scientific community is a group of scientists who have completed comparable educational training in similar scientific literature about their specialization. In addition, the community has its own subject matter that is marked by the boundaries of its technical literature.

Most of the subjects knew very little about any type of hierarchical arrangement of members of a scientific community. Only after asking directly about it did subjects attempt to relate any conceptions about a hierarchy. Only the top members of a scientific community, the "experts" or "Nobel Prize winners", were described in a hierarchical explanation. Only Diane mentioned the hierarchical levels of the experimental and theoretical scientists. In addition, Diane was the only subject that recognized that research assistants or technicians can be considered part of the scientific community, and they do the bulk of the actual experimentation and gathering of data in a lab setting. Reflecting on her lab experiences, Diane emphasized that the technicians "were assigned to gather the data and then it was given to the scientist for him to interpret." Thus, most of the time of the laboratory scientist is interpreting data and writing research papers. In contrast, most of the other subjects believed the majority of a laboratory scientist's time was spent running tests and gathering the experimental data.

Moreover, there was very little understanding by subjects of a "paradigm" in the Kuhnian sense and its affect on the beliefs and operation of a scientific community. Only two subjects mentioned the effect of the scientific community in determining the "rules of the game." Alice commented that the scientific community determines "scientific investigations, lab studies ... and different types of research." In a more detailed account, Diane stated that the scientific community has "different standards just like different professional organizations have their own rules and ethics.... They set their own rules of what's acceptable and what's not acceptable." Most subjects viewed the determination of the kind of research problems pursued in a scientific community to be more a factor of funding than influenced by the scientific community. Jane explained, "If you get the money, then you are going to have a bit more influence as to what can be studied." No subject commented initially on the effect of the scientific community and its paradigm on the credentialing of its practitioners. Thus, most subjects did not have a realization of the effect of a scientific community's paradigm on the determination of research problems and experimental methods as well as the schooling of scientists.

In contrast, the importance of communication between scientists within a scientific community was recognized by all the subjects. Beth stated that:

> They [scientists] are very open with sharing the knowledge they have gained and the observations that they have made. They are very open with the procedures, with data, with interpretations, and it's there for others who have the background, knowledge, and the interests to look at what has been done, the data that has been collected, and the interpretations and inferences that have been drawn. Science knowledge is only advanced when that has been done many, many times.

Diane reinforced Beth's comments by advocating that "without the communication, there is no knowledge." Bob thought that scientists would be foolish not to share their findings because someone else could obtain the same results and claim to be the first. David was adamant in believing it was an obligation of scientists to share information by expressing, "If they do not communicate ... they are not really scientists." Thus, the subjects were cognizant of the communal aspect of scientists sharing information within a scientific community believing it is a basic requirement to be considered a "scientist."

Moreover, the subjects were questioned about the role of the scientific community in the process in which experimental findings become acceptable scientific knowledge. All subjects related the importance of replication of experimental results in determining the acceptability of findings. Jane explained:

> When people have repeated ... your experiment and got the same results or they observed something under the same conditions and found ... those same solutions or results from that observation, and it is done many times then that knowledge will be accepted.

Diane stated, "You need other people to be able to validate what you have found." The recent incident of scientists rejecting cold fusion was given by two of the subjects as an example of the scientific community's ability to determine the acceptability of experimental results. In addition, the issue of scientific debates whether through the literature or through meetings and the persuasive nature of the arguments were described by Beth, Diane, Bob, and Jane. Bob commented, "The debate is constant, and people are researching based on whatever their particular hypothesis is ... and as they gather evidence, one gathers more convincing evidence than the others." Beth stated that scientists "have glorious debates, but that's one of the wonders of science. That we can all have the same problem, and we have different explanations."

However, there was confusion among the subjects on the process of the final acceptance of experimental findings as scientific knowledge. Alice explained:

> The majority rules. I visualize this conference of scientists ... sitting in a room and if 45% of them say this is what we have found and the other 35% say we disagree, then the 45% rules.

Finally, Alice admitted she did not know. David believed there was a committee in Washington, D. C. that reviewed experimental findings and decided on its acceptability as knowledge. Like Alice, he commented, "I don't know that." The other four subjects had a better understanding of the process of the role of the scientific community in the acceptance of scientific knowledge. Diane expressed:

> Once you get to that point where lots more people are supporting you then it [scientific findings] becomes accepted because you have the majority of people who believe what you have done to be right.

Bob explained, "I think it would be based on consensus ... whatever comes out to be the most acceptable form of a model to explain what happens ... and the one most people can buy into."

The aforementioned examples illustrate that the subjects' difficulty in understanding of the extensive nature of the interaction of scientists in a scientific community in arbitrating the acceptability of knowledge. Most subjects mentioned that the question of the process involved in knowledge becoming acceptable had not ever occurred to them. They tended to want to use terms of absoluteness in describing the process such as "when it is found to be true" (Jane) or when one "had hard scientific data to support it" (Beth). In addition, the term "proven" was used by subjects or as Alice relates that it becomes accepted knowledge when "we have not been able to disprove it." The subjects' usage of the terms "true," "hard data" and "proven" will be examined a subsequent section. Because this kind of knowledge had been produced by scientists, subjects tacitly accepted its credibility without fully considering the human and social dynamics involved in its creation. At least in some of the subjects' cases, scientific knowledge has been reified to the extent that it had been taken for granted to be "true."

In discussing the social role of science and technology with subjects, a clarification of those two terms was necessary. There was confusion among the participants of the exact nature of science in relation to technology. The basic problem was the conception of technology as just "applied science" and its relationship to the general broad term "science." In thinking of technology as applied science, some subjects believed technology to be a component of science whereas other subjects viewed it to be different than science. For example, all subjects related the idea that technology was applied science. However, when asked if science and technology were the same, three subjects responded affirmatively and three negatively. Jane responded, "Yes, ... you just take the knowledge that you have gained from science and use it to solve some problem or make some device." Similarly, Alice and Diane viewed science and technology as the same with technology being applied science.

However, Beth and Bob were very careful in explaining their differentiation between science and technology. Beth explained:

> Science is the basic research that explains how things work. A scientist will tell me how sound and light waves work. A technologist and engineer will use that knowledge and make me a VCR or laser disk. He puts that basic knowledge into something that will make my life easier.

Bob equated "science" to pure science and "applied science" to technology. In addition, both Bob and David thought that technology depended on science. Bob said, "I can see science without technology, but I can't see technology without science."

Moreover, even though some subjects did not equate science and technology, the view of technology as applied science permeated all subjects' descriptions of the aims of science with the exception of one subject. Responses to questions about the aims of science included the improvement of the quality of life (Beth), cures for diseases (Diane), solutions to societal problems (Alice & David), and increase food supply (Jane). Only Bob related that "science is not studied for any other purpose than discovery."

Furthermore, when asked about the social roles of science and technology, four of the subjects related the practical aspects of technology. Framing the question of science and technology in the social perspective helped most of the subjects differentiate the different purposes of science and technology. Beth, Diane, Bob and Jane conceived the social function of science as investigating the natural world whether the information was useful or not. They viewed technology as the practical application of science to benefit society and humankind. However, as indicated above, three of those four subjects still included examples of technology in their explanations of the aims of science.

Therefore, the sample teachers' conceptions of science and technology were difficult to differentiate because of their conflicting answers to questions. Five subjects would use the words science and technology interchangeably in one case only to use the words as separate entities in another case. Only one subject, Bob, was consistent in his answers regarding his conceptions of science and technology. Thus, these differing responses to the words "science" and "technology" as well as the phrasing of questions about the two words have large implications for any future test design studying those entities.

In addition, subjects' views of technology as just applied science as well as technology depending on science is in contrast to the model's explanation of technology. In the model, technology is viewed as being much more than just applied science possessing its own resources as a research entity. In other words, technology is much more than finding practical applications of scientific research. Technological possibilities are not limited by scientific research and can exist without science.

Furthermore, only two subjects viewed scientific knowledge as amoral. Beth explained, "It is not the knowledge that is good or bad, but it is how it is used". Thus, Beth as well as Diane realized that moral judgement can only be made on the ways humans use knowledge, not on the knowledge itself. The other four subjects did not separate knowledge from its uses viewing knowledge as either good or bad.

Finally, all subjects viewed science as interacting with other social institutions such as the government, general public, religious bodies, educational establishments, and private businesses. The main issue mentioned concerning science and its interactions with these institutions was funding. It was strongly felt that funding was the driving force behind research to the point of determining the problems that "needed" to be investigated by scientists. Relating her experience at a laboratory, Diane said scientists "research where the money is."

In summary, subjects' understanding of the dynamic nature of scientific communities in determining research methodologies and the acceptability of knowledge was limited. On many occasions, they expressed the concern that they had never really thought about these issues. Their conceptions of the communal nature of scientists continued to reveal a somewhat idealistic view of scientists. In addition, their remarks tended to be focused on a positivist perspective of knowledge. The acceptability of knowledge was based on unbiased experimentation that yielded "facts"and "hard data" that were "proven." The political dimension of consensus-making in scientific communities was not well understood and was reduced by some subjects to the "majority rules" in determining acceptable knowledge. It seemed difficult for subjects to discuss that knowledge was based on consensus, and they wanted to use the "terms of absoluteness" such as proven or true in reference to knowledge. The confusion of the terms science and technology is evident of a misunderstanding of the social roles of each. In general, subjects did not fully understand the sociological effects of the scientific community in the Kuhnian sense or the epistemological aspects of the acceptability of research problems, investigative methods, and the resulting knowledge structures.

The Historical Aspect of Scientific Knowledge

To ascertain subjects' conceptions about the historical nature of scientific knowledge, questions were asked about the manner in which knowledge has changed over time. In addition, the researcher was interested in identifying whether subjects' views of the historical change of scientific knowledge was cumulative or revolutionary. Finally, subjects expressed their views about progress in science.

In examining the manner in which scientific knowledge has changed over history, only two subjects mentioned anomalies and their effect on changing current paradigms. Beth commented, "Part of the fun of science is anomalies - when what you think is going to happen, doesn't happen." She continued to describe her belief that "when new data come along, we have to be willing to make changes in those theories and laws." Bob explained, "If something were to happen and it was repeatable, and the law did not apply, then the law would have to change." In addition, Bob commented, "As the evidence becomes more convincing in one direction or the other, the area with the most convincing evidence becomes the new knowledge base." Two of the subjects mentioned that scientific knowledge changes when new technology was designed to gather evidence using the example of plate tectonics. Otherwise, subjects viewed changes in knowledge over time as more the addition of new discoveries rather than the rejection of current knowledge structures. Diane explained, "We learn a little bit and that leads us to new areas that we want to look into." There was no concept of the Kuhnian view of competing paradigms by the subjects.

In addition, four of the six subjects viewed historic changes in scientific knowledge as cumulative rather than revolutionary. Beth responded, "The body of science knowledge builds in tiny little increments as scientists add a little bit to that body of knowledge." She offered the example of the quote by Isaac Newton that states, "I stand on the shoulders of giants" indicating a cumulative perspective. Diane supported Beth's view by stating, "Our new knowledge is built on old knowledge.... From the beginning of time, things have been documented and passed down and experimented on." These subjects conceived of "wrong" knowledge of the past as being improved rather than discarded.

However, David and Bob mentioned that change in scientific knowledge is revolutionary and cumulative. Bob explained, "I think we lose some [knowledge], because it is tossed and no longer even works ... and I think that obviously it accumulates." All the subjects conceived progress in science as solving problems improving our view of the natural world. Jane commented, "Being able to explain more fully why things happen, and being able to solve more problems around us.... I consider that progress."

Because the subjects had no conception of the effect of paradigms on the production of scientific knowledge and the resulting conflicts of paradigms in the Kuhnian sense, there was very little understanding of the historical change of that knowledge. Even though Beth mentioned "anomalies" in describing change, she persisted in presenting a cumulative view of the history of science. The subjects with the cumulative view of knowledge exhibited no hesitation in discussing the question. It was very obvious to them that science has progressed in that manner. The cumulative view of knowledge by four of the subjects is not surprising due to the prominence of this view in many textbooks. This cumulative view does indicate an positivist's perspective of knowledge. It was surprising to the researcher that two subjects were cognizant of a somewhat revolutionary view in addition to a cumulative view of the development of science. One of these subjects, Bob, does extensive reading in science which may account for his perspective. Furthermore, the subjects' ideas of the progress of science as problem solving agrees with the Kuhnian perspective. However, Kuhn would disagree that progress as problem solving offers a better view of the natural world as the subjects advocated. He would only say that new knowledge can only solve problems the old knowledge could not. Thus, it would appear that subjects would benefit from a study of the history of science to appreciate the cumulative as well as the revolutionary nature of scientific knowledge over time.

Specific Beliefs About the Natural World

The production of scientific knowledge by scientists is based on certain basic beliefs about the natural world. Subjects were asked their conceptions about these beliefs, and they had a great deal of difficulty with their answers regarding the basic beliefs of science. It appears to be an issue that is so taken-for-granted that they had not ever really thought about it. Although not stating it directly, all the subjects believed there is an absolute reality of nature. Two subjects responded that they believe that the natural world can be comprehended. Bob expressed the belief that "it is possible to understand all of it given some day given enough time." In addition, only two subjects explained that there are causes for natural phenomena. David advocated, "There is an explanation for everything in the world." Beth reinforced this view by stating, "There are certain basic laws and forces that govern what happens out there." Other basic beliefs of science stated was that nature is not static (Bob and Diane), there is an order to nature (Alice), and there are cycles in nature (Beth and Jane).

It was interesting that in four of the six cases the conversation about the basic beliefs of scientists evolved into a discussion of humanity's effects on the natural world. When considering the basic ideas of nature, subjects related their concern for the survival of humans. In relating humanity's influences on natural cycles, Jane responded, "We have to take care of this planet because it is basically ... all we have." Alice indicated, "In order for man to survive, we have no alternative but to respect our natural world and to care for it." Therefore, it appears when subjects think about the basic issues of orderliness, causality, and comprehension of the natural world, they relate those beliefs to a concern of their survival as human beings.

Thus, the subjects' understanding of the basic assumptions of scientists as they investigate the natural world was limited. It serves as an example of the taken-for-granted nature of subjects' cognition of the basic principles of science. The subjects may have been cognizant of these basic beliefs, but it was very difficult and in some instances impossible for them to relate them. Indicating the difficulty of verbalizing an answer, Bob stated, "I could probably touch on some of them, but I don't know if I could pull them all out." Since scientific knowledge is based on these foundations, it would be beneficial for the subjects to become more aware of their existence.

Observation and the Production of Knowledge

Observation of natural phenomena plays a basic role in scientific inquiry. To ascertain subjects' views about scientific observation, initially they were asked about their conceptions of the act of observing. In addition, questions were asked about the importance of observation in science and the factors which might affect a scientist's observations. Finally, the role of instrumentation in scientific observation was discussed.

An understanding of subjects' views of the concept "to observe" was necessary to analyze their responses. Five of the six subjects possessed a view of observation congruent with the model's definition of the term. Jane explained, "Observe means to look, to touch, to taste, or to hear - any kind of information we gather through the senses."

Similarly, the other four subjects described the act of observing as involving the use of all the senses. In contrast, Diane viewed observation in the sense of visual perception using the eyes more than the use of all the senses.

All subjects recognized the importance of observation in the production of scientific knowledge. David advocated, "Observation is the most important thing in science" whereas Bob explained, "Science cannot be done without observation." Bob continued to explain that all phases of scientific research depend on observations. Furthermore, Beth emphasized the replication of observations by other scientists as being vital to science in the determination of the acceptability of knowledge. She explained, "Before you ... accept something as a scientific fact then more than one person would ... have observed it. It would have to be something that could be replicated and duplicated."

In addition, all but one subject believed expectancy effects affected the act of observing. Beth emphasized that scientists sometimes see what they expect to see based on their desire to prove an idea. She said that scientists "can want something to be there, even subconsciously, and read more into what is actually there." In describing what influences scientists' observations, Diane explained, "What they believe, they want to see ... they try to see that particular thing happening." She continued by relating an incident at the national laboratory where she worked one summer when she saw an occurrence happen in an experiment upon which the scientist disagreed with her saying the occurrence was not suppose to happen until eight seconds later. Diane was disturbed by the incident and said, "It was like fudging data in a sense."

Moreover, the experiences, knowledge base, and emotions of scientists were believed by subjects to contribute to bias in observing. Diane explained, "Some scientists, based on what they know, come with an idea that one way is better than another way, and they ignore this aspect and concentrate on their own." In relating to the background experiences of scientists influencing observation, Alice responded that sometimes they "look hard enough and ... will find it even though it is really not there." Emotional influences on scientific observation was mentioned only by Bob who stated, "Scientists' observations ... could be influenced by whether he and his wife argued that morning." Furthermore, Beth discussed the issue of the race to be first in science and its effect on observation. She used the example of the cold fusion incident and said, "Those guys so wanted to be the first that there was an eagerness on their part for something to be there."

The role of instrumentation in making observations was viewed as very important by all the subjects. Diane summed up the views of all the subjects by stating, "It is extremely important and invaluable." The primary reasons for the subjects' conceptions about the importance of instrumentation was their view of the objectivity and preciseness of instruments in validating experimental results. Beth commented, "An instrument has no biases" and it "is going to measure it as it is." Diane concurred with Beth by stating that instruments "relied less and less on human decision making." In addition, Diane explained, "They are so precise it is just incredible and the more precise, the more validity that adds to your research." All subjects viewed that the quantitative output of such instruments in the form of numbers or graphs added credibility to the results. Alice stated, "It makes the collection of data more valid."

It is interesting that when subjects discussed the traits of scientists as described in the previous humanistic dimension section, they tended toward an idealistic perspective. However, upon focusing on one trait, objectivity in observation, the subjects were more realistic in their descriptions. Only Beth, after revealing the factors she felt affects observation, was somewhat steadfast in an idealistic version of a scientists' objectivity. She said, "If it [scientific knowledge] is not based ... on unbiased observation, then it is not real science." The subjects were aware of the effects of background experiences, expectations, knowledge base, emotions, and human limitations on scientific observation. They did not use the terms "sensation selection" or "perceptual filtration, "but they understood their influences. However, no subject mentioned the importance of language in observation or that the accepted paradigm informed the knowledge base that affects observation. Neither were they cognizant of the effects of scientists' professional training on observation nor the extensive amount of the theory-ladenness of observation.

Moreover, all subjects viewed observations made by scientific instrumentation as completely objective. This positivist perspective by subjects was revealed by their insistence that the data from instruments in the form of numbers or graphs produced "valid" knowledge void of human influence and biases. There was no comprehension of instrumentation as "reified theory" or its dependence on the tenets of an accepted paradigm. The realization of the human element in the design and construction of the scientific instrumentation was absent. Even though the subjects were cognizant of specific factors that affect scientific observation, they possessed no comprehension of the effects of the theory-ladenness of instrumentation.

Scientific Knowledge as a Result of Inquiry

An understanding of the processes of scientific inquiry is paramount in order to comprehend the credibility of the resulting scientific knowledge. To ascertain subjects' views about the nature of scientific inquiry, questions were asked pertaining to their conceptions of the importance of scientific inquiry, its methodology, inductive/deductive reasoning, and the validity of the resulting knowledge structures.

The fundamental importance of scientific inquiry to the scientific enterprise was recognized by all participants. The "experimentation" of science was viewed as a distinguishing factor in determining if knowledge was "scientific." Beth advocated, "Only science is based on knowledge gained through experiments ... that's the difference." The subjects emphasized the importance of the duplication and replication of experiments that added validity to any findings. Jane explained, "When other people have ... duplicated your experiment and got the same results ... then that knowledge will be accepted."

Moreover, it was in the discussion of the importance of scientific inquiry that the issue of scientific methodology arose. All subjects attributed the credibility of scientific knowledge as opposed to other types of knowledge to the use of "the scientific method." Beth differentiated scientific knowledge from other types by communicating that scientific knowledge "is arrived at through the process of the scientific method." Jane explained, "I think scientific knowledge is different from the others in that it is arrived at through a very systematic process - the scientific method" whereas Alice indicated, "You would have more confidence in your thoughts in that you would have carried out the typical scientific investigative problem-solving steps." Furthermore, Alice was intent on a methodology in science by stating, "You have to have a method to acquire any knowledge at all." In addition, Jane attributed the "wrongness" of past knowledge to the lack of the proper use of the scientific method. The subjects' meanings of "scientific method" was explored in detail. Participants viewed scientific methodology as an approach to problem solving (Beth), a structured way to solve problems (Diane), a procedure to answer questions (David), a method to acquire knowledge (Alice), a logical way or organizational sequence to solve problems (Bob), and a method of thinking (Jane).

Furthermore, when subjects were asked about scientific methodologies, all subjects commented that there was not just one scientific method. Yet upon describing scientific methodology, the subjects outlined the typical steps of the idealized scientific method. Without exception, they began their depiction of scientific inquiry with a problem or question followed by gathering information to form a "hypothesis". The hypothesis is tested and from data accumulated from the tests, conclusions are formed. Moreover, subjects' conceptions of the scientists' deviations from a standardized method was limited to a view of only small departures from a methodology. Jane thought that the scientific method may "vary a little bit" whereas Diane viewed scientists as sometimes changing the methodological order, but she stated, "For the most part, I think they try to follow it." All subjects acknowledged that the sequence of steps may be altered by scientists, but in every case the participants insisted that there was some procedure or sequence in scientific inquiry.

In addition, all subjects communicated an inductivist's and positivist's view that scientific methodology and experimentation produces "proven" knowledge. David responded, "They [scientists] have used the scientific method, and they have proved that these things are right" whereas Diane expressed, "You can experiment and you can get the results you need to prove something." Subjects believed that to be "knowledge," it had to be "proven" and scientific knowledge was different because it was "proven." In describing the knowledge structures (facts, theories, and laws), as will be explained in the next section, the subjects used the terminology "proven" or "disproven" to differentiate between the structures. When asked about their definitions of "proven", the subjects struggled with their explanations. Beth explained, "Middle schoolers never ask me these kinds of questions." Upon continual probing of their meanings of "proven", in every case, the subjects communicated that "proven" indicated that the same results were obtained from the replication of experimental tests and in two instances, references included verification by "the scientific method." The reasoning seemed to be that experimental methodology produces hard data (Beth), quantitative data (Diane), facts (David), or replicated data (Bob and Jane) that "proves" a result. Thus, the method legitimizes the resulting knowledge.

In every case, quantitative experimental data was conceived as very important in scientific inquiry. Jane advocated, "The best science is that science that is quantitative," and she continued to explain that her usage of "hard data" referred to quantitative experimental data. Diane explained, "It [quantitative data] adds more validity to it [experimental results] and ... you can prove it with the data." In addition, David said, "In order ... to prove something you have got to have ... a lot of stats, a lot of numbers." With the exception of two subjects, the participants conceived quantitative data as being objective and having more validity than qualitative data. In contrast, Bob and David viewed both as having equal value. Bob stated, "I don't think either one of them has any value without the other."

Moreover, most subjects conceived scientific inquiry as being logical in nature. Diane corresponded that scientific knowledge is produced by experimental results that "seem to be the most logical explanations" whereas Jane attributed it to a method of logical thinking. In explaining why scientific knowledge is perceived as more valid than other types of knowledge, Bob explained "Because of the logical way in which it is arrived at." When asked if scientific inquiry involves inductive or deductive reasoning, all subjects responded that it involves both. However, upon asking the participants their understanding of deductive and inductive logic, only one subject could explain the difference. Beth explained, "One is when you find out for yourself, that's inductive ... and deductive is when you it is pretty much given to you" whereas Diane stated, "Deductive is sort of breaking down and inductive is more intuitive." Beth and Diane as well as three other subjects admitted they did not know. Only Jane described the differences in deductive and inductive logic correctly.

Thus, the participants were not fully cognizant of the many, diversified methodologies that are used in the scientific enterprise due to the variety of theoretical structures and goals of the different sciences. They tended to take a simplified view of scientific inquiry. While admitting there is not one scientific method, they described the typical textbook description of the scientific method upon being asked to depict the methodology used by scientists. In addition, in describing scientific inquiry, they would use the terminology "the" scientific method not realizing the implications of the word choice. They were resistant in conceiving scientists varying much from the sequence of steps outlined in the ideal model of inquiry.

Moreover, in conceiving scientific methodology as a step-by-step procedure, the subjects had a positivist's point of view that scientific knowledge has a special validity because it is based on objective quantitative data that "proves" it. The method seemed to legitimize the evidence and validate the knowledge. Although subjects felt like scientific inquiry was logical in nature, all subjects did not understand the inductive/deductive nature of knowledge that results in its probabilistic nature. They believed that logic and the "method" was the ultimate authorities that determine the validity of knowledge discounting the impact of scientific communities in the arbitration of knowledge. There was no understanding of the theory-ladenness of experimentation nor the relativism of facts. By their answers, these teachers believed scientific inquiry produces knowledge structures that are proven in some absolute sense. They possessed a popular view of scientific inquiry that suggests scientific knowledge is firmly based on proven, objective data.

Scientific Knowledge Structures

Through the many investigative methods of science, the resulting scientific knowledge structures are composed of facts, theories, and laws. These structures form a basis of a natural world view that depict its composition and organization. To ascertain subjects' conceptions of the relationship of these knowledge structures and natural reality, subjects were questioned about their views of the reality of nature as portrayed by these knowledge structures. In addition, subjects were asked to relate their understandings of facts, laws, and theories as well as hypotheses and models.

The researcher discussed in detail with the subjects their conceptions of the scientific knowledge structures and the reality of the natural world. Initially, subjects were asked if they believed that scientific knowledge reflects the reality of nature. In general, all subjects with the exception of one viewed that scientific knowledge reflected the reality of nature. In particular, they believed laws and facts describe reality whereas theories possibly do not. However, they were very specific in qualifying their answers with a statement about contemporary scientific understanding. For example, in answering a question about whether scientific knowledge reflects reality, Beth responded:

> I think it probably does as accurately as our methods and our instruments at this point in time lets us understand what is there.... Our scientific explanations are the best we can do of what we have observed.

Bob explained, "I think as we continue to increase scientific knowledge in all directions and in all areas, each of those areas is getting closer to actual reality. Alice communicated she believes that scientific knowledge reflects reality "as we know it for 1991." In contrast to the other subjects, Diane, in responding to a question about whether scientific knowledge relates the real natural world, said:

> Probably about 1% about what is really out there ... we have been able to explain only a minute part of it.... Its our best explanation we have ... but we just don't know. We can't say its right or wrong.

Thus, subjects' qualifications that contemporary knowledge only reflects reality as we know it for this point in history indicated a view that scientific understanding of reality does change. Although not using the terminology "structural reality," they were describing a changing reality portrayed by the knowledge structures. For example, Bob explained:

> Reality is based on what you know ... until something else comes along to change it.... Right now, scientific knowledge states what's "real" ... but that may not be absolute because as we add to scientific knowledge, we might add to or change what is "real."

Beth related, "We describe it [reality] as we think it is and when new data come along, we have to be willing to make changes." David advocated, "We have nothing else better to accept until somebody comes along with a better explanation.... We have to accept what we have." Thinking about the history of science, Jane responded, "I think our knowledge about reality has changed because we find out more." Thus, five of the six subjects believed that our scientific knowledge does reflect generally the reality of nature. However, they are very cognizant of the changing of a "structural reality" as new information is acquired through scientific inquiry. Thus, even though the subjects tended toward a realist position that advocates a direct ontological relationship between scientific knowledge and natural reality, a pluralistic realist position was also evident by the subjects' responses about the changeable nature of scientific knowledge.

Furthermore, in an attempt to understand teachers' views of the relationship of the particular knowledge structures and what is really "out there," the researcher discovered that the issue of "truth" became evident as it related to natural reality. As described below, subjects differentiated between the different types of knowledge structures (facts, theories, and laws) by using the terms "true" or "untrue." In other words, if subjects felt like a structure reflected reality, it was viewed as true, if not, the structure was untrue. Again, this aspect of subjects' conceptions reveals a realist's ontological viewpoint of the knowledge structures. The exception to the usage of the term "truth" by the subjects was Diane who stated, "I never use the word 'truth'.... I think of truths as more moralistic. I don't use the word scientifically." In addition, the terminology of "proven" or "disproven" was used to explain the different aspects of the knowledge structures. As was explained in the previous section, the subjects' conceptions of "proven" refers to the verification of an experimental result by the replication of the experiment many times producing the same result. For the subjects, the word "proven" insinuates truthfulness. For example, David states, "It takes years and years, experiment after experiment, to prove. If it is proven, it is true." Descriptions of the teachers' conceptions of each of the knowledge structures will be explained below in which the words "true/untrue" and "proven/unproven" will be used by the subjects. An understanding of the subjects' meanings of those words as described above will help in a comprehension of their various differentiations of the knowledge structures.

The first knowledge structure explored with the participants was a scientific fact. Subjects were asked to describe their conception of a "scientific fact." Jane responded, "I think a fact is a specific bit of information that is true because if it is not true, you can disprove it." Jane continued to explain that by "true" and "proven" she meant, "that under particular circumstances, this occurrence happens over and over again." Bob saw a fact as a law with a smaller base of application and he viewed facts as true and proven. However, later in the interview, Bob began to question his conception of a fact and said, " I think a fact is a law, it is a truth, but ... let's stay away from the word 'true'.... I don't know." Alice was very straightforward with her answer by saying, "A fact is what we know to be true at this particular point in time.... Facts are proven." Similarly, David commented, " A fact is something that actually has occurred at some point in time" and is proven "by experimentation, by replication - if the same holds true over and over again, then we have to accept it as fact." He further explained, "A fact is true and a nonfact would not be true." Diane and Beth were unsure of their conceptions of a scientific fact. Diane said, "A fact, I never really thought about a fact" whereas Beth responded, "I'm not sure I'm clear on scientific fact."

Thus, in at least three of the above cases, the subjects were unclear and somewhat surprised at their inability to convey a meaning for "scientific fact." Yet, in some of the previous conversations about scientific knowledge, they have stated that their confidence in science rests in its foundation on "facts." For example, Beth said, " Science should have a basis in fact" whereas Diane expressed, " Science should deal with observable facts" and "is mainly facts." Bob communicated, "Laws are based on explanations of facts." This is an example of the taken-for-granted terminology that can be used by science teachers that upon focusing on the word, the familiar becomes unfamiliar and the difficulty of describing the word's meaning illicits surprise.

Furthermore, the subjects' views of a scientific fact or their usage of the word, as in the cases of Beth, Diane, and Bob, illustrate the popular definition of the word "fact" in that it is a true entity that has been proven and is the epistemological authority for knowledge. There was no clear conception of the relativism of scientific facts due to their theory-ladenness and lack of absolute validity. Contrary to the subject's views, facts are products of theory and are not proven in any absolute sense.

In order to understand the next two knowledge structures, theories and laws, the researcher felt it was necessary to first comprehend subjects' views about hypotheses. When asked "What is a hypothesis?", three of the six subjects replied, "an educated guess" which is by far the most common answer given by students, teachers, and textbooks. Jane responded, "It is a proposed solution to a question." Beth was more detailed in her answer by stating:

> A hypothesis is a possible answer to a question or problem that is based on some knowledge.... It is just as likely to be wrong as it is to be right. You won't know until you have done an experiment to test that hypothesis.

Bob explained:

> It's an attempt to explain something you don't know. Around that explanation, you can develop experimentation to see if it works or not.... The only way that you can really develop a workable experiment is to take a chance and make a guess of how it is going to happen.

At least in the case of Beth and Bob, the typical sequence of "the scientific method" is reappearing in their conceptions of the formation of a hypothesis as a necessary step in scientific inquiry. In addition, four subjects believed that a hypothesis was the initial step in a maturational process in which theories become laws. Beth commented, "You build to theories from hypotheses and then eventually to the laws." In other words, laws develop from theories not hypotheses. Bob was somewhat unsure of the relationship between laws and hypotheses by stating that "if there is one instance [that the law is contradicted] then it can't be a law, it can be an hypothesis again." However, several questions later, Bob related that hypotheses become theories that later become laws. Thus, hypotheses are conceived by the subjects as informed guesses or proposals and in at least some instances, an initial step in scientific inquiry that produces theories and eventually laws.

Furthermore, teachers' conceptions of scientific theories and laws were investigated. Most subjects viewed scientific theories as possible explanations to natural phenomena. Beth stated, "A theory is an hypothesis" on which "experiments have been done and there is a lot of evidence to support it." In addition, she called a theory "a possibility" and a "possible explanation for something that has been observed." Diane related, "A theory I think is ... something that we try to explain what we see out there, but it can't actually be totally tested." David stated, "A theory is your best guess that has been tested and is at the present time accepted." Bob conceived a theory as "scientific speculation" whereas Jane was unsure of a meaning.

Moreover, scientific laws were viewed in a somewhat different perspective than theories. Beth conceived laws as "something that can be supported with hard data ... and probably absolute on the basis of the data that has been collected." She also referred to laws as "scientific truths." In addition, Diane explained, "A law is something that has withstood the test of time and is ... correct in every situation they have ever tested it ... and has been proven beyond a shadow of a doubt." Similarly, David supported Diane's consistency idea of laws by stating, "A law is when it is going to happen all the time." In his description of a law, Bob indicated:

> A scientific law is something that has withstood multiple applications. It would be something that could be applied in lots of different ways and by lots of different people for the long term.

In an attempt to understand participants' conception of laws and theories, the researcher asked subjects about the differences in laws and theories. It was in this line of questioning that the words "proven" and "truth" again appeared in subjects' answers as well as the conceptions of a maturational relationship between theories and laws. Jane was unsure about the differences in laws and theories stating, "I really have not had the two clearly defined to me. It is like words people use, but when you have to be pinpointed on it, what's the difference?" Beth stated a law is "a scientific truth" as compared to a theory which does not have all the evidence to support it as a law. In comparing the law of conservation of energy to the theory of evolution, Beth explained, "For a law, we have all the pieces" and for a theory, "it is hard to get the data you need." Similarly, Diane responded, "I think a law is ... proven to be correct ... and it has never been disproven and then I think a theory is ... just hard to prove." David stated, "A law is something that has been proven ... and a theory is not proven" whereas Alice agreed with David's conceptions. Bob also believed laws are proven and that theories have a more limited base of evidence. He commented, "A theory is something that ... hasn't been tried enough in enough different situations so that you can use it to predict for sure." However, Bob struggled with describing differences in theories and laws. He commented:

> If a new dimension were to happen and it was repeatable and the law did not apply, then the law would have to change and probably go back to a theory .... But if that was possible, how could it be a law? I'm sure glad I don't discuss this with my kids because I would lead them astray. I would confuse them totally because I am confusing myself.

Thus, all subjects, with the exception of Jane, believed that laws were "proven" being based on a large amount of replicated data which seemed to indicate to the subjects laws were true in some absolute sense.

Due to the "unproven" status of theories as conceived by the participants, five subjects believed that a theory is an intermediate step to producing a "proven" law. Beth stated, "A theory is put forth and then eventually when enough data is collected and the possibility of any of it not being true is completely eliminated, then it becomes a scientific law." Diane responded, "I see a law as being a theory that has been proven" whereas David explained, "A theory cannot be disproven unless you have got absolute proof, then that becomes a law." Alice agreed with the previous subjects by relating "a theory is what could be proven to be a law in years to come." Bob indicated, "I would think theories have to be constantly corrected" and "when they are no longer corrected ... then you have to start considering it a law." Thus, all subjects, with the exception of Jane who was unsure of the basic meanings of laws and theories, conceived theories as having the possibility of becoming laws. There was no clear understanding of the different functions of a law as describing relationships and a theory as explaining relationships between phenomena. Scientifically speaking, theories do not become laws nor do laws become theories. Both knowledge structures are derived from hypotheses.

Furthermore, the changing nature of theories as knowledge structures was more evident in respondents' answers than laws. Due to the conception explained above that theories may become laws, subjects were very willing to think of theories as tentative. However, they revealed the conception of laws as being more stable knowledge structures. To be a law it had to be proven, a truth, absolute, and very reliable which suggests a rigidity that is resistant to change. In fact, subjects were willing to not call a knowledge structure a "law" if it had to be altered. For example, Bob explained that laws "should not be laws if they had to change." In addition, the subjects that viewed a law as a "proven theory" related the belief that if a "law" is disproven it would return to being a "theory." Beth was resistant to thinking that past laws in history have changed because "at that point in time we did not have the scientific method" inferring that "the" method legitimizes the "proof" of a law. Alice was very persistent in answering questions about the changeability of laws and theories by always adding the phrase "as we know it in 1991" or "at this particular time." Diane demonstrated the least amount of absoluteness in her conceptions of the tentativeness of laws by stating, "who knows maybe ten years down the line something will come up that it just won't fit for that situation - so I don't think anything is absolute." In addition, as stated above, subjects conceptions of scientific facts seem to reveal the same status of rigidity to change as laws. Thus, there appears to be the cognition by subjects of degrees of tentativeness to the knowledge structures.

Finally, participants' conceptions of a scientific model were investigated. All subjects viewed scientific models as visual representations of scientific concepts. Diane said that models are "something that we use to give them [students] the visual aspects of things we are unable to see." David explained, "A model is something ... either on paper or it is three dimensional ... that you put to scale that represents something that is either tangible or not tangible." Bob commented, "They are an attempt to show you what something is, looks like, or how it physically fits together." Jane expressed that a model is " a mock-up or a physical representation of something." Diane was the only one to mention computer modelling. Following an attempt to understand subjects' conceptions of models, the researcher inquired into the relationship of models and the real natural world. Most subjects acknowledged their belief that models do not represent the reality of nature. They frequently used the model of the atom as an example in responses. Bob stated, "I don't think that any model that I have seen of the atom describes what it is going to look like." Diane expressed, "Like the atomic model .. we just don't know that it illustrates the theory." Contrastingly, David was unsure about models relating to reality by stating, "I really don't know if they do. Sometimes I question models myself."

In summary, subjects generally felt that scientific knowledge reflects the reality of nature revealing a realist position that advocates an ontological viewpoint of knowledge. However, a pluralistic realist position was also evident in the subjects' expression of the changing status of the knowledge structures as they relate to natural reality. A scientific fact was considered "proven" and "true" by subjects indicating the popular view of a fact versus the scientific view of a fact that demonstrates its theory dependency and lack of absolute validity. Hypotheses were viewed by respondents as "educated guesses," "proposed solutions," and "possible answers" as well as an initial step in the develop of theories. Subjects conceived theories as possible explanations based on the available evidence whereas laws were viewed as more reliable based on replicated data. In a comparison of theories and laws, participants believed theories were unproven whereas laws were proven and truthful in an absolute sense. All subjects believed that theories can become laws demonstrating no comprehension of the two very different functions of each knowledge structure. The tentativeness of the knowledge structures seemed to be viewed by subjects in degrees of change with theories being the most changeable and facts and laws being the least changeable. Finally, all subjects viewed models as representations of entities in nature that may not resemble the actual thing. It was in the area of questioning about the scientific knowledge structures that the "familiar" seemed to become "unfamiliar" to the respondents. On many occasions, some mentioned above, the subjects exhibited difficulty in describing familiar terms like facts, theories and laws. It illustrated the taken-for-grantedness by subjects of these knowledge structures that they use on a regular basis in their classroom instruction.

The Uniqueness of Science as a Way of Knowing

Even though science overlaps with other ways of knowing, there are some distinguishing characteristics that differentiates it from other knowledge. These features include its testability, predictive power, consistency, replication and communal review. To determine subjects' views about the uniqueness of scientific knowledge, interview questions focused on science as a way of knowing and the distinguishing attributes of scientific knowledge.

Initially, subjects were asked whether science was the only way of knowing. In answering this question, some subjects exhibited difficulty in thinking about other "ways of knowing" than science. For example, Diane stated, "How else would we know?... I guess I don't quite understand.... What other types do you mean? I am not sure what other types are besides science. I think of science as covering everything." Bob commented, "To experience something is not necessarily science, is it? I am trying to think of some other examples." When asked, Alice paused a long time and then responded, "No, there is not." She conceived all knowledge as being the same. Similarly, David, after pausing for a brief period of time, conceived science as the only way of knowing and commented, "I mean, how else are you going to know?" Jane responded, "Do I understand you to mean could I know something in sociology?" and then admitted she had never thought of other ways of knowing. With the exception of Alice, the above subjects eventually thought of other ways of knowing such as mathematical (Diane), religious (Diane, Bob, Jane), and historical (Bob). Beth was the only subject who did not hesitate in answering the question about science as the only way of knowing. She explained, "Oh, no. I think you can know with your heart ... feelings, intuition. There are other ways of knowing." For Beth, the other modes of knowing included religious, personal, and cultural. Thus, for three subjects the existence of other forms of knowing besides science was not part of their subjective reality. At least they had not thought of history, religion or math as other ways of knowing and in the cases of Alice and David, there were no other ways of knowing besides science.

If subjects indicated there were other ways of knowing, the researcher inquired about the manner in which scientific knowledge was different than other types of knowledge. Beth responded, "Only science is based on knowledge gained through experiment, observation, and ... the use of the scientific method" and "repeated verification and duplication" as well as "observable facts." Describing religious, personal, and cultural knowing, Beth explained, "Their basis is more in emotion and in things of the heart - subjective." Diane stated, "I think ... science as being something proven, where religious knowledge, you have to take it as faith that there is a God although no one can ever prove that." Bob explained, "Scientists are more involved in looking at a concept that can make predictions. I am not sure that historians are necessarily looking at making predictions." In addition, he stated, "Science is based on testing ... and it is self correcting" whereas "religion doesn't tend to correct itself.... It's based on real faith." Jane expressed that the experimental nature of science makes it different from other knowledge modes, and she acknowledged, "Thinking scientifically follows a certain or broad general sequence of doing things-the scientific method." Furthermore, she indicated the different nature of science and religion by stating, "You can't take science and prove the Bible." Therefore, according to the subjects, the uniqueness of scientific knowledge is attributed to its methodology that includes experimentation, replication, predictive nature, and self-correctibility. There was a strand of positivism that was reflected in the respondents' answers that "the method" in science produces "proven" knowledge. Except for the context of the replication of experimental findings, the subjects did not mention the uniqueness of the communal interactions in science.

Finally, subjects were asked whether science was the best way of knowing? Beth did not think science was the best way but believed that the different types of knowledge had different roles to play. She explained:

> That is why I go to church.... I need that faith in God, but then I go to the science book when I want to explain how.... I feel sorry for those folks who are caught up in one aspect of knowledge that they can't even give a hearing to the other.

Diane struggled with the question stating, "I guess that science in a sense adds a lot of validity to what you know. I don't know." However, later she commented, "I say it's the best way." Bob thought science was the best way and related, "It is the only way that you can really know. I think through religion ... people say they know. I think that what they really are saying is they accept. They don't know, but they accept." Contrastingly, to the question about science being the best way of knowing Jane responded, "Not really. We have solved a lot of problems with science but honestly it is no better." Therefore, among those subjects that conceived there are different ways of knowing, two out of four believed science was the best way.

In summary, most subjects had not conceived science in the terminology of a "way of knowing" and initially exhibited difficulty in thinking of other modes of knowing. It was very natural for them to think of knowing as being only scientific. Only two subjects were steadfast in their conception of science as the only way of knowing. Subjects conceived the experimental, predictive, and replicative nature of scientific knowledge as attributes of uniqueness. Only one subject mentioned the revisionary nature of scientific knowledge and no respondent related the communal interactions of science except in the context of experimental replication. In addition, they felt very comfortable with their conceived absoluteness of scientific knowledge using terminology such as "proved" and "verified" as opposed to other types of knowledge which were based on more "subjective" conditions such as faith and emotion. It was evident that "the scientific method" legitimized their conceptions of the validity of scientific knowledge. However, only two subjects thought science was the best way of knowing whereas two subjects recognized that different modes of knowledge have different aims or roles.

Teachers' Conceptions of the Nature of Scientific Knowledge: Influences on Teaching Methodologies

The final theme addressed in the interview sessions included questions relating to subjects' views about the relationship of their conceptions of the nature of scientific knowledge and their instructional methodologies. In addition, the respondents' views of the factors that affected their particular conceptions of science were ascertained. Finally, participants' opinions on the barriers that prevent them from teaching the nature of scientific knowledge more effectively were identified.

Initially, subjects were asked about their views of the factors that influenced their conceptions of the nature of scientific knowledge. Beth responded that her interactions with education and science university faculty as well as with individuals in science education professional organizations affected her conceptions of science. Diane expressed that her high school and college science schooling experiences, reading, and middle school teaching experiences provided her with her conceptions of science. However, she emphasized that recently her summer experience at a research laboratory facility had changed many of her views of scientific inquiry. She explained, "I think I'm more aware now of what real scientists are really like" and "what life is really like out there [in the scientific community]." David related that his experiences as a surgical technician in the Air Force and his college training in science influenced his conceptions. Alice credited her students and reading books as the factors that helped her formulate a science world view. Experiences in the Navy, college science course work and extensive reading of scientific literature have all assisted Bob in forming his conceptions of scientific knowledge. Lastly, Jane communicated that college science course work and her brief interactions with university science researchers have influenced her views. Thus, the most frequently indicated factor influencing their science world views was their experience in college science course work. Other factors included reading scientific literature, personal experiences with scientific work (armed forces, research labs), high school course work, and students.

In every instance, subjects felt that their conceptions of scientific knowledge affected their methods of teaching. Beth responded, "What we've talked about [her views of the nature of scientific knowledge] would have to be the driving force behind everything I do in the classroom because I'm not going to do something I don't believe in." In addition, she commented, "I really view science as something you do and not something you read about." Thus, Beth largely involves her students in laboratory/hands-on activities in her classes. Similarly, Diane stated that she teaches science as inquiry with hands-on activities which is the way she enjoyed it as a student. She explained:

> You don't just learn science by reading a textbook. The times I've enjoyed science most was when I was right in there doing certain things. Those are the things that I remember the most ... when I did things. So, that's the way I teach.

Therefore, Diane emphasizes lab activities in her classroom. She continued to describe that her summer experiences at a research lab influenced her teaching. Diane commented:

> I give a lot more input about my experience ... and relate it to something we did.... I'm more aware now of what real scientists are really like, and I can share that with the kids. The other thing is the current research.... I can bring that to my kids.

Furthermore, Alice believed that her views of the inquiry method of science has influenced her emphasis on critical thinking and the Socratic method of teaching. She explains, "If a child asks a question, I respond by asking a question. I try to teach the kids to do that to me. Question everything. I say everything. To me, the best learners are those people who can question." She continued, "Science ... really stimulates the mind. It poses questions that have answers, but yet at the same time those answers can be questioned." These problem-solving capabilities of science are emphasized by Alice in her teaching strategies, in particular with lab exercises. In response to the reasons she felt laboratory work was important, she replied:

> So that children can feel confident that when they set out to solve that problem, this variable can be involved, and if the experiment doesn't come out like it's supposed to come out, that it is not wrong.... They have the right to experience the problem-solving skills development.

Alice reports that her class is involved in problem-solving/laboratory activities about 50% of the time. Similarly, David views the inquiry methods of science as important in science teaching. However, he reported only doing laboratory/hands-on activities 25% of the time.

Bob emphasized his views of the tentativeness of science in his classroom. He explained:

> I try not to be one of those "this is the fact, this is the way" type. It is not just the way I teach.... I tend to teach more of an inquiring method. I think we spend more time trying to figure out what or how it works, than saying this is it.

In addition, his conceptions of science as inquiry are reflected in his teaching. To the question about the importance of laboratory exercises, Bob related,

> Because that is what science is. I mean science is not fill-in-the-blank type questions. That is not what science is.... The part of science that is important and valuable is the research part. Teaching kids how to do that is more important. How to handle solving a problem using some materials and equipment to find out something is a lot more important than having them take a book and pick out the key words in a paragraph.

Bob reported using hands-on laboratory activities about 60% of the time in his classroom. Similarly, Jane's view of science as a method of inquiry influences her emphasis on hands-on activities. Jane reported doing hands-on, laboratory exercises about 40% to 45% of the time.

Thus, subjects acknowledged that their conceptions of the nature of scientific knowledge influenced their teaching methodologies. In every instance, subjects reported that their views of science as problem-solving permeated their instruction by their emphasis on laboratory, hands-on student activities. They viewed such instruction as demonstrating the skeptical, tentative, critical thinking, and problem solving nature of science. The amount of time reported of actual hands-on, experiential teaching of science ranged from 25% to 60%. However, there was no implicit indication that the humanistic, communal, observational, and historical aspects of the nature of scientific knowledge was reflected in their teaching practices. Therefore, it demonstrates the previously mentioned lack of understanding of these areas of scientific knowledge by the subjects.

Finally, the last theme addressed was to identify any ways subjects could improve their science instruction as well as any barriers that might prevent them from teaching the nature of scientific knowledge more effectively. All subjects believed they could teach science in a more effective manner. To the question about methods of teaching science more effectively, Beth responded, "I would do it from a total lab perspective" and she further explained, "I would have a lab every single day. We would pose big problems like pollution, water, air, and then we would be involved in investigations that would be student planned.... They would come up with solutions." Similar to Beth's perspective, Diane stated, "What I would like to do is totally teach it [science] from a lab aspect.... It would be totally hands-on, field trips and outdoor experiences." In addition, David, Bob, and Jane viewed an improvement of students' conceptions of the nature of scientific knowledge would be achieved by an increase in laboratory/hands-on techniques as well as field trips. Contrastingly, Alice would improve science instruction by just instituting a literature-based methodology and not necessarily increasing the number of laboratory/hands-on activities she already does in her classroom.

However, to questions about the barriers that prevent such methodologies from being instituted, the subjects included school scheduling, funds, class size, parental expectations, tradition, textbooks, equipment, planning/instructional time, and state curriculum requirements. In addition, Beth mentioned competency testing as a deterrent.

> Teachers feel the pressure to get kids ready for end-of-year course testing ... because those scores are looked at carefully.... As long as that testing program is there, it encourages recall of factual information.

Interestingly, in most cases, textbooks were condemned by the subjects as an instructional tool and seen as a deterrent to teaching an adequate view of the nature of scientific knowledge. Commenting on textbooks, Diane stated:

> You get a presentation of knowledge and you might get a little experiment that illustrates it, but it is almost going in the reverse of science.... There might be a little chapter that tries to explain what scientific knowledge is, but by that, it doesn't really do anything.

To the question of textbooks representing the scientific enterprise correctly, Alice responded, "They try to, but they do a lousy job." Beth responded, "Kids really have no conception of what science is really about because that textbook is there." Bob expressed that textbooks represent a static view of science. He explained, "They [textbooks] pretty much say this is it. It would be nice to get a textbook that was more inquiry than fact; instead what we get is about 95% fact." Contrastingly, Jane replied, "They [textbooks] have gotten better in that they put more activities in the books." She did voice concerns about lack of depth in textbooks concerning the nature of scientific knowledge. In addition, David thought that textbooks express an adequate view of science "for the most part." Although David said, "I hate them," he still uses textbooks. Beth, Diane, Alice, and Bob think textbooks are a waste of instructional money. In opposition to an adequate view of the nature of scientific knowledge, textbooks were viewed as a static representation of science (Beth, Diane, Bob), a source of facts and truth (Diane, Beth, Bob), failure in representing the dynamics of the production of scientific knowledge (Diane, Bob) and an intimidation to students (Alice).

In summary, the most often mentioned factor that affected subjects' conceptions of the nature of scientific knowledge was their experience in college science course work. Other factors included experiences in scientific work (armed forces or research lab), high school courses, reading scientific literature and students. Thus, the importance of these areas in affecting preservice science teachers conceptions of the nature of scientific knowledge should be recognized. In addition, all subjects acknowledged that their conceptions of the nature of scientific knowledge affects their teaching methodologies. However, the only dimension of science that was identified by the subjects as permeating their teaching methods was inquiry. There was no explicit indication of the humanistic, historical, or social aspects of science being demonstrated in their instruction. These findings indicate the implicit nature of these dimensions in the subjects' subjective reality.

Moreover, all subjects felt that they could improve their teaching of the nature of scientific knowledge. With the exception of one subject, the participants viewed the incorporation of a total hands-on/laboratory curriculum as the best way to teach science. Contrastingly, Alice believed a literature-based science curriculum with no increase in experiential student activities would accomplish the same purpose. The subjects listed many barriers that prevented them from teaching science more effectively. One barrier, textbooks, was seen by most subjects as a particular deterrent to teaching the nature of scientific knowledge effectively. The subjects conceived textbooks as representing science as a static discipline, science as producing proved truth or facts, and science that is void of inquiry and communal interactions.

Summary

The chapter has described six middle school science teachers' conceptions of the importance of science education and the nature of scientific knowledge. In addition, their conceptions of the influences that their science world views have on their instructional methodologies were explained.

The subjects' views of the importance of science education were inclusive of most of the elements of scientific literacy as well as the National Science Foundation's goal clusters. However, the subjects did not conceive of two important dimensions of scientific literacy: the understanding of science as a human enterprise and the cognition of historical nature of science. Moreover, most subjects viewed themselves as "scientists" in the way they studied and attempted to understand the world. Thus, the researcher had to explain to the subjects the study's operational definition of a scientist in order to ascertain their views. All subjects described the typical ideal traits of scientists that are usually depicted in science education literature including textbooks. They tended to view scientists as objective realizing only the effects of expectations on objectivity. The effects of paradigmatic beliefs, language, and professional schooling on objectivity were not recognized by the subjects. In addition, subjects believed scientists are very open-minded, very willing to share all information, and motivated more by intrinsic (desire, curiosity, caring) than extrinsic (financial rewards, peer approval, prestige, and awards) reasons. Subjects tended to hold scientists in the highest regard being disturbed by any contradictions to their somewhat idealized view of scientists.

Furthermore, subjects' conceptions of the dynamic nature of scientific communities in deciding research methodologies and the acceptability of knowledge was limited. They revealed a positivist perspective of knowledge acceptability implying that scientific knowledge is proven by unbiased observation, facts and "hard data." The political and sociological dimension of consensus-making in scientific communities was not well understood and some subjects believed the acceptability of knowledge was based on a "majority rules" criterion. The different social roles of science and technology were misunderstood by most of the subjects. In addition, due to subjects' lack of awareness of the effect of paradigms on the production of scientific knowledge and the resulting conflicts of paradigms in the Kuhnian sense, the subjects exhibited little understanding of the historical nature of science. Most subjects conceived the progression of scientific knowledge as cumulative discounting any revolutionary perspectives. Moreover, the subjects exhibited difficulty in relating the basic assumptions of scientific inquiry. It demonstrates the taken-for-grantedness of these basic principles by subjects.

When subjects focused on scientific observation, they tended to be more realistic in their conceptions of a scientist. Subjects communicated the effects of expectations, background experiences, knowledge base, emotions, and human limitations on scientific observation. Only one subject was steadfast in viewing observation as objective. Subjects were not cognizant of the effects of language, theory, nor professional training on observation. Contrastingly, all subjects viewed observational information gained through scientific instrumentation as objective which reveals no understanding of the theory-ladenness of instrument design and construction. Moreover, the subjects tended to have a simplified view of scientific inquiry. While admitting that there is more than one method in science, they described scientific inquiry using the typical textbook step-by-step process that is characteristic of "the" scientific method. They were resistant to conceiving scientific inquiry varying much from the typical steps demonstrating a positivist, inductivist's view that scientific knowledge has a special validity due to an experimental method that produces facts and proves knowledge. Thus, the subjects were not completely aware of the many experimental methodologies used in science due to a variety of theoretical structures and goals of research. All subjects conceived scientific inquiry as logical, but they had no comprehension of its deductive/inductive nature. To the subjects, logic and "the" method was the ultimate authority in the acceptability of knowledge discounting the impact of scientific communities in the arbitration of knowledge.

Furthermore, subjects generally conceived that scientific knowledge reflects the reality of nature demonstrating a realist position that advocates an ontological viewpoint of knowledge. In addition, a pluralistic realist position was revealed by the subjects conceptions of the changing status of knowledge structures as they relate to reality. In differentiating between the different knowledge structures, subjects tended to use the "terms of absoluteness," proven/unproven and true/untrue, continuing to demonstrate a positivist viewpoint. Scientific facts were conceived by subjects in the popular perspective as true and proven as opposed to a relativistic viewpoint that accurately describes scientific facts. Hypotheses were viewed as an initial step in the development of only theories.

Subjects conceived theories as unproven explanations based on available evidence whereas laws were proven and truthful based on more reliable, replicated data. Demonstrating no comprehension of the different functions of laws and theories, all subjects viewed that theories may become laws. Moreover, subjects had difficulty thinking of other ways of knowing besides science. Subjects did relate the experimental, predictive, and replicative nature of scientific knowledge as attributes of uniqueness. As opposed to other modes of knowing which are based on faith and emotion, the subjects felt comfortable with their conceived absoluteness of scientific knowledge that is "proven" and "verified." However, only two subjects conceived of science as the best way of knowing.

Moreover, the most common element that influenced their conceived views of the nature of scientific knowledge that was mentioned by the subjects was college science course work. Other influential areas included scientific work experiences, high school courses, literature review, and students. All subjects conceived that their views of scientific knowledge influence their teaching methodologies. However, the only dimension communicated by the subjects as permeating their instruction was scientific inquiry. There was no indication that the humanistic, historical, or social aspects of scientific knowledge was being reflected in science instruction. Most subjects related that they could improve their instructional methods in science by the incorporation of a totally hands-on/laboratory curriculum. However, barriers described by subjects to this type of methodology included scheduling, class sizes, parental expectations, tradition, planning/instructional time, money, equipment, testing mandates, and state curriculum requirements. Textbooks were also conceived by subjects as an hindrance to the improvement of science instruction due to their inaccurate portrayal of the nature of scientific knowledge.

Lastly, many of the questions asked in the interviewing process about the nature of scientific knowledge addressed the "familiar." However, many times the "familiar" became "unfamiliar" when subjects had to delineate a meaningful answer. Such commonly used terms as facts, laws, theories, and technology became somewhat unfamiliar to them. It demonstrated the taken-for-grantedness of many of the basic principles of science by these teachers. Furthermore, some of the issues involving the nature of scientific knowledge addressed in the interviews were previously never considered by these subjects. For example, Beth commented, "You are making me think about things I've never thought about before" whereas Bob stated, "You are asking questions I have not thought about." Therefore, compared to the dimensions of the nature of scientific knowledge as outlined in the model, these subjects possessed a somewhat less than adequate view of scientific knowledge and the historical, sociological, experimental and humanistic processes that produce it.

CHAPTER V

CONCLUSIONS: IMPLICATIONS FOR SCIENCE EDUCATION AND RECOMMENDATIONS

Introduction

Based on the literature, an interpretive model was formulated that describes the nature of scientific knowledge in eight dimensions. It was posited by the model that the nature of scientific knowledge is humanistic, socially constructed, historical, based on specific beliefs, observation based, a result of inquiry, composed of structures, and unique. It served as a comprehensive framework to compare the conceptions of six middle school science teachers about nature of scientific knowledge. The previous chapter delineated the subjects' conceptions of scientific knowledge and compared their views to the interpretive model. Encouraging aspects of subjects' conceptions of the nature of scientific knowledge included their comprehension of the importance of scientific observation, the communal sharing of experimental results, and the significance of scientific experimentation. However, the subjects tended to view scientists in an ideal manner, did not understand the sociological dimension of decision-making in scientific communities, had little comprehension of the revolutionary nature of historical science, and were not cognizant of the theory dependency of observation or instrumentation. There was a tendency by subjects to view scientific inquiry as a simple step-by-step process typical of "the" scientific method which legitimizes proven, truthful knowledge. In addition, subjects did not understand the different functions of theories and laws as knowledge structures. Even though there were slight variations in the adequacy of science world views by different subjects, generally these six middle school science teachers' conceptions of scientific knowledge were less than adequate as compared to the model. This chapter will discuss the implications of these findings on science education and student comprehension as well as recommend strategies to improve teachers' conceptions of the nature of scientific knowledge. In addition, suggestions for future inquiries into this topic will be given.

Implications For Science Education

The six middle school science teachers' conceptions of the nature of scientific knowledge revealed deficiencies compared to the study's model. The findings of this research project have many broad as well as specific implications about student comprehension of the nature of scientific knowledge and the current instructional methodologies being implemented in middle school science classrooms. The study's results also indicate a need for strategies for the improvement of teachers' conceptions of the nature of scientific knowledge as well as for science curriculum improvement. In addition, subjects' conceptions of the importance of science education and the influences of their views on their classroom methodologies provide insights into areas of improvement.

Initially, inquiry into teachers' conceptions of the importance of science education revealed a partial understanding of scientific literacy and the goals outlined by the National Science Foundation. Subjects' science education goals included the development of critical thinking/problem solving skills, affective concerns, career opportunities, and custodianship of the natural world. However, subjects' views of goals narrowed considerably when asked about middle school science education. One of the two goals mentioned is of particular interest: the preparation of students for high school. This finding seems to indicate that these middle school teachers are very concerned about teaching the content of science which is emphasized in high school . How students learn science greatly influences their attitudes about what science is. In teaching predominantly content, scientific knowledge is represented in a very static manner . Schwab (1960) calls such instruction "the rhetoric of conclusions." Thus, what results is scientific knowledge that is portrayed to students as reified, objective, and noncontroversial. This approach may discourage creative students from seeking science careers because they perceive science as boring and personally irrelevant. In contrast, if science is taught as a process, students could understand better the humanistic, sociological, historical, and experimental nature of scientific knowledge. Students could participate in the scientific processes of investigation developing an understanding of the human interactions of knowledge production.

Interestingly, the subjects admitted the goals of science education were not being achieved and attributed the reason to lack of planning time and hands-on/laboratory student activities. In other words, they advocated more interactive science teaching but because of time, their instruction tends to be more content driven than process driven. In fact, the time spent by the subjects in conducting hands-on/laboratory student activities ranged from 20% to 60% of the total instructional time. Thus, for whatever the reason, 40% to 80% of the subjects' classroom instruction time was spent in content driven instruction. Although content can be learned and does inform process instruction, the processes of science are seldom adequately learned in a content instructional context.

Moreover, these six successful science teachers probably use hands-on/laboratory activities more than most teachers. Yet, they felt the obligation to primarily convey science content to students. However, the subjects neglected to mention the understanding of the humanistic nature of science as well as a cognition of the history of science as important goals of science education. These goals are the types of goals that can be approached adequately in process science instruction. Thus, it appears that teachers may feel more comfortable with teaching the end products of science (content) which they conceive as understanding rather than the dynamic processes of science that entails its humanistic, sociological, and historical dimensions which they do not fully comprehend.

In discussing the humanistic aspects of scientific knowledge, the researcher discovered that four of the six subjects viewed themselves as scientists. This finding has significant implications for test design as well as students' understanding of the humanistic nature of scientific knowledge. Since students learn many behaviors by imitation and identification, the role model created by the teacher is very influential. If teachers are portraying themselves to students as scientists, teacher behaviors will tend to be transferred by students into their conceptions of scientists' behaviors. In other words, the characteristics portrayed by the teacher may be seen as characteristics of a scientist by middle school students. If, by their behaviors, teachers characterize science as an emotional, stimulating search for answers that strives to produce creative, tentative solutions through many types of methodological inquiries, then students would acquire a reasonable view of scientists. However, if teachers' behaviors portray science as an unemotional, objective search for absolute solutions through "the" scientific method, students would be misguided in forming their views of scientists' behaviors. Realizing the somewhat idealized conceptions of scientists held by these teachers, it would seem to be difficult for them to realistically characterize scientists by their behaviors. A much better disposition in this matter would be for teachers to admit they are not scientists, but are science educators or as Bob phrased it, "students of science."

In describing scientists, the subjects listed the idealized traits usually associated with scientists in textbooks and science education materials. They were cognizant of some of the influences on scientists' objectivity such as expectancy effects, but did not relate the effects of paradigmatic beliefs, language, and professional schooling on objectivity. In fact, the subjects said scientists were more objective than subjective. Most of the subjects believed scientists were very open-minded, motivated mostly by inward drives and openly shared their experimental findings. Thus, subjects' conceptions of scientists tended more toward an idealistic view than a realistic perspective. The implication of this finding is that teachers perpetuate the idealism of scientists that is often found in science textbooks and science education literature. Thus, students will tend to conceive scientists in an unrealistic manner. There would be no comprehension on the students' part of the full range of the behavior patterns of scientists that are typical of the human race that includes both prejudice as well as openness. In addition, with teachers' portrayal of an idealized version of scientists, the limitations and inadequacies of scientists' humanity would not be realized by students. Thus, students would tend to think of the resulting knowledge produced by such scientists as being objective and absolute. Ideal scientists legitimize a view of "ideal" knowledge. An in-depth biographical study of scientists would increase the awareness of teachers and students of the human qualities of scientists that permeates all scientific knowledge.

Moreover, it was evident that Diane possessed the most realistic view of scientists. This can be directly attributed to her summer experience at a national laboratory during which she worked with scientists. Thus, in addition to biographical studies of scientists, conceptions of the human qualities of scientists by teachers can be improved by actually working with them. In this real life setting, teachers could interact with scientists and learn about their biases and limitations.

Furthermore, subjects possessed a limited understanding of the sociological dimension of scientific knowledge. There was no conception of paradigms in the Kuhnian sense by subjects. Thus, there was no realization of the effects of paradigmatic beliefs on observation, experimentation, and research methodologies. Although subjects were cognizant of the communal aspect of scientists sharing information and the value of the replication of experiments, they expressed concern that they had not really thought about how knowledge becomes ultimately accepted. They tended to think of the acceptability of knowledge in a positivist perspective in which accepted knowledge is based on unbiased experimentation that yields "hard data" that proves facts, theories and laws. The political dimension of consensus-making in scientific communities was not well understood and was interpreted by some subjects as the "majority rules" in determining acceptable knowledge. The implications of this finding suggests that teachers convey scientific knowledge to students in terms of absoluteness. Knowledge is not seen as being arbitrated by interactions of scientists, but is based on objective data and is proven to be true. Thus, students tend to think of knowledge as the truth, and it seldom changes. Knowledge is reified to the extent that its human and sociological constructions are not evident. An understanding of the social nature of the acceptability of knowledge would enlighten this positivist viewpoint about scientific knowledge. Teachers and students need to be cognizant of the arbitration of scientific knowledge by scientific communities. Students should be involved in active debates about their experimental findings which will foster an understanding of the social dimensions of scientific communities. In this way, scientific knowledge can be seen as constantly in a state of examination and change. Its validity cannot be divorced from the sociological aspects of decision-making. Thus, scientific inquiry does not appear to be examined within a social context in the classroom. Science is presented to students in social isolation.

In addition, the terms science and technology were confused by the subjects. Most of the subjects would use the words interchangeably in one case only to separate their meanings in another case. Viewing technology as applied science as conceived by some subjects is in disagreement with the model's interpretation. Technology is not limited by scientific research and can exist without science. Teachers' confusion of the difference in science and technology leads to the perpetuation of this misunderstanding in students.

Such "technoscience" views should be brought to the awareness levels of students and the different social roles of science and technology discussed.

Furthermore, subjects possessed little understanding of the historical nature of scientific knowledge in the context of Kuhnian paradigms. Most subjects conceived science as progressing through history cumulatively. Science is seen as adding one or more pieces to the puzzle of nature and these pieces are added incrementally to make the science of today. The implication of promoting this view of historical science is the incorrect portrayal of scientists in the past working on the same set of problems using the present set of paradigmatic beliefs. Thus, students may think past beliefs "silly" when based on current paradigmatic beliefs. Teachers need to portray historical science as a revolutionary process in which past beliefs were discarded and replaced by new ones. In addition, in past times, scientists worked on different problems that were outlined by the dominant paradigm controlling the view of nature. Discounting the revolutionary nature of the history of science negates the effect of theoretical paradigms on viewing the natural world. Students need to understand the past conflicts of paradigms and the revolutionary way in which the view of the natural world has changed. An understanding of the history of science demonstrates that science can never commit itself irrevocably to any fact, theory, or law no matter how acceptable it appears within the current paradigmatic view of nature. Scientific knowledge can then be viewed as uncertain and tentative. An in-depth study of the history of science by teachers would assist in an understanding of the revolutionary nature of scientific knowledge over time.

The taken-for-grantedness of the basic beliefs of science about the natural world was very evident in the difficulty subjects had in relating any conception of them. Subjects never seemed to have considered these basic assumptions of science. However, the basic beliefs that nature is understandable, causal, orderly, consistent and predictable need to be discussed with students because they underpin any foundation for the acceptability of scientific knowledge. For example, scientists make generalizations from a finite number of observations because it is believed that nature is consistent or what has happened in the past will continue to happen in the future. If the natural world was considered inconsistent, the effect on the knowledge structures of science would be significant. Teachers and students need to consider the importance of these assumptions about the natural world on the credibility of scientific knowledge.

In addition, all subjects recognized the importance of observation to science. In contrast to the above idealized view of scientists, the subjects were far more realistic of scientists when they described objectivity in scientific observation. Most subjects were aware of the effects of background experiences, expectations, emotions, and human limitations on observation. However, the importance of language, the effect of professional training and paradigmatic beliefs were not communicated by the subjects. The subjects were not cognizant of the extensive involvement of theory in observation. Thus, subjects tended to put a great deal of confidence in observation as a firm basis for scientific inquiry. This positivist perspective of "seeing is believing" would have implications on teaching methodologies. If observation is presented to students as a simple process of validating experimental findings, the products of that process (facts, theories, laws) would be viewed as firm and unchanging. Only when the theory dependency of observation is realized can students begin to understand the complex, involved nature of observation and the tentative nature of the resulting scientific knowledge structures.

Moreover, subject's conceptions that scientific instruments produce objective observations have similar implications. In promoting this viewpoint, the human factor behind the design and construction of instrumentation is neglected. It is just another way in which the human element of science is removed from the awareness levels of students. In addition, it presents a false impression in students of the validity of the data. It is important for students to understand that instruments are as fallible as the theory on which they are based.

Furthermore, the teachers tended to see the various methodologies in science in a simplistic way. Most subjects tended to view science as more credible than other types of disciplines because of its methodology. Even though they admitted there is not one scientific method, the subjects described the typical step-by-step textbook description of "the" scientific method upon being asked to depict scientific inquiry. In addition, they used the terminology "the scientific method" not realizing the connotations of their word choice. The subjects also believed the method produced objective data that proved scientific knowledge. Subjects tended to use the term "proven" in describing knowledge that had resulted from the use of "the" scientific method.

The implications of portraying scientific inquiry as a single methodology are significant. By thinking scientific inquiry is done in that way, students would think there is a simple relationship between observation and theory. In addition, the impression of a straightforward, step-by-step method of deriving knowledge discounts the elements of creativity, imagination, and the communal arbitration of knowledge production. The method is seen by students as legitimizing objective knowledge proving that it is truthful and absolute perpetuating a positivist view of science. It creates excessive confidence in scientific knowledge by students. Furthermore, the method is viewed as the criterion that demarcates science from other disciplines. The many processes of scientific inquiry are negated creating the belief in students that there is only one procedure for conducting scientific research. Lastly, the idea of a special method is also detrimental because it discounts the theory ladenness of observations, factual relativism, and dependency on paradigmatic beliefs. Since there was no understanding by the subjects of the inductive/deductive elements of scientific inquiry, there could be no effective classroom instruction on the reasons for the probabilistic nature of scientific knowledge.

To ascertain subjects' conceptions of natural reality, they were asked about the relationship of scientific knowledge structures (facts, theories, and laws) to reality. The subjects tended toward a realist position that advocates a direct ontological relationship between scientific knowledge and reality. However, it was encouraging that they also portrayed a pluralistic realist view by their responses about the changeable nature of scientific knowledge. It was in discussing natural reality in relation to the knowledge structures that the subjects again revealed their positivist viewpoint by using the words "true" and "proven." Scientific facts were seen as "true", whereas theories were "unproven" and laws were "proven." The use of such "terms of absoluteness" by the teachers has consequential implications for students. Teachers that use such terminology in portraying scientific knowledge are giving students the false impression that there are tests of absolute validity. Instead of representing scientific knowledge as fallible, human constructions, such positivist language used by teachers characterizes knowledge as absolute with a proven, existential status. This view portrays scientific knowledge as representing "the way it really is". Such a dogmatic portrayal discounts any awareness of the tentativeness of knowledge. Thus, students might be confused when new information contradicts traditional scientific principles. A complacency about scientific knowledge might result in students which would discourage confidence to question statements in science or critically analyze scientific decisions.

Moreover, subjects viewed hypotheses as an intermediate step to theory formation which finally results in the formation of scientific laws. The science teachers were not cognizant of the difference between a law and theory. Theories explain whereas laws describe relationships. Theories do not become laws. The significance of this lack of understanding of laws and theories is that the misconception about a maturational relationship between laws and theories will be transmitted to students.

By asking subjects about the uniqueness of scientific knowledge, insights were obtained into subjects' views of knowing scientifically. It was interesting that most subjects did not recognize other ways of knowing, and thus had difficulty thinking of alternative kinds of knowledge. The implication of not being cognizant of other ways of knowing relates to teachers advocating wrongfully the application of scientific criteria to all types of knowledge. There are questions science cannot answer. Students need to recognize that there are many ways of knowing, each based on its own goals, methods of accumulating evidence, ways of decision making and sets of assumptions. It is in the recognition of the different and plural ways of knowing that scientific knowledge can be viewed with humility.

In addition, subjects did view the experimental, predictive, and replicative nature of scientific knowledge as attributes of uniqueness. However, they tended to contribute those attributes to the objectivity of science through the use of "the scientific method". They viewed other types of knowledge as being based on subjective factors such as faith and emotions. Again, the positivist perspective of the subjects was revealed through their conceptions of scientific knowledge as being proven and truthful as compared to other types of knowledge. By integrating the human influences on the production of scientific knowledge, teachers could illustrate to students the subjective nature of science.

In discussing the influences of subjects' conceptions of the nature of scientific knowledge on their teaching methodologies, an attempt was made to ascertain the origin of their science world views. The most often mentioned factor that influenced subjects conceptions was their experiences in college course work. According to the Biographical/Professional Background Questionnaire (see Appendix A) completed by the subjects, the average number of undergraduate science courses taken was seven (number of courses ranged from five to nine) and the average number of graduate science courses taken was eight (four of the subjects took no graduate science courses). Viewing the seemingly adequate number of science courses taken by the subjects in college and their deficiencies in conceptions, the implication is that these courses are not addressing the elements of the nature of scientific knowledge. In addition, none of the subjects indicated on their questionnaires that they had taken any philosophy or history of science courses. Thus, there is the need for the integration of ideas about the nature of scientific knowledge in the preservice and inservice training of teachers. Presently, the science courses taken by science education majors are very content driven. In order to improve teachers' conceptions about the nature of scientific knowledge, courses need to be designed that integrate the eight dimensions of the model elaborated in this dissertation with pedagogy. Therefore, preservice/inservice teachers would not only learn about the humanistic, sociological, historical, and experimental elements of scientific knowledge but also investigate instructional methodologies to incorporate them in the classroom setting. Moreover, the next significant finding is the influence of actual work in a laboratory on conceptions of scientific knowledge. The one teacher who worked in a national laboratory possessed many insights that the other teachers did not. Thus, working in a laboratory setting for a period of time for preservice/inservice teachers would provide valuable insights into the nature of scientific knowledge.

The one instructional methodology to improve the teaching of the nature of scientific knowledge most often mentioned by the subjects was an increase in hands-on/laboratory activities. They did realize that teaching just content was not the best method of teaching the nature of scientific knowledge. Teaching the processes of science through hands-on/experimental activities would help promote a better understanding of the dimensions of scientific knowledge. However, teachers need to distinguish between experimental activities in schools which are designed for pedagogical purposes and authentic scientific research. In addition, there was no indication by subjects of the incorporation of the humanistic, historical, or social aspects of the nature of scientific knowledge into their instructional methodologies. Thus, these areas of the nature of scientific knowledge need to be explored by teachers.

Moreover, the subjects listed many barriers to the improvement of science education including scheduling, class size, parental expectations, resources, textbooks, testing, and state curriculum requirements. Planning and instructional time limitations seem to be real problems for the subjects who sincerely wanted to integrate more hands-on/laboratory student activities. It takes time to plan and implement hands-on activities and due to the lack of time, teachers rely on the textbook. In order to institute teaching strategies and a new curriculum that incorporates the dimensions of the nature of scientific knowledge as outlined in this dissertation, these conceived barriers must be addressed.

Thus, these middle school science teachers were poorly prepared to present an adequate view of the nature of scientific knowledge to students. The deficiencies in the teachers' conceptions of the nature of scientific knowledge have many implications for students' understanding and current instructional strategies. The findings of this study indicate the need for changes in the preservice/inservice training of teachers in order to improve their conceptions of the nature of scientific knowledge.

Recommendations

Based on the findings of this study into middle school science teachers' conceptions of the nature of scientific knowledge and the implications of those findings as described above, recommendations for the improvement of preservice as well as inservice teachers' conceptions are proposed. In addition, curricular concerns are addressed in the recommendations.

The goals of the recommendations for the improvement of teachers' conceptions of the nature of scientific knowledge are identified below. The preservice/inservice middle school science teacher should:

1. View scientists in a realistic manner understanding their full range of behaviors.
2. Understand the effects of a paradigmatic view of nature and the functions of scientific communities in the arbitration of the acceptability of scientific knowledge.
3. Demarcate the social roles of science and technology.
4. Convey the revolutionary perspective of the history of science accounting for the conflict of paradigms and the tentativeness of knowledge using historical examples.
5. Be aware of the basic assumptions of science.
6. Recognize the theory dependency of observation.
7. Be cognizant of the many methodologies used in science discounting the concept of "the scientific method."
8. Portray scientific knowledge not in absolute terms but as tentative and fallible.
9. Use language that is appropriate in conveying an accurate view of the nature of scientific knowledge.
10. Comprehend the functions of the knowledge structures of science and their relationship to natural reality.
11. Understand that science is only one way of knowing.
12. Integrate the basic dimensions of the nature of scientific knowledge into teaching methodologies and curriculum materials.

In order to obtain the stated goals, the following recommendations are proposed. These recommendations refer to middle school preservice/inservice science teachers. In these recommendations, the term "academic work" refers to college courses for preservice teachers or inservice teachers who return to an academic institution whereas "teacher training" refers to training sessions conducted for inservice teachers. In addition to science content courses, the preservice/inservice science teacher should participate in:

1. Academic work/teacher training in the history and philosophy of science. This experience should include reading pertinent literature such as the works of Kuhn, Popper, Lakatos, Feyerabend, and Chalmers as well as the biographies of scientists. In addition, the philosophical and historical perspectives of scientific discoveries should be examined through the use of case studies as well as the review of scientists' original work. It is essential that the content of these courses be tailored to the needs of science educators.

2. Academic work/teacher training in the sociology of science. This experience should include reading the works of Kuhn, Latour and Woolgar, and Chalmers. The content of this course must be tailored to the needs of the science educator.

3. Academic work/teacher training that integrates with pedagogy the dimensions of the nature of scientific knowledge as outlined in this dissertation. Particular instructional methodologies should be investigated as well as the implications of teacher behaviors and language on students' understanding of the nature of scientific knowledge.

4. Academic work/teacher training in the development of curriculum materials that accurately portray the dimensions of the nature of scientific knowledge.

5. Academic work/teacher training in the examination of existing science curriculum materials for their portrayal of the nature of scientific knowledge and the modification of these materials to integrate the dimensions of the nature of scientific knowledge as outlined in this dissertation.

6. A full-time internship with research scientists for at least eight weeks. This internship would involve intensive interaction with research scientists in all phases of experimentation and analysis of data.

The implementation of these recommendations will enhance middle school science teachers' conceptions of the nature of scientific knowledge. Previous studies (Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Lavach, 1969) of programs to enhance teachers' views that incorporated some of the recommendations did improve teachers' views of the nature of scientific knowledge. It is realized that the conceived barriers outlined by the subjects to the improvement of science education such as state curriculum requirements and end-of-course testing will also need to be addressed to assist in teachers' delivery of their enhanced and more sophisticated views of the nature of scientific knowledge to students . However, it is believed that much improvement of students' conceptions of the nature of scientific knowledge through improved teacher conceptions can be accomplished in the current institutional framework of schools.

Recommendations for Further Studies

The science teacher is pivotal to the improvement of students' conceptions of the nature of scientific knowledge. Therefore, it is imperative that further studies be done into the conceived views of science teachers. It would be informative for the format of this study to be replicated with other samples of middle school science teachers to compare the results. In addition, the scope of this study did not allow an in-depth probing of subjects' views on each dimension of the model of the nature of scientific knowledge. Therefore, it is recommended that studies be done on each model dimension individually to ascertain teachers' conceptions of that particular area of scientific knowledge. Moreover, it is recommended that studies need to be completed on the extent present curricular materials represent the nature of scientific knowledge as depicted in the study's model. Finally, studies should be conducted into the degree that teachers' language and teaching methodologies reflect the study's model of the nature of scientific knowledge. Further studies into teachers' conceptions are necessary to ascertain the adequacy of their views and to plan specific strategies to improve their conceptions of scientific knowledge.

Conclusion

This research study has investigated the conceptions of the nature of scientific knowledge of six middle school science teachers. The findings of this study support the results of previous studies by suggesting that science teachers possess a less than adequate view of the nature of scientific knowledge. Teachers are the key to the improvement of students' views of the nature of scientific knowledge as well as the integration of these concepts into the curriculum. However, teachers cannot be expected to teach adequately concepts they do not understand or of which they are not cognizant. Therefore, it is important that teacher training programs examine these findings and institute the recommended strategies to increase the cognition of their science education graduates about the dynamic nature of scientific knowledge. In addition, inservice science teachers need to be trained by school districts in all areas of comprehension of the nature of scientific knowledge. It is in the understanding of the many dimensions of scientific knowledge as outlined in this study that teachers can begin to enhance students' understanding of this very important dimension of scientific literacy.

In conclusion, there exists a crisis in science education. As practitioners of the discipline, science teachers possess a limited view of the nature of scientific knowledge which translates into restricted and inaccurate student conceptions. The human, sociological, historical and experimental aspects of scientific knowledge have been negated by the objectification and reification of scientific knowledge by teachers in the schooling of science. Students are alienated by present methodologies that separate them from any personal meaning with scientific knowledge because it is experienced as external to them. Students need to understand that science is a dynamic interaction between nature and humankind in which humans will never know "for sure." More than any other time in human history, a recognition of the fallibility and tentativeness of scientific knowledge is necessary to influence the future of humankind. Science educators have a professional obligation to present to students as authentic view as possible of the nature of the scientific knowledge. This dissertation is important because it has delineated those deficiencies in the conceptions of science teachers as well as created an interpretive model of the nature of scientific knowledge. A transformation of teacher training needs to occur in order to enhance teachers' views of the nature of scientific knowledge. A radically different school science could result enabling students to view science as problematic resulting in the confidence to examine what it means to know scientifically.

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APPENDIX A

BIOGRAPHICAL/PROFESSIONAL BACKGROUND QUESTIONNAIRE

Please complete the following questionnaire and return in the pre-stamped addressed envelope. Please use the reverse side to complete any answers. Thank you for your cooperation.

NAME ______________________________

ADDRESS ______________________________
Street

____
City State Zip

HOME PHONE NO. ____________ BIRTHYEAR ____________

EMPLOYER ______________________________

CERTIFICATION AREA(S) ____________________ LEVEL ______

SCHOOL NAME ______________________________

SCHOOL PHONE NO. ______________________________

WHAT GRADE LEVEL ARE YOU PRESENTLY TEACHING? ____________

HOW MANY STUDENTS DO YOU TEACH DAILY? ____________

WHAT GRADE LEVEL(S) HAVE YOU PREVIOUSLY TAUGHT? ____________

HOW LONG HAVE YOU TAUGHT AT YOUR PRESENT SCHOOL? ____________

TOTAL NUMBER OF YEARS OF TEACHING EXPERIENCE ____________

DO YOU HAVE TENURE? ______________________________

HONORS, AWARDS, AND PUBLICATIONS ____________________

____

____

PROFESSIONAL MEMBERSHIPS ____________________

RECENT INSERVICE ACTIVITIES ____________________

____

____

EDUCATIONAL BACKGROUND

UNDERGRADUATE:

School	Year Graduated	Degree	Major

GRADUATE:

School	Year Graduated	Degree	Major

POST GRADUATE:

School	Type of Coursework

TYPE OF COLLEGE COURSEWORK

UNDERGRADUATE:

Number of science courses completed? ______________________

Number of science education courses completed? ______________________

GRADUATE:

Number of science courses completed? ______________________

Number of science education courses completed? ______________________

DID YOU COMPLETE A COURSE IN THE HISTORY OF SCIENCE IN:
UNDERGRADUATE SCHOOL? _____ GRADUATE SCHOOL? _____

DID YOU COMPLETE A COURSE IN THE PHILOSOPHY OF SCIENCE IN:
UNDERGRADUATE SCHOOL? _____ GRADUATE SCHOOL? _____

HAVE YOU PARTICIPATED IN ANY INSERVICE ACTIVITIES THAT INVOLVED DISCUSSIONS OF THE HISTORY AND/OR PHILOSOPHY OF SCIENCE? _____ IF SO, WHAT TOPICS WERE DISCUSSED? ______________________________

____

HAVE YOU PARTICIPATED IN ANY INSERVICE ACTIVITIES THAT INVOLVED DISCUSSIONS OF THE NATURE OF SCIENTIFIC KNOWLEDGE?______________
IF SO, WHAT TOPICS WERE DISCUSSED? ______________________________

____

WHY DID YOU BECOME A SCIENCE TEACHER? ______________________

____

____

WHY DOES SCIENCE INTEREST YOU? ______________________________

____

____

DO YOU HAVE ANY RELATIVES WHO ARE INVOLVED IN SCIENCE EDUCATION OR SCIENCE AS A PROFESSION? ______________________________

DO YOU SEE YOURSELF AS A SCIENTIST? ______ WHY OR WHY NOT?

____

____

____

APPENDIX B

INTERVIEW THEME AND QUESTION GUIDELINE

The unstructured interview themes and questions listed below served as a guideline to ensure that all themes and questions were addressed during the interview sessions. The list indicates types of questions that were asked rather than the actual questions. The questions were rephrased and reordered during the actual interviewing process.

Introduction

1. Why did you become a science teacher?
2. Describe your work situation -grade, class schedule, number of students.

The Importance of Science Education

1. How would describe the purposes of science education?
2. What is meant by scientific literacy? What are its elements?
3. Do you believe the purposes of science education are being achieved? Why or why not?
4. What are the purposes of middle school science education?

The Humanistic Nature of Scientific Knowledge

1. Define a scientist.
2. What are the characteristics of scientists? What motivates a scientist?
3. Are scientists objective?
4. What consumes most of a scientists time?

The Social Dimension of the Nature of Scientific Knowledge

1. How do scientists interact to determine scientific knowledge? How do these interactions affect scientific knowledge?
2. Describe a scientific community. Are there levels of hierarchy within a scientific community?
3. How does communication between scientists affect knowledge?
4. How does scientific knowledge become acceptable?
5. What is science? What is technology? Are they the same?
6. How does science interact with other social institutions?
7. Does scientific knowledge have a morality?

The Historical Nature of Scientific Knowledge

1. How has scientific knowledge developed throughout history?
2. Why does scientific knowledge change? How does it change?
3. Describe scientific progress.

Basic Beliefs About the Natural World

1. What are your beliefs about nature?
2. What are scientists' beliefs about the natural world?

Observation-Based

1. Explain the act of observing.
2. What is the role of observation in science?
3. What factors affect what one observes?
4. What is the role of instrumentation in scientific observation?

A Result of Inquiry

1. Describe scientific inquiry. What are its dimensions?
2. Is there a particular type of methodology in scientific inquiry?
3. Does scientific knowledge have a special kind of reliability ?
4. Explain deductive or inductive reasoning. What are their roles in scientific inquiry?

Knowledge Structures

1. Explain your understanding of scientific facts, theories and laws. What is the function of each?
2. What is a scientific hypothesis?
3 What is the relationship of these knowledge structures and reality?
4. What are scientific models? Do they reflect reality?

Uniqueness of Scientific Knowledge

1. Is science the only way of knowing?
2. How is science different from other ways of knowing?
3. Is science the best way of knowing?

Instructional Methodologies

1. How do you teach science?
2. Describe your impression of the important of the classroom teacher.
3. What influenced your views of the nature of scientific knowledge?
4. Do you think your views of the nature of scientific knowledge affect the way you teach? If so, in what ways?

5. Do you think textbooks influence conceptions of the nature of scientific knowledge?
6. What role does laboratory activities play in understanding the nature of scientific knowledge? What percentage of your class time do you do laboratory activities?
7. If you could improve the way you teach science and the nature of scientific knowledge, how would you do it?
8. What are the barriers, if any, that prevent you from teaching science and the nature of scientific knowledge as you would like?