Current reforms emphasize the development of scientific literacy as the principal goal of science education. The nature of science is considered a critical component of scientific literacy and is assumed to be an important factor in decision making on science and technology based issues. However, little research exists that delineates the role of the nature of science in decision making. The purpose of this investigation was to explicate the role of the nature of science in decision making on science and technology based issues and to delineate the reasoning and factors associated with these types of decisions.

The 15-item, open-ended "Decision Making Questionnaire" (DMQ) based on four different scenarios concerning science and technology issues was developed to assess decision making. Twenty-one volunteer participants purposively selected from the faculty of geographically diverse universities completed the questionnaire and follow-up interviews.

Participants were subsequently grouped according to their understandings of the nature of science, based on responses to a second open-ended questionnaire and follow-up interview. Profiles of each group's decision making were constructed, based on their previous responses to the DMQ and follow-up interviews. Finally, the two
groups' decisions, decision making factors, and decision making strategies were compared.

No differences were found between the decisions of the two groups, despite their disparate views of the nature of science. While their reasoning did not follow formal lines of argumentation, several influencing factors and general reasoning patterns were identified. Participants in both groups based their decisions primarily on personal values, morals/ethics, and social concerns. While all participants said they considered scientific evidence in their decision making, most did not require absolute "proof," even though Group B participants held more absolute conceptions of the nature of science. Overall, the nature of science did not figure prominently in either group's decisions.

These findings contrast with the assumptions of the science education community and current reform efforts and call for a reexamination of the goals of nature of science instruction. Developing better decision making skills — even on science and technology based issues — may involve other factors, including more values-based instruction and attention to intellectual/moral development.
UNDERSTANDINGS OF THE NATURE OF SCIENCE AND DECISION MAKING ON SCIENCE AND TECHNOLOGY BASED ISSUES

by

Randy L. Bell

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Dean of Graduate School

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Randy L. Bell
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CHAPTER I
THE PROBLEM

Introduction

Never in our history has the impact of science and technology on society been greater. From superconducting supercolliders to cloning, average citizens are constantly confronted with the consequences of new advancements in science and technology.

In response to the increasing implications of scientific and technological advancements, science educators and national science organizations have increasingly emphasized the development of a scientifically literate citizenry. Generally defined, scientific literacy refers to understanding the concepts, principles, theories, and processes of science, the nature of science, and an awareness of the complex relationships between science, technology, and society (Bybee, 1997). A scientifically literate citizenry, it is argued, is better able to make reasoned decisions on complex science and technology based issues. As explained by the American Association for the Advancement of Science (AAAS), "The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics and technology and to acquire scientific habits of mind; without a scientifically literate population, the outlook for a better world is not promising" (1989, p. 13).
Efforts to improve scientific literacy among students in public schools have abounded since the term was coined in 1952 by James Bryant Conant (Cohen & Watson, 1952). The stated goal of many of the science-technology-society-based curricula developed during the 1960s and 1970s was fostering scientific literacy. Generated, in part, by research scientists, these "alphabet" curricula sought to improve students' scientific literacy through increased attention to science curriculum and a purported inquiry approach to science instruction. While it is generally agreed that these curriculum-heavy, "teacher-proof" approaches did not achieve the desired results, the vision of enhancing students' scientific literacy has persisted to the present. Indeed, the principle goal of current reforms in science education is still the development of a scientifically literate citizenry (AAAS, 1990, 1993; National Research Council [NRC], 1996).

Reformers agree that, in order for these changes to come about, less emphasis should be placed on teaching science content and more emphasis placed on broad, overarching themes, including scientific inquiry and the nature of science. The nature of science, also known as epistemology of science, or science as a way of knowing, refers to the values and assumptions inherent to scientific knowledge (Spector & Lederman, 1990). These values and assumptions include, but are not limited to, parsimony, tentativeness, subjectivity, and creativity. Although it was stated as a goal of science education as early as 1907 (Lederman, 1992), the nature of science did not attract researchers' interests until the two decades following the Soviet launching of Sputnik. It was at this time that such notable scholars as Mead and Metraux (1957), Yager (1966),
Welch and Pella (1968), Klopfer (1969), Hurd (1969), Tamir (1972), and Rubba (1976) directed their attention toward this aspect of scientific literacy.

Recently, the nature of science has enjoyed renewed attention in science education reform documents as a primary component of scientific literacy (AAAS, 1990, 1993; Bybee, 1997; Klopfer, 1969; Lederman, 1986; NRC, 1996; National Science Teachers Association, 1982). In fact, the nature of science has even been equated with scientific literacy (Mackay, 1971). These documents mandate that teachers of science from kindergarten to graduate school are not only to teach in a manner consistent with current views of the scientific enterprise, but to instruct students in specific aspects of the nature of science. Such reform amounts to a huge and uncertain undertaking, since research has shown that, for the most part, few students or teachers are able to articulate adequate understandings of this elusive construct (Duschl, 1990; Lederman, 1992, among others).

What, then, is the justification for the effort and expense of such an undertaking? From an educational perspective, most agree that educating children to simply recall scientific facts, laws, and theories is not enough. Rather, teachers and science educators want students to know why scientific knowledge and ideas have merit and may be trusted. For example, Munby (1982) promoted science instruction that fosters "intellectual independence" and provides students with "all the resources necessary for judging the truth of knowledge independently of other people" (p. 31). Norris (1992) extended this argument to the "rational trust" of experts when firsthand evidence is impractical. These issues attain practical significance for individuals deciding whether to
accept the advice or opinion of scientific "experts" and how to respond to public issues related to science and technology. Thus, public understanding of the nature of science is considered a critical component of democracy, in which people must make decisions on science and technology based issues.

Science educators referred to this democratic justification for nature of science instruction as early as 1961: "Widespread public understanding of the nature of scientific endeavor is essential for a healthy society" (Behnke, 1961, p.206). Recent commentary has been more specific about the rationale for nature of science instruction and has equated it with the goal for scientific literacy: to improve citizens' abilities to make reasoned decisions in a world increasingly impacted by the processes and products of science (Collins & Shapin, 1986; Cotham, 1979; Lederman, 1983; Millar & Wynne, 1988). By knowing the characteristics of scientific knowledge and the way it is constructed, the argument proceeds, citizens will be better able to recognize pseudoscientific claims, distinguish good science from bad, and apply scientific knowledge to their everyday lives. Driver, Leach, Millar, and Scott (1996) labeled this the "democratic argument".

The democratic argument for promoting public understanding of science focuses on the understandings needed to participate in the debates surrounding [science and technologically based] issues and in the decision-making process itself...an understanding of the issues requires not just knowledge of science content, but also an understanding of the nature of science and scientific knowledge. (p.18)
Given the importance science educators have placed on the ultimate outcome of nature of science instruction and scientific literacy, it is disconcerting to realize that the democratic argument remains an untested assumption.

Statement of the Problem

Whether one's understanding of the nature of science significantly impacts decision making is an important question. The answer to the question holds significant implications for current directions in science education reform. Unfortunately, direct ties between people's understanding of the nature of science and their decision making remain relatively unexplored.

Assessments focusing on adult understandings of the nature of science have reported mixed results. Many researchers have claimed that preservice teachers, especially those preparing to be elementary teachers, possess inadequate views of the nature of science (Carey & Stauss, 1970; Cotham & Smith, 1981; Kimball, 1967-68; King, 1991; Schmidt, 1967). Researchers have concluded that inservice teachers' conceptions need improvement as well. (Anderson, Harty, & Samuel, 1986; Behnke, 1961; Gallagher, 1991; Miller, 1963; Wood, 1972). Other assessments have reported more impressive understandings in samples of inservice teachers (Lederman, 1986; Pomeroy, 1993; Welch & Pella, 1968), philosophy students (Cotham & Smith, 1981; Rubba & Anderson, 1978), and scientists (Schmidt, 1967; Welch & Pella, 1968). Confounding these equivocal results are the limitations of the methodologies and instruments used in these assessments.
Research exploring decision making and the formation of moral judgments on science and technology based issues has found that individuals base decisions on a variety of factors. Zeidler and Schafer (1984) suggested that comprehension of science, positive attitudes, and a strong commitment toward a particular issue were all positively related to the level of moral reasoning used to make social judgments. Fleming (1986a) found that adolescents primarily viewed science and technology based issues in ways that stressed the social aspects of the issue. Students who used nonsocial cognition focused on their perceptions of scientists and the institution of science when analyzing and discussing science and technology based issues (Fleming, 1986b). The single study that directly addressed the role of nature of science conceptions in decision making found that students did not base decisions about their daily conduct on their understandings of the tentative nature of scientific knowledge (Lederman & O'Malley, 1990).

Piaget (1972) and Iozzi (1976) theorized that individuals tend to reason at more sophisticated levels in areas which they have more knowledge. If the nature of science is related to one's decisions on science and technology based issues, as so many think it is, then it follows that those who understand the nature of science should reason differently on these issues than those who do not. The purposes of this investigation were to assess the influence of people's understanding of the nature of science on their decision making regarding science and technology based issues and to delineate the factors and reasoning people use when making these types of decisions. The research questions guiding the investigation were
1. What is the relationship, if any, between understandings of the nature of science and decisions regarding science and technology based issues?

2. What is the relationship, if any, between understandings of the nature of science and the factors used to reach decisions on science and technology based issues?

3. What is the relationship, if any, between understandings of the nature of science and the reasoning used to reach decisions on science and technology based issues?

Significance of the Study

This investigation is significant for both practical and theoretical reasons. In terms of practical implications, it is important to realize that nature of science instruction is generally viewed as a means to an end; i.e., a citizenry capable of making reasoned decisions on science and technology based issues in a democratic society. This study gets at the very heart of this rationale for nature of science instruction: Does knowledge of the nature of science facilitate what science educators think it will? Will effectively teaching this construct, which seems to have eluded our best efforts, actually do for society what advocates claim?

Incredible amounts of time and effort have been expended to help students develop desired understandings of the nature of science. Given the current state of affairs, much more will need to be expended before science educators can claim that they know how to teach the nature of science effectively. It is unwise to pursue such an undertaking without empirical support. This study provides the first assessment of the anticipated outcome of nature of science instruction. If impacts can be identified, the
science education community can be more confident that the energy and expense invested to achieve public understanding of the nature of science will effect the desired outcomes. Furthermore, delineating the specific role of the nature of science in decision making provides insight into which aspects are most important to emphasize in instruction. For example, understandings of the characteristics and role of evidence in the construction of scientific knowledge may be more critical to decision making than views of creativity in science. If the nature of science is found to have little or no impact on decision making, science educators may want to place more effort into developing the knowledge, skills, and, possibly, values that do. Therefore, regardless of the specific findings of this study, it has the potential to inform the education of both teachers and students in regard to nature of science instruction and decision making on science and technology based issues.

The theoretical implications relate to the connection between the nature of science and scientific literacy. The nature of science is not only recognized as a critical component of scientific literacy, it shares the same primary goal in science education as the broader construct; i.e., preparing citizens who are able to make reasoned choices on science and technology based issues. Identifying the factors and reasoning people use in making these decisions can serve as an initial assessment of the assumed outcome of scientific literacy, and should inform subsequent investigations into the effectiveness of the various aspects of this construct.

While it is never comfortable to assess the efficacy of cherished ideas and assumptions, the only other choice is to walk the path of ignorance. And how can the
science education community ask others to make reasoned choices on difficult issues when it refuses to do so?
CHAPTER II
REVIEW OF THE LITERATURE

Introduction

The explicit goal of helping students develop adequate conceptions of the nature of science can be traced back to the turn of the century (Central Association of Science and Mathematics Teachers, 1907). Not until the 1960s, however, did the nature of science achieve its current high status. At this time, researchers described understanding the nature of science as "one of the most commonly stated objectives for science education" (Kimball, 1967-68, p. 110). One commentator has estimated that the past three decades have seen more than a billion dollars appropriated for research, teacher education programs, and innovative curricula with the sole purpose of improving the teaching and learning of the nature of science (Matthews, 1994).

Despite the longevity of the concern for developing adequate understandings of the nature of science, and the effort expended to achieve it, progress remains disappointing. Researchers have consistently reported that students do not possess desired understandings of the nature of science (Duschl, 1990; Lederman, 1992). Historically, these poor results have been blamed on a variety of factors, including curricula rife with misconceptions about the nature of science and the inadequate understandings of teachers. More recently, criticism has been directed toward the nature of science construct itself (Alters, 1997). According to critics, the nature of science is too vague a concept to be agreed upon by philosophers and science educators. How then, are students supposed to understand what experts cannot agree upon? The solution to this conundrum requires a specific definition of the nature of science, or at
least a characterization of the construct, that can be agreed upon by science educators. Does such a solution exist?

The Nature of Science

Primarily due to the complexity of the historical, philosophical, and academic facets of science, science educators have found the nature of science construct difficult to define concisely. As Shamos (1995) put it, "brief definitions may be meaningful to the expert but rarely tell the full story." Rather than attempt to encapsulate the meaning of the nature of science in a line or two, most writers have chosen to list what they view as its principle characteristics. For example, Kimball (1967-68) developed his model of the nature of science based on the available literature on the nature and philosophy of science. The model describes science as a dynamic and tentative enterprise driven by curiosity. According to Kimball, tension exists in science between its aim to be comprehensive yet seek the simplest explanation. Rubba and Anderson (1978) also developed a model of the nature of science based upon a review of the literature. They listed the principle characteristics of science as amoral (cannot be judged good or bad), creative, developmental (tentative), parsimonious (attempts to achieve the simplest explanation), testable, and unified by interconnected laws, theories, and concepts.

More recently, the AAAS (1989) listed three major elements in its description of the nature of science. The first describes science as a world view in which the world is understandable, scientific knowledge has both tentative and durable qualities, and science recognizes its inability to provide complete answers to all questions. The second element describes scientific methods of inquiry, which are empirically based,
nonauthoritarian, and a complex blend of logic and imagination. In scientific inquiry, scientists seek to explain and predict natural phenomena. And while scientists try to identify and reduce the effects of personal bias, they recognize it as an unavoidable aspect of any human endeavor. The final element describes the social and political aspects of the scientific enterprise.

These examples indicate that "nature of science" is a multifaceted concept, apparently as difficult to define as it is to learn. Presently, no consensus exists among philosophers of science, scientists, or science educators as to a precise definition or characterization of the nature of science. Philosophers of science continue to adopt divergent positions on the major questions and issues about science and scientific knowledge (Driver, Leach, Millar, & Scott, 1996), which suggests that the nature of science is, in itself, tentative (Lederman, 1992). However, Lederman and his colleagues have recently argued that the majority of the disagreements about what constitutes the nature of science are irrelevant to K-12 instruction (Smith, Lederman, Bell, McComas, & Clough, 1997). Additionally, Lederman and Abd-El-Khalick (1998) suggested that consensus does exist on many aspects of the nature of science that are accessible and relevant to K-12 students. Included among these are the concepts that scientific knowledge is (a) tentative (subject to change), (b) based on empirical evidence (derived from observations of the natural world), (c) based on observation and inference, (d) subjective (theory-laden), (e) creative, and (f) is socially and culturally embedded. This is the characterization of the nature of science used in the present investigation.
The Nature of Science and Decision Making

In conjunction with the concern about students' understandings of the nature of science, many researchers have explored the understandings of various adult groups, including preservice and inservice teachers, college students, and scientists. These nature of science assessments are relevant to the present review for two reasons. First, the AAAS and NRC reform documents both argue for integrated nature of science instruction that spans the breadth of the science curriculum from kindergarten through twelfth grade. Any assessments of K-12 students would, therefore, have to be considered formative, rather than summative. Second, although children do make some choices about how to conduct their everyday lives, adults are generally in the position to make substantial personal decisions and decisions on science and technology based issues in our society. The reviewed assessments are further limited to peer reviewed, published investigations that utilized samples from within the United States. This last criterion reflects the potential geographic sample pool of the investigation described in Chapter III of this document. For the purpose of convenience, the 14 nature of science investigations included in this review have been grouped into three categories: a) comparisons among various groups of adults, b) general assessments of particular groups of adults, and c) validation of nature of science instruments that include adults.

Compared to the myriad of assessments of understandings of the nature of science, researchers have given sparse attention to decision making on science and technology based issues. These studies have explored the decisions of adults (Zeidler & Schafer, 1984) and adolescents (Fleming, 1986a, 1986b; Lederman & O'Malley, 1990).
The first three of these studies focus on the factors influencing individuals' decision making on environmental issues, while the last study explores the influence of students' views of the tentative nature of scientific knowledge on decisions that guide their everyday lives.

Research on Adult Conceptions of the Nature of Science

Comparisons Among Various Groups

In an early investigation of teachers' beliefs about the nature of science, Behnke (1961) used a mailed questionnaire to survey high school science teachers' and scientists' views about science and the scientific enterprise. The study was designed to answer four questions:

1. Are there significant differences between a group of science teachers and scientists with respect to their opinions on certain aspects of science and science teaching?

2. Are there differences of opinion on science and science teaching between selected groups of physical science and biology teachers?

3. Do teachers from different geographical regions differ in their opinions about science and science teaching?

4. Are there variations in the opinions of science teachers as a result of differences in educational background and teaching experience?

Behnke believed it was important to ascertain teachers' views about science because their opinions and attitudes would "directly and significantly influence the quality of science teaching" (Behnke, 1961, p.193).
The researcher-developed survey instrument consisted of 50 statements to which respondents could respond as favoring, opposing, or taking a neutral position. The statements were distributed among four categories, including the nature of science, the relationship of science and society, the role of scientists in society, and science teaching. The instrument also solicited demographic information, such as educational background, years of teaching experience, subjects taught, etc. Behnke claimed to have used pilot testing to eliminate "unsatisfactory" statements in each category, but provided no detail for the testing was accomplished. Additionally, no description of the instruments' reliability or validity was provided.

The questionnaire was originally sent to 400 biology and 600 physical science teachers randomly selected from the membership roles of the National Science Teachers Association. The two to three ratio of biology to physical science teachers was meant to reflect the proportion of these teachers in the membership roles. Additionally, Behnke stratified the sample into groups reflecting three geographical regions: the Northeast, the South, and the West-Midwest. The return rate for the science teachers was 50% for the biology teachers and 71% for the physical science teachers.

In addition to the science teachers, Behnke selected one hundred scientists across the United States from a list furnished by the American Association for the Advancement of Science. Fifty-two of these scientists were classified as working in various fields of the life sciences and 48 in the physical sciences. Seventy percent of the scientists responded to the questionnaire.
Fourteen of the items on the questionnaire were designed to evoke responses indicative of the participants' views of the nature of science. The teachers and scientists were in general agreement on the nature of science items, which were phrased from a sociological point of view. Thus, both groups generally agreed that team research was more productive than individual research and disagreed that investigations should be limited due to possible bias of the investigator. Conversely, the teachers and scientists showed little agreement on the statements about the goals and limitations of science. For example, only 20% of the scientists believed that the goal of science is to improve human welfare, while 50% of the teachers were in agreement with the statement. Disturbingly, the responses of more than half of the science teachers reflected the belief that scientific knowledge is not tentative. Even more surprising to Behnke was the fact that 20% of the scientists believed the same.

Responses to the items pertaining to science and society showed little difference between the two groups. Additionally, the scientists and teachers were in agreement that scientists should participate in public affairs. However, a marked difference was evoked by the item that stated scientists should conform to social pressures. Eighty-percent of the scientists agreed with this statement, compared to 4% of the teachers.

There was also much agreement between scientists and teachers with regard to what science to teach and how to teach it. For example, both groups indicated that scientific facts about human reproduction should be taught in high school science classes. On the other hand, the introduction of moral issues into science teaching was approved by a much larger percentage of teachers than scientists. Additionally, there
was considerable disagreement about the competency of biology teachers who rejected evolutionary theory. Most of the scientists believed that such teachers were not qualified to teach biology, compared to only a third of the teachers who questioned their competency.

Once the opinions of the science teachers had been compared with those of the scientists, the data from the teachers were analyzed to determine intragroup differences with respect to subject taught, regional location of school, and educational background. In general, Behnke concluded that the various subgroups were more alike than different. Furthermore, Behnke found that the differences among the teachers were less marked than those between the scientists and the teachers.

In light of the apparent poor understandings of the nature of science exhibited by the teachers, Behnke suggested several improvements to science teacher education. First, he suggested that preservice science teachers should complete coursework in the history and philosophy of science in order to increase their understanding of the nature of science and the scientific enterprise. However, Behnke believed that nature of science instruction should not be limited to separate courses, but should be included in regular science content courses. Behnke also stated that preservice science teachers should be required to complete coursework in the sociology of science. Behnke believed that knowledge of the sociology of science would provide them with better understandings of the status of scientists in our society, the necessity of autonomy in scientific endeavor, and the influence of society on science and vice versa. Finally, Behnke
suggested that preservice science teachers should have opportunities to conduct small-scale research in order to acquire the skills, knowledge and insight for scientific inquiry.

Miller (1963) compared understandings of the nature of science of biology teachers to five separate student groups in grades 7 through 12. The 51 teachers participating in the study included both preservice and inservice biology teachers from 20 different high schools in Iowa. The student sample included 205 7th-grade students, 328 8th-grade students, 52 9th-grade students, and 63 10th-grade students, all randomly selected from 8 different schools. Additionally, 87 11th- and 12th-grade students from 60 different high schools were selected for their high quality science work. Miller did not describe the criteria used for the selection of these students.

Each participant completed the Test On Understanding Science (TOUS), form W. The mean scores of the six groups (one teacher, and five student groups) were then compared using the $t$ statistic at an alpha level of 0.01. The mean scores ranged from 23.6 for the seventh-grade students to 43.6 for the biology teachers on the 60-item multiple choice instrument (Table 1).

Comparison of individual scores indicated that 80 students (11%) actually achieved higher scores than the 13 (25%) lowest scoring teachers. Furthermore, 33 (38%) of the high ability 11th- and 12th-grade students scored higher than half of the teachers. Miller found the results of these comparisons disturbing. As he put it, "We cannot afford to have practicing high school biology teachers who spew out facts and figures, and judge and grade 10th grade students when some of these teachers do not understand science any better than some 7th graders!" (Miller, 1963, p. 513). To
remedy teachers' inadequate understandings of science, Miller suggested that science educators consider the enhancement of teachers' understandings of the nature of science a primary goal. Additionally, he called for improvements to the economic, prestigial, and professional aspects of teaching in order to attract more capable teachers to the profession.

In a replication of Miller's (1963) investigation, Schmidt (1967) administered the TOUS to high school students, preservice and inservice secondary science teachers, preservice elementary teachers, and working scientists. Neither selection criteria nor background information was provided for any of the sample, and the sample size was provided for only the preservice secondary teachers ($n = 29$), preservice elementary...
teachers \((n = 43)\), and scientists \((n = 116)\). Results of the TOUS administration are provided in Table 2.

As in Miller's study, substantial proportions of 9th-grade students (14%) and 11th- and 12th-grade students (47%) scored higher on the TOUS than the inservice teachers. Working scientists achieved the highest scores, but their mean score was still 10 points lower than the maximum possible score. Schmidt interpreted this data as indicating that an adequate TOUS score may be somewhat lower than previously accepted. Nevertheless, he suggested that the inservice teachers' TOUS scores were low enough to necessitate the development of ways to improve their understandings of the nature of science. To achieve this goal, Schmidt recommended that teachers work with scientists, rather than complete additional coursework.

Table 2
Comparison of Mean TOUS Scores for Participants in the Schmidt (1967) Study

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample Size</th>
<th>TOUS Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 7</td>
<td>?</td>
<td>24.9</td>
<td>10-40</td>
</tr>
<tr>
<td>Grade 9</td>
<td>?</td>
<td>34.0</td>
<td>12-48</td>
</tr>
<tr>
<td>Grades 11 &amp; 12</td>
<td>?</td>
<td>41.0</td>
<td>23-52</td>
</tr>
<tr>
<td>Inservice Science Teachers</td>
<td>?</td>
<td>45.5</td>
<td>33-55</td>
</tr>
<tr>
<td>Preservice Science Teachers</td>
<td>29</td>
<td>48.0</td>
<td>37-58</td>
</tr>
<tr>
<td>Preservice Elementary Teachers</td>
<td>43</td>
<td>40.5</td>
<td>29-50</td>
</tr>
<tr>
<td>Working Scientists</td>
<td>116</td>
<td>50.8</td>
<td>36-59</td>
</tr>
</tbody>
</table>
Kimball (1967-68) compared understandings of the nature of science among scientists, science teachers, and philosophy majors. Kimball suspected that earlier reports of teachers’ understandings of the nature of science erred by sampling a cross section of people assigned to teach science, whether qualified or not. He attempted to avoid this problem by sampling only those teachers who had majored in science during their undergraduate programs. In addition to the teachers, Kimball sampled practicing scientists and philosophy majors in order to compare their views with those of the teachers.

Kimball developed the Nature of Science Scale (NOSS) in order to ascertain respondents’ views of the nature of science. The instrument is based upon a theoretical model constructed from a review of the literature of the nature and philosophy of science, including Bridgman (1950), Bronowski (1956), Conant (1961), Holton (1952), Nagel (1958), Schwab (1960), and Whitehead (1961). Face and content validity were established with the help of a panel of science teachers, school science supervisors, science professors, and science education professors. The final version of the instrument contained 29 items arranged in a three-choice, Likert-type scale. Individual scores were determined by awarding 2 points for each response in agreement with the model, one point for each neutral response, and 0 points for each response in disagreement with the model.

Kimball sent the NOSS to 965 science and philosophy majors who graduated from Stanford University and San Jose State College during the years 1952, 1958, 1962, 1963, and 1965. A total of 712 replies were received, for a return rate of 74%. A
second mailing to nonresponders resulted in 39 additional replies. Statistical analysis using the \( t \)-test revealed no differences in mean scores between the original sample and the nonresponders. Comparisons among the scientists, teachers, and philosophers were made by \( F \) and \( t \)-tests, followed by an item-by-item comparison of each groups' responses using chi-square. The results of these comparisons indicated that the science teachers did not respond differently from working scientists when the variable of undergraduate education was controlled. Neither the scientists nor the teachers, however, achieved high mean scores (34.73 and 35.41, respectively, out of 58 possible points). Kimball found no differences among the understandings of either scientists or teachers for the different graduating classes. He interpreted this result as indicating that scientists and teachers formulate their conceptions about the nature of science during their undergraduate careers. Kimball reported that the philosophy majors achieved significantly higher scores than all of the science majors combined, as well as the practicing scientists. Interestingly, the higher scores of the philosophy majors were primarily due to their agreement with the seven items dealing with science methodology, an area of science that one would expect to be most familiar to the scientists. Kimball concluded that his study provided evidence supporting the frequent suggestion that undergraduate science majors should be required to complete coursework in the philosophy of science.

Anderson, Harty, and Samuel (1986) used the NOSS to compare the nature of science understandings of preservice teachers enrolled in a secondary science methods course at Indiana University in 1969 and 1984. The samples consisted of 24 (1969) and
21 (1984) preservice secondary teachers. The demographics of the samples differed, with a much higher proportion of females and graduate students in the 1984 group. Despite these differences, the researchers assumed the equivalence of the two groups based on their approximately equal distribution across majors and one investigator's firsthand knowledge of the individuals in both groups.

The NOSS was administered to both groups on the first day of the science methods course, which was the last course the preservice teachers completed before student teaching and graduation. The researchers reported a Cronbach's alpha internal consistency coefficient of 0.74 for the 1984 sample. In order to facilitate scoring the responses, the researchers altered the scoring procedure, assigning one point for responses that disagreed with Kimball's model, two points for neutral responses, and three points for responses that agreed with the model. Possible scores could therefore range from 29 (little agreement) to 87 (much agreement).

The mean total score of the 1969 group was 52.8 ($SD = 4.1$), while that of the 1984 group was 58.1 ($SD = 7.3$). This 5.3 difference indicated that the 1984 group responses were significantly more in agreement ($t = 3.2, p < 0.008$ level) with the Kimball Model Response Scores than those of the 1969 group. In all, the 1984 group demonstrated greater agreement with the Kimball Model Response on 24 of the 29 items; however, the majority of these gains were less than 0.3 points per item. The researchers attributed these gains to (a) secondary preservice programs attracting older students with significantly greater understandings of the nature of science, and/or (b)
science instructors providing students with instruction that better promotes understandings of the nature of science.

Despite the gains of the 1984 group, means of item sets representing particular assertions of the Kimball Model Response indicated little or no agreement on four of the eight declarations. These declarations included: (a) scientists believe the universe can be ordered, (b) curiosity is the driving force of science, (c) science strives for parsimony, and (d) there is no single scientific method. The researchers concluded that neither the 1969 nor the 1984 groups possessed adequate understandings of the nature of science to adequately address the construct in classroom instruction. Like Kimball (1967-68), the researchers recommended adding philosophy of science coursework to the undergraduate curriculum of preservice teachers to remedy the problem.

Pomeroy (1993) reported the results of a study designed to explore the beliefs and attitudes of a sample of research scientists, secondary science teachers, and elementary teachers. The purpose of the study was to determine the extent of any differences between scientists' and teachers' view of the nature of science, scientific method, and related aspects of science education.

The participants consisted of 71 volunteer research scientists and 109 volunteer secondary and elementary teachers in Alaskan cities. The responding teachers, split 55% elementary to 45% secondary, reported a mean of 12.7 (SD = 7.05) years of teaching experience. As a whole, the secondary teachers were more likely to be male, had completed more science courses, and had more research experience than their elementary counterparts.
The single data source consisted of a researcher-developed instrument containing 50 agree-disagree statements on a five to one Likert scale. Individual items reflected a range of beliefs from traditional, Baconian beliefs, to more contemporary views consistent with Popper, Gould, and Kuhn. The survey also included items designed to illuminate respondents' beliefs about K-12 science education. Pomeroy reported no information concerning the validation of the instrument.

Data analysis consisted of identifying underlying clusters occurring in groups of survey statements, analyzing these clusters as sets, and describing the sets using summary statistics. The cluster sets were identified using a combination of a 50 x 50-item Pearson correlation matrix analysis combined with clustering statements into categories designed to represent traditional and nontraditional views of science and science education. The composition and internal consistency of the generated clusters revealed that they were all variations of three basic clusters: a traditional view of science, a traditional view of science education, and a nontraditional view of science.

Comparisons of the mean scores of scientists vs. all teachers, men vs. women, and secondary science vs. elementary teachers were performed for each cluster using t-tests. In general, the moderate to high internal consistency for each cluster (ranging from 0.59 - 0.81), coupled with the philosophical consistency of these beliefs, suggested reasonable reliability for the instrument as well as coherence of beliefs among the participants.

The combined mean score in the “Traditional” cluster was neutral (3.02, SD = 0.56) for all respondents combined. Traditional views were expressed more strongly by
scientists (mean = 3.14, SD = 0.52) than the combined teachers (mean = 2.92, SD = 0.63). This difference was statistically significant (p < 0.022). Secondary teachers expressed more traditional views (mean = 3.20, SD = 0.46) than elementary teachers (mean = 2.88, SD = 0.64), but the difference in means was not statistically significant. In terms of gender, the results showed that men in these samples expressed traditional views more than women. However, multiple regression analyses demonstrated that these results were due to sampling; i.e., the majority of women in the sample were elementary teachers. Pomeroy speculated that the more traditional views of scientists and secondary teachers may be explained by their (a) deep initiation into the norms of the scientific community, and (b) training in the tradition of Kuhn’s (1970) “normal” science. These background factors, Pomeroy argued, would lead them to accept objectivity as a goal of science despite its implausibility, since “normal” science does not provide the tools to deal with alternatives.

The mean combined score of all the groups for the “Nontraditional” cluster was relatively high (mean = 4.03, SD = 0.46). This result suggested that the beliefs of the participants, as a whole, were in closer agreement with modern views of the nature of science than with logicoempiricism. Unlike in the traditional cluster, there were no significant differences among subgroups.

The mean combined score of all the groups for the “Traditional Views of Science Education” cluster was below the midpoint (mean = 2.73, SD = 0.56). The combined group of teachers (mean = 2.15, SD = 0.48) expressed significantly less (p < 0.0001) agreement with this cluster than did the scientists (mean = 2.70, SD = 0.51),
and elementary teachers (mean = 1.98, SD = 0.41) scored significantly lower (p < 0.0001) than secondary teachers (mean = 2.36, SD = 0.49).

Finally, there was a moderate (R = 0.418), significant (p = 0.0001) correlation between traditional science attitudes and traditional science education attitudes among the participants. This correlation confirmed a link between beliefs about science and science education, which Pomeroy viewed as reinforcing the importance of addressing the philosophy of science in science education.

Pomeroy concluded that the elementary teachers in this sample had relatively more contemporary views of the nature of science when compared to the views of the secondary teachers and research scientists. She speculated that their contemporary views may have resulted from the fact the elementary teachers had taken significantly fewer science courses, and so were less likely to be inducted into science methodology as their secondary counterparts. Additionally, Pomeroy suggested that the elementary teachers' views of the nature of science might arise from constructing views about how children learn through reflecting on their own practices.

General Assessments

By the early 1970s researchers recognized the central role that classroom science teachers play in the development of students' views of the nature of science (Lederman, 1992). Accordingly, researchers began to shift their focus from the science curriculum to the teacher as the principle agent in fostering adequate conceptions of the nature of science. Given the recognition that it is impossible to effectively teach what one does not understand, several early investigations sought to assess teachers'
understandings of the nature of science. The ensuing line of research, which includes five studies spanning two decades, are discussed in this review.

In the first of these assessments, Carey and Stauss (1970) investigated the relationship between preservice teachers' understandings of the nature of science and various academic variables, such as the number of college-level science and mathematics courses completed and grades achieved in these respective areas. The sample consisted of 35 preservice secondary teachers and 221 preservice elementary teachers enrolled in the teacher education program at the University of Georgia during the 1967-68 academic year. The researchers collected various academic data for the participants and used the Wisconsin Inventory of Science Processes (WISP) to determine their views of the nature of science. The WISP consists of 93 statements which attempt to measure students' knowledge of the assumptions inherent to the scientific enterprise and various processes of science. Responses are recorded along a three-choice Likert scale, which includes the options of "always or nearly always accurate," "always or nearly always inaccurate," or "didn't know or didn't understand the question." Carey and Stauss reported the WISP subscale scores (Assumptions of Science, with 36 items and the Operations of Science, with 57 items) along with the WISP total scores. Data analysis included calculating descriptive statistics and correlation coefficients for each of 10 academic variables and the WISP total and subscale scores and testing for statistical significance at an alpha level of 0.05.

Results of these analyses indicated that, on average, the preservice secondary teachers had completed better than three times the number of science credit hours
compared to their elementary counterparts (68.0 versus 19.2). The preservice secondary
teachers' also achieved higher mean scores (mean = 68.00, SD = 7.27) than the
preservice elementary teachers 59.84 (SD = 7.25) on the 93-item WISP. However,
Carey and Stauss found no statistically significant relationships between the preservice
secondary teachers' WISP scores and academic variables. Apparently, neither the
amount of college science coursework completed, nor achievement level in science
courses contribute toward the development of conceptions of the nature of science
consistent as measured by the WISP.

A single significant relationship was evident between the preservice elementary
teachers' Operation of Science subscale scores and their total college grade scores, but
the correlation coefficient was quite small (r = 0.142). When the preservice elementary
and secondary teachers were combined, statistically significant correlation coefficients
were obtained between both the total and subset WISP scores and the number of
college credit hours completed in biological (r = 0.300) and physical science (r =
0.349), as well as the total college science hours (r = 0.375). Additionally, the overall
college grade point average showed a significant correlation with the WISP total test (r
= 0.164) and the Operations of Science subset (r = 0.177) scores. Finally, the
statistically significant relationships were seen between the number of high school
science units completed and the WISP total test (r = 0.224), and the Assumptions of
Science (r = 0.149) and Operations of Science (r = 0.228) subset.

Although several statistically significant relationships were found between the
WISP scores and various academic variables for the preservice elementary and
combined teacher groups, Carey and Stauss emphasized that the coefficients were relatively small and unimpressive. The researchers concluded that little, if any relationship exists between the preservice secondary and elementary teachers' science backgrounds and their understandings of the nature of science.

Wood (1972) also used the WISP to assess preservice elementary and secondary science teachers' understandings of the nature and processes of science. Wood reasoned that it was imperative for new teachers entering the teaching profession to possess adequate understandings of these aspects of science, since they were heavily emphasized in the recently developed curricula, e.g., the Biological Sciences Curriculum Study, Integrated Physical Science, and the Physics Science Study Committee. Three research questions guided the investigation:

1. What are preservice elementary and secondary (science) teachers' concepts of the nature and processes of science, as measured by the WISP?

2. What relationship exists between preservice elementary and secondary (science) teachers' concept of the nature and processes of science, as measured by the WISP, and the variables of sex, number of university science credits, number of years of high school science, and the average grade in science at the university level?

3. Is there any difference between university students majoring in elementary or secondary (science) education and their concept of the nature and processes of science, as measured by the WISP instrument?

The sample selected for participation in the study consisted of 443 students enrolled in the elementary and secondary science methods courses in the fall term of
1969 at five Wisconsin State Universities. The WISP was administered by the respective science methods instructors at each of the participating universities before the 3rd week of class. In addition to their responses to the WISP, Wood collected background information for each participant, including (a) sex, (b) teaching specialty, (c) secondary science major, (d) total university science credits, (e) number of years of science taken in high school (grades 9-12), and (f) average grade of all the science courses taken at the university level.

Participants’ WISP scores ranged from a low of 45 to a high of 81, with a mean of 65.89 and a standard deviation of 6.04. The 365 elementary education students’ mean score (65.35) was significantly lower ($p < 0.01$) than that of 78 secondary education students (68.67). It appeared that no specific aspect of the nature or processes of science was grossly misunderstood by the participants. Only eight of the 93 statements were inaccurately answered by over 60% of the participants. WISP items dealing with scientific observations, experimentation, and communication of scientific knowledge were “correctly” answered by over 90% of the participants, and thus, appeared to be especially well understood.

Comparisons of the participants’ background variables to the WISP scores revealed a significant correlation ($p < 0.01$) only between the average grade of university science courses and the WISP score. This correlation was positive ($b = 0.266$), indicating that higher average science grades were associated with higher WISP scores. Wood concluded that little, if any, relationship exists between the factors of sex,
number of university science courses and years of high school science and their knowledge of the nature and processes of science.

Wood listed three implications of these results that warrant further exploration. First, the participants' relatively low average WISP scores may indicate that many preservice elementary and secondary teachers will find it difficult to teach science in accordance with modern philosophies. This conclusion is somewhat surprising, given that the lowest average WISP score had a 70% match with desired responses. Second, the lack of correlation between the number of science courses completed by the participants and their WISP scores indicate that preservice understandings of the nature and processes of science may not be a product of university science courses. Wood recommended a greater focus on the nature and processes of science in these courses, or special courses in which these topics could be addressed. Third, the science methods instructor may have the responsibility to provide opportunities to learn about the nature of science and science processes, since this type of instruction is apparently not occurring in college science courses.

Lederman (1986) pointed out that while many science educators criticized teachers' lack of understanding of the nature of science, the literature lacked a precise definition of what constitutes an "adequate" conception. To provide a partial remedy for this situation, Lederman assessed teachers' and students' understandings of the nature of science in order to compare these understandings to the notion of an "adequate" conception.
Eighteen high school biology teachers from nine schools, along with their students from one 10th-grade biology class, were randomly selected to participate in the study. All participants were following the New York State Regents Biology syllabus in which one of the specified goals was for students to develop an understanding of the nature of science. The 7 female and 11 male teachers averaged over 15 years of teaching experience and each had a minimum of 5 years of experience. Their average class size was 22.72 students and contained a mix of students in terms of race, sex, and socio-economic status.

Teachers' and students' conceptions of the nature of science were assessed by pre- and posttests with the "Nature of Scientific Knowledge Scale" (NSKS) (Rubba, 1976). The researchers administered the pretest during the first week of fall semester and the posttest at the end of the school year in June. Descriptive statistics and t-tests were used to construct profiles and analyze the teachers' and students' understandings of the nature of science.

The NSKS is a 48-item instrument designed to assess a respondent's understanding of scientific knowledge on a five-choice Likert scale. The NSKS reports six subscales that measure the respondent's beliefs about various aspects of the nature of science (amoral, creative, developmental, parsimonious, testable, and unified), in addition to an overall score. The NSKS is scored in terms of the consistency of responses with the premise of each NSKS subscale—a high score indicates high consistency, while a low score indicates low consistency. The maximum score for each subscale is 40 points, while the maximum overall score is 240 points. Alternatively,
scores of 24 points on a subscale or 144 points on the overall score indicate "neutral" positions.

As indicated in Table 3, except for the Parsimonious subscale, students scored higher than the "neutral" position on each NSKS scale. The $t$ tests indicated that students' scores for each scale differed significantly from the "neutral" position. Lederman concluded that the students in his study possessed adequate conceptions of each aspect of the nature of science measured by the NSKS, except for "parsimonious."

Table 3
NSKS Mean Subscale and Overall Scores

<table>
<thead>
<tr>
<th>Subscale/Scale</th>
<th>Pretest Students' Mean Score</th>
<th>Pretest Teachers' Mean Score</th>
<th>Post-test Students' Mean Score</th>
<th>Post-test Teachers' Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>162.74</td>
<td>192.56</td>
<td>166.20</td>
<td>195.06</td>
</tr>
<tr>
<td>Amoral</td>
<td>25.99</td>
<td>33.78</td>
<td>27.26</td>
<td>34.06</td>
</tr>
<tr>
<td>Creative</td>
<td>25.47</td>
<td>31.11</td>
<td>25.98</td>
<td>31.83</td>
</tr>
<tr>
<td>Developmental</td>
<td>28.64</td>
<td>32.44</td>
<td>28.48</td>
<td>31.94</td>
</tr>
<tr>
<td>Parsimonious</td>
<td>22.74</td>
<td>26.78</td>
<td>23.28</td>
<td>26.83</td>
</tr>
<tr>
<td>Testable</td>
<td>30.37</td>
<td>34.50</td>
<td>31.00</td>
<td>35.72</td>
</tr>
<tr>
<td>Unified</td>
<td>29.53</td>
<td>33.94</td>
<td>30.23</td>
<td>34.67</td>
</tr>
</tbody>
</table>
Lederman further noted that teachers scored higher than the "neutral" position on each NSKS scale for both the pre- and posttests. Additionally, the teachers in Lederman's study all exhibited higher NSKS scores than students on each NSKS scale. In contrast to the earlier investigations of Miller (1963) and Schmidt (1967), data from the individual classes indicated that all the teachers scored higher on every scale than did their respective students. Lederman did not report t test results for the teacher mean NSKS scores. However, he stated that as a group the teachers scored significantly higher than the "neutral" conception on every NSKS scale and, therefore, concluded that the teachers possessed adequate conceptions of the nature of science.

Lederman concluded that the results of his study were not in agreement with previous research indicating that neither teachers nor students possessed adequate understandings of the nature of science. He criticized earlier researchers' use of undeclared, arbitrary cut-off points to define "adequacy." According to Lederman, previous researchers may have focused too much on numerical abstractions of students' and teachers' beliefs, rather than illuminating what participants actually believed.

Gallagher (1991) summarized the findings of a series of investigations on science textbooks, preservice and inservice secondary science teachers' understandings of the nature of science, and how this knowledge influenced teaching in secondary schools. Inspection of the glossaries and selected passages from several unnamed biology and physics textbooks revealed strong emphases on vocabulary, principles, and explanations of principles. Efforts to describe how scientific knowledge is formulated and validated were conspicuously absent. These texts generally presented scientific knowledge as
revealed truth. While it was typical for the textbooks to include an initial chapter depicting science as a process of acquiring knowledge, subsequent chapters gave little or no attention to the nature and processes of science.

In order to describe the portrayal of science by secondary science teachers, Gallagher summarized the findings of three unpublished reports of an ethnographic study of 27 teachers from five high schools in two different districts. No demographic information was provided for these teachers. Data were gathered from more than 1,000 hours of classroom observations over a period of 2 years, as well as from formal and informal interviews with teachers and administrators.

The classroom observations showed that all 27 teachers heavily emphasized teaching science content. Scientific principles, relationships, and laboratory experiences received far less attention than terminology, which was the focus of most classwork, homework, and tests. Gallagher emphasized that these teachers were all certified to teach science and that all had at least 10 years of experience as science teachers. Thus, the teachers' stress on scientific facts could not be attributed to misassignments or lack of experience. Instead, Gallagher concluded that the problem was mainly the result of the inadequate education the teachers' received at the university level. Specifically, he criticized content-intensive science courses and the general lack of education in the areas of the history, philosophy, and sociology of science.

To further probe the causes of science teachers' beliefs about the nature of science and their emphasis on teaching the facts of science, Gallagher explored the ways in which prospective science teachers view subject matter. The sample for this analysis
was the prospective secondary science teachers in his required course on science teaching methods. These candidates were well-prepared academically, having completed more than 80 credits of tertiary-level science study at a grade point average of at least 3.2 prior to enrolling in Gallagher's course.

His students' inadequate responses to a series of classroom activities and problems designed to challenge their understandings of familiar scientific phenomena led Gallagher to conclude that these prospective science teachers had not integrated their formal scientific knowledge with common experiences. This lack of integration was presented as the primary reason that science teachers are typically unable to aid secondary science students in learning the nature and processes of science.

In conclusion, Gallagher found that both the prospective and practicing secondary science teachers in his studies had inadequate knowledge of the history and philosophy of science, primarily because they had limited opportunities to study these fields. Additionally, he claimed that the teachers developed distorted views of science because their science education at the university focused on the body of knowledge of science at the expense of emphasizing the processes of science. Finally, the emphasis on factual knowledge in popular secondary science textbooks served to reinforce teachers' distorted views of science. To remedy this situation, Gallagher recommended changes in the preparation of secondary science teachers, including coursework about the history, philosophy, and sociology of science.

King (1991) conducted an investigation to examine preservice teachers' knowledge, beliefs, and attitudes toward history and philosophy of science.
Additionally, the study sought to assess the potential role of history and philosophy of science on the preservice teachers' instructional goals. Thirteen preservice teachers in Stanford University's Teacher Education Program in science participated in the study. All 13 of the participants had completed a bachelor's degree in their subject area specialty and 3 had completed one course in history and philosophy of science.

Data sources consisted of a researcher-generated, open-ended questionnaire and semi-structured interviews. The questionnaire was administered to each of the participants on the first day of their introductory course in curriculum and instruction in science. It consisted of 14 questions, including questions about the participants' educational backgrounds, the nature of science, recognition of key philosophers and historians of science, and their goals as science teachers. The interviews were conducted by the researcher from 1 to 2 weeks after the participants had begun teaching. Eight questions were asked during each interview, covering such topics as what the respondents thought was important to teach in an introductory science curriculum course, what, if any, experiences they had in scientific research, and how they would teach what they had earlier indicated on the questionnaire was most important about their discipline.

The three participants who had completed a history or philosophy of science course answered the questionnaire's philosophical questions with more articulate and reasoned responses. When asked what they thought was most important to teach about their respective scientific disciplines, 11 of the 13 participants answered in general, rather than content-specific terms. Typical among the answers were teaching students
how to learn, problem solve, and become independent thinkers. Only three participants mentioned teaching content/facts as a goal of their science instruction. Nine of the 11 interviewed participants expressed the belief that the history and philosophy of science was an important component of science instruction. According to these students, knowledge of history and philosophy of science can make science more relevant, help students think critically, and show how people can affect science. While these participants believed that history and philosophy of science should be addressed in their instruction, they had no clear understanding of how to teach this way.

Many stated that they had little knowledge of the historical and philosophical knowledge of their scientific disciplines and at least three participants were not even sure what “philosophy” meant. As one participant put it, “I learned science as a collection of facts with no knowledge of how those facts came to be facts...The only thing I feel prepared to do now is to teach my students the facts I learned.”

Responses to the questionnaire indicated that most of the preservice teachers did not enter teaching with the vision of imparting scientific facts to students. Instead, several stressed the social construction of scientific knowledge and subjectivity in science as important to teach. King’s major finding was that these preservice teachers had little or no knowledge of history or philosophy of science. Consequently, most had no clue how to incorporate these fields in their teaching. King recommended sustained study of the history and philosophy of science as undergraduates and in science teacher education courses to remedy the problem. According to King, such instruction would
provide preservice teachers with the necessary knowledge to properly address the
nature of the scientific discipline in the classroom.

**Instrument Validations**

Welch and Pella (1968) compared the nature of science understandings of high
school science teachers and research scientists in their attempt to establish construct
validity for their Science Process Inventory (SPI). The SPI was based upon a set of
elements of scientific processes gleaned from the writings of science educators and
philosophers. These elements were then presented to 14 research scientists, who
established content validity and offered suggestions for improvement. Welch and Pella
based the construction of items for the instrument upon the resulting descriptive outline
of the processes of science.

In addition to the expert judgment on content validity, item analysis of the
responses of 380 students to a pilot version informed the development of the final
version of the instrument. The final version of the SPI consisted of 150 statements
pertaining to the activities, products, and ethics of science to which students are asked
to express agreement or disagreement. Total scores are obtained by summing the
number of agreements with a key based on the aforementioned descriptive outline.

Welch and Pella gathered validity, reliability, and usability information through
analysis of the results obtained by administering the SPI to all of the students (N =
1,283) in two Wisconsin high schools. The researchers used correlation coefficients to
compare the SPI scores to scores obtained on a test of general mental ability (Henmon-
Nelson Test of Mental Ability) and reading ability (the STEP Reading Test) for the
1,040 students who completed all three tests. These comparisons were made to enable the researchers to identify factors or constructs that accounted for variation in the students' SPI test performance.

To establish the reliability of the SPI, Welch and Pella used the Hoyt analysis of variance method. This method yields a conservative estimate of reliability based upon the amount of correlation among the item responses within one test. The resulting reliability estimate was 0.79, which the researchers took as indicating adequate reliability.

The 1,283 high school students achieved a mean score of 107.5, with a standard deviation of 10.4 and a range of 70 to 134. Welch and Pella calculated separate coefficients with the mental ability test for each of the three grade levels represented in the sample of high school students. The resulting coefficients were 0.61 for the 10th-grade students, 0.64 for the 11th-grade students, and 0.62 for the 12th-grade students. Thus, 37% to 41% of the variance in these students' SPI scores could be attributed to variation in the Henmon-Nelson scores.

Welch and Pella completed a similar analysis between the SPI scores and two measures of reading ability. The researchers were forced to use two measures of reading ability because the two participating high schools used different assessments for this construct. The product-moment correlation coefficient between the SPI and STEP Reading Test was 0.65, while that between the SPI and the Iowa Test of Educational Development (reading) was 0.66. Thus, reading ability accounted for approximately 44% of the variance in the SPI scores.
Welch and Pella established construct validity by comparing the mean SPI score of the 1,283 high school students to that of 16 high school science teachers and 19 research scientists. The investigators predicted that the research scientists would achieve higher scores on the SPI than the science teachers, who would in turn achieve higher scores than the high school students. The actual process involved testing the null hypothesis that there would be no significant difference between the mean scores of the high school students, science teachers, and research scientists. SPI mean scores were 107.5 for the high school students, 129.4 for the secondary science teachers, and 135.0 for the research scientists. Welch and Pella used a one-way ANOVA to determine whether the mean SPI scores (107.5 for the high school students, 129.4 for the secondary science teachers, and 135.0 for the research scientists) were significantly different. The ANOVA indicated that there was a significant difference in the means at the alpha level of 0.05. Subsequent post hoc tests (Scheffe's) demonstrated that all three means were significantly different at the alpha level of 0.05. On the basis of these data, the researchers rejected the null hypothesis and concluded that construct validity of the SPI was adequately supported.

Rubba and Anderson (1978) developed and validated the Nature of Scientific Knowledge Scale (NSKS) to serve as an assessment tool for secondary school students' understandings of the nature of scientific knowledge. The instrument was administered to college freshmen in order to establish construct validity and, therefore, provides an assessment of adult understanding of the nature of science.
Rubba and Anderson based the NSKS on the first of Showalter's (1974) seven-dimension definition of scientific literacy: The scientifically literate person understands the nature of scientific knowledge. Showalter listed nine factors under this dimension; however, Rubba and Anderson were able to consolidate it into a more concise, six-factor model of scientific knowledge. These six factors included the amoral, creative, developmental, parsimonious, testable, and unified characteristics of scientific knowledge. Content validity of the model was supported by the endorsement of three science philosophers, who agreed that the model reflected the prominent attributes of scientific knowledge generally held among science philosophers and scientists.

Next, 12 to 14 positive affect item statements and the same number of negative affect item statements were written for each of the six factors of the model. Response choices were aligned along a five-choice Likert scale. Refinement of these original statements was informed by observing sixth grade students read the statements aloud and noting the words that they stumbled on, mispronounced, or stated that they did not understand. Further refinement was effected through a form and content evaluation provided by 10 science education doctoral students, who checked that the positive item statements were resonant with their respective model factors and that the negative item statements were consonant with their respective model factors.

The resulting 114-item instrument was administered to a group of 31 high-science ability high school juniors. These students identified problems with some of the items, whose wording was subsequently changed. Next, a panel of nine experts, including science philosophers, science educators, scientists, high school teachers, and a
psychometrician, judged the content validity of the 114 item statements against the
original Nature of Scientific Knowledge model. After two rounds of revision, 72 item
statements were judged to measure the respective factor in the model of the nature of
scientific knowledge by seven or more of the panel members.

These 72 items were then attached to a five-point Likert scale and randomly
arranged as a tryout instrument. The tryout instrument was administered to 674 students
in a midwest high school. The discriminating quality of each item was assessed by
calculating a Pearson product-moment correlation coefficient between each item and the
total score for the 12 items in each subscale. These correlations ranged from \( r = 0.62 \) to
\( r = 0.09 \). The most reliable combination of items were identified by picking the
combination of items with the highest mean coefficient alpha. The highest mean
coefficient alpha was obtained with the four positive and four negative items with the
highest item-to-factor item score correlation for each model factor. These 48 items were
randomly arranged to form the final version of the Nature of Scientific Knowledge Scale
(NSKS).

Reliability of the NSKS was assessed by calculating both coefficient alphas and
test-retest coefficients. The coefficient alphas were calculated for the responses of a
variety of student responses, including high school students (grades 9 - 12) and college
chemistry, philosophy of science, and nonscience majors. The resulting coefficients
ranged from 0.65 to 0.89. The test-retest reliability was established using two groups of
high school students, 52 freshmen general science students, and 35 senior advanced
chemistry students. Six weeks elapsed between test administrations. The Pearson
product-moment correlation coefficients calculated between the test and retest were $r = 0.59$ and $r = 0.87$, respectively.

Construct validity of the NSKS was examined by assessing the anticipated difference in scores between two groups of college freshmen. The first of these groups consisted of 40 students who had completed an introductory philosophy course. The second group was comprised of 125 freshmen biology students at the same university who had not completed any history of science or philosophy of science coursework. The mean scores of the two groups were compared using $t$ tests for independent samples. The group of freshmen who had studied philosophy of science had higher total mean scores (170.80, $SD = 15.47$) than did the group of biology students (164.99, $SD = 12.73$). These differences were significant at the alpha = 0.05 level. Furthermore, the developmental, parsimonious, testable, and unified mean subscale scores for this group were also significantly higher than those of the biology students at alpha = 0.05. Rubba and Anderson accepted these findings as evidence of NSKS construct validity.

Cotham and Smith (1981) developed the Conceptions of Scientific Theories Test to quantitatively assess teachers' conceptions of the tentative nature of scientific theories. The structure of this instrument was dictated by the developers' concern that previously existing instruments were based on single (supposedly enlightened) interpretations of the nature of science. The COST was designed to avoid this bias by providing nonjudgmental acceptance of four alternative conceptions of science, with no single point of view being considered the "correct" one.
The COST consists of 40 items in four subscales. Each subscale corresponds to a particular aspect of scientific theories, including Generation of Theories (inductive versus inventive), Testing Theories (conclusive versus tentative), Ontological Implications of Theories (realist versus instrumentalist), and Theory Choice (objective versus subjective). Individual items are scaled using the following modified Likert scale: 1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree. Respondents' relative tentative and revisionary conceptions of science are determined by calculating the means of items in each contrasting theory alternative.

The COST differs from other instruments by providing a theoretical context for each of the four item-sets by prefacing each set with a brief description of a scientific theory and some episodes drawn from its history. The items following each theory description refer back to the description. The four theoretical contexts are: (a) Bohr's theory of the atom, (b) Darwin's theory of evolution, (c) Oparin's theory of abiogenesis, and (d) the theory of plate tectonics. A fifth "context" contains items that refer to general characteristics of scientific theories and is, therefore, not prefaced by a description.

Philosophy literature, including the works of Hempel (1966), Kuhn (1970a,b), Martin (1970), and Nagel (1961), served as the primary source of the constructs represented by the subscale items. In keeping with their criterion of sensitivity to multiple conceptions, Cotham and Smith developed two alternatives for each subscale. In addition to the philosophic literature, information from interviews and questionnaires submitted to nine preservice and inservice elementary school teachers informed the
wording of subscale items. Cotham and Smith provided no information about these interviews and questionnaires.

Eighty items were initially written and divided into pilot forms A and B. These pilot tests were distributed among 56 college physical science students, most of whom were elementary education majors. Pearson product-moment correlation coefficients between item and subscale were calculated and used to select the 40 items exhibiting the strongest relationship to the respective subscales. These items comprised the final form of the COST.

Cotham and Smith reported two different procedures for establishing the construct validity of the COST. The first procedure dealt with the COST's ability to discriminate between the contrasting groups of elementary education majors, college chemistry students, and college philosophy of science students at a midwestern university. The sample of elementary education majors consisted of 50 students enrolled in a course in physical science for elementary majors. The sample of chemistry students consisted of 30 volunteer chemistry and chemical engineering students. The philosophy student sample consisted of 30 volunteers from philosophy of science courses.

Cotham and Smith used a one-tailed $t$ test to determine if the elementary education majors' subscale scores were significantly lower than those of the other groups. These comparisons were made in two steps. First, the elementary majors' scores were compared to the philosophy students' scores. Table 4 presents the results of this analysis.
Table 4
Comparison of Subscale Means for Philosophy and Elementary Education Students

<table>
<thead>
<tr>
<th>Scale</th>
<th>Group</th>
<th>Mean (SD)</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory Choice</td>
<td>Philosophy Students</td>
<td>2.90 (0.39)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elementary Education Students</td>
<td>2.64 (0.24)</td>
<td>3.11*</td>
</tr>
<tr>
<td>Generation</td>
<td>Philosophy Students</td>
<td>2.49 (0.44)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elementary Education Students</td>
<td>2.20 (0.30)</td>
<td>3.26*</td>
</tr>
<tr>
<td>Testing</td>
<td>Philosophy Students</td>
<td>3.05 (0.49)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elementary Education Students</td>
<td>2.50 (0.30)</td>
<td>5.61*</td>
</tr>
</tbody>
</table>

Note. *p < 0.01

Next, the elementary students' scores were compared to the chemistry students' scores (Table 5). The mean scores for the COST subscales ranged from a low of 2.18 (out of 4) for the chemistry students on the Generation subscale, to a high of 3.05 for the philosophy majors on the Testing subscale. All elementary student mean scores were significantly lower than the comparison groups, except for the Generation subscale comparison with the chemistry students. Cotham and Smith did not specify why the participants' scores on the Ontological Implications subscale were not used in these comparisons.
The second approach to establishing construct validity of the COST involved using a multitrait-multimethod matrix developed by Campbell and Fiske (1959). In this procedure, scores for each trait-method unit are correlated with scores for all other trait-method units. For the COST, the traits are the four constructs upon which the subscales are based, while the methods are the five different theoretical contexts in which the traits are measured.

Results of the analysis indicated that all subscales except Theory Choice had correlation coefficients that satisfied the above requirements for discriminant validity. The percentages of relevant coefficients for the Theory Choice subscale were comparatively low. However, Cotham and Smith chose to keep this subscale as part of the COST, due to the fact that no other instruments assessed understandings of the issue embodied in the Theory Choice subscale.

Table 5
Comparison of Subscale Means for Chemistry and Elementary Education Students

<table>
<thead>
<tr>
<th>Scale</th>
<th>Group</th>
<th>Mean (SD)</th>
<th>t value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>Chemistry Students</td>
<td>2.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elementary Education Students</td>
<td>2.20</td>
<td>-0.13</td>
</tr>
<tr>
<td>Testing</td>
<td>Chemistry Students</td>
<td>2.91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Elementary Education Students</td>
<td>2.50</td>
<td>4.29*</td>
</tr>
</tbody>
</table>

Note: *p < 0.01
Due to the fact that a considerable range of variance existed for the three groups who piloted the COST, Cotham and Smith used the standard error of measurements as a measure of the instrument's reliability. The relatively low values of the standard error of measurement (all less than 0.3) indicated that the COST possessed adequate reliability. Cotham and Smith concluded that the COST should prove to be a useful and valid measure of teachers' conceptions of the tentative and revisionary nature of science.

Research on Decision Making on Science and Technology Based Issues

Only four published studies explore how adults and adolescents make decisions on complex science and technology based issues. The first (Zeidler & Schafer, 1984) examines the factors that college students use to make moral judgments on environmental issues. The second and third studies (Fleming, 1986a,b) examine the reasoning of adolescents on science and technology based issues. The fourth and final study (Lederman & O'Malley, 1990) examines adolescents' understandings of the tentative nature of scientific knowledge and the influence of these understandings on their personal decisions regarding scientific claims.

Zeidler and Schafer (1984) conducted a study examining how science content knowledge, moral reasoning ability, attitudes, and past experiences relate to the formation of moral judgments on environmental social issues. The research was guided by three principle objectives. The first objective was to determine if environmental science majors exhibit higher levels of moral reasoning on nontechnical environmental social issues than on general social issues and if they reason at higher moral levels on environmental problems than nonscience majors. This objective was based on the work
of Piaget (1972) and Iozzi (1976), who theorized that individuals tend to reason at more sophisticated levels about topics in which they have more knowledge, interest, and experience. The second objective was to examine the extent to which possible mediating factors (environmental attitudes, knowledge and personal experience) account for the differences in moral reasoning. A third objective was to examine how such mediating factors are used in arriving at a moral decision.

Zeidler and Schafer chose subjects from two distinct groups at Syracuse University. The first group was comprised of 86 3rd- and 4th-year environmental science majors, 23 of which were female and 63 male. The second group consisted of 105 1st- through 4th-year nonscience majors and included 66 females and 39 males. The researchers did not specify how these subjects were selected.

The investigation consisted of both quantitative and qualitative approaches to address the research objectives. In Phase One, the researchers used a multiple posttest only design with predicted higher order interactions to determine if environmental science majors exhibited higher levels of moral reasoning on nontechnical environmental social issues than on general social issues. Additionally, the extent to which possible mediating factors accounted for differences in moral reasoning was examined during this initial phase. Phase One data collection consisted of the subjects' responses to four instruments:

1. The Defining Issues Test (DIT), which measures moral reasoning on general social problems by having subjects rank statements reflecting different levels of moral judgment with regard to stories presenting social dilemmas.
2. The Environmental Issues Test (EIT), which measures moral reasoning on specific nontechnical environmental issues in a format similar to the DIT.

3. The Test of Ecology Comprehension (TEC), which measures knowledge of interrelated environmental concepts.

4. The Ecology Attitudes Inventory (EAI), which measures environmental attitudes, including verbal commitment, actual commitment, and affect.

Zeidler and Schafer performed a 2 x 2 repeated measures ANOVA for unbalanced data to examine group differences (environmental majors versus nonscience majors) in moral reasoning applied to the two different contexts (social and environmental). The researchers also performed stepwise and hierarchical multiple regression analyses on the scores of the four instruments to determine the extent to which the aforementioned mediating factors accounted for differences in moral reasoning.

In Phase Two of the study, the researchers observed and identified mediating factors in conversations as people formed moral judgments. Paired subjects were asked to work together in order to decide which of their responses would be placed on a single EIT questionnaire representing both their opinions as one. In order to stimulate conversation, the researchers purposively selected the 11 subject pairs so that they would have similar attitudes toward the environment, but different levels of moral reasoning. Each pair's conversation was tape recorded and transcribed for later analysis.

Results of the Phase One analyses indicated that science majors did not reason at higher levels than nonscience majors on the general measure of moral reasoning (DIT).
However, the science majors demonstrated significantly higher levels of moral reasoning in their responses to the nontechnical environmental issues (EIT). Correlated with these higher reasoning levels were science majors' more positive attitudes toward the environment and greater commitment to and comprehension of ecology as compared to the nonscience majors. These results led the researchers to conclude that the reasoning used in resolving science-oriented moral dilemmas depends on attitudes, commitment and comprehension in addition to general reasoning ability.

In Phase Two of the research, pairs of students possessing similar attitudes and commitment toward the environment, but who reasoned at different levels when they responded individually to the EIT issues, were challenged to develop a single, consensus response to the same issues. Analysis of the ensuing lively discussions demonstrated that, as a result of such encounters, students with lower initial reasoning levels tended to accept the higher reasoning level of their partners.

Zeidler and Schafer identified four reasoning patterns exhibited by the students as they engaged in these argumentative encounters. In "causistical reasoning," students confused matters of fact with the hypothetical. Students who exhibited this type of reasoning subjectively argued about whether a particular issue statement occurred, rather than objectively deciding whether a particular issue was important in itself. Many students exhibited "normative reasoning," in which they referred to previous personal experiences when arguing their point of view. A third reasoning pattern identified by the researchers was "resolving means and ends." Students who exhibited this reasoning pattern tended to view the environmental dilemmas in terms of resolving whether
particular actions justified the intended results. Finally, some individuals who exhibited higher moral reasoning tended to view EIT dilemmas reflecting higher stages of moral reasoning as being "broader" and "more abstract" than the dilemmas reflecting conventional stages of moral reasoning.

Given the results of Phase One of the investigation, Zeidler and Schafer suggested that science teachers who wish to prepare students to resolve moral dilemmas regarding science and social policy need to do more than teach science content. They should endeavor to help students develop positive attitudes, and a care and concern for science-oriented social issues, as well as a commitment to the resolution of these issues. An implication of the Phase Two results was that students' reasoning abilities may be improved by encouraging students with different lines of reasoning to develop consensus resolutions of moral dilemmas. Additionally, the researchers suggested that by being cognizant of inhibiting reasoning patterns, (i.e., causistical reasoning and normative reasoning), teachers can make students aware of their attempts to redefine the problem and encourage students to examine the applicability of personal experiences to the dilemma being considered. Promoting such metacognition in students holds promise for improving their abilities to address social dilemmas at higher moral levels.

Fleming (1981a) explored the nature of the interaction between adolescents' knowledge of the physical and social worlds when making decisions on STS related social issues. The purposes of the investigation were to identify the domains of reasoning that adolescents use when making decisions on STS related social issues and to explore any relationships between the domains.
Thirty-eight adolescents who had completed introductory courses in high school chemistry and biology participated in the study. The researcher did not report any demographic information for the participants other than that their mean age of 17.3 years. He used semi-structured interviews focusing on one of two scenarios dealing with nuclear power plants and genetic engineering. Each interview was audio-recorded and transcribed. Analysis of the transcriptions was performed by organizing the justification statements of the participants into categories. Some of these categories were provided by a scoring manual (Davidson, Turiel, & Black, 1983), while others were created by the researcher from the participants' responses. These categories were tested by three raters, who achieved inter-rater reliabilities ranging from 84% to 96% on a random selection of 20 interview transcripts.

The results of this analysis indicated that the primary domain of reasoning for these adolescents lie within the area of social cognition. The two social cognitive domains used by the participants were (a) the moral domain, which emphasizes concepts regarding the welfare and rights of others and justice, and (b) the personal domain, which emphasizes self preservation, respect for individuality, and control over one's physical state.

Fleming classified 70% of the participants as moral reasoners, with concern for the potential for harm to others as the central reason for the classification. Interestingly, these individuals tended to view uncertainties in scientific data as increasing the risk of harm to others. Therefore, once they perceived potential harm to others in an issue, additional scientific data offered by the researcher were considered irrelevant. The
remaining 30% of the participants were classified as personal reasoners. For these individuals, there was a strong belief that individuals should make their own decisions about risk. Harm to others was not a major concern. Rather, the issues of personal, especially economic, benefits dominated.

To further explore the adolescents' reasoning during the interviews, Fleming attempted to force the participants to coordinate their views of the personal issue of self-determination and the moral issue of harm to others through the use of "salient events." The salient event involved offering each participant a simulated "radioactive" device to wear or a flask of "bacteria" to take home to store in the refrigerator. The simulation provided for a test of thought into action by comparing the hypothetical position proposed by the participant to their actions. For participants who were already reasoning in the moral domain, the salient event had virtually no effect and served simply to confirm the correctness of their opinion. Personal reasoners, however, were highly influenced by salience. For these individuals, the salient event appeared to prompt a reexamination of the hypothesized perspective that others' safety was their own business and forced the participants to reason morally about the science and technology based issues.

In conclusion, Fleming asserted that because students approach science and technology based issues primarily from the domain of social cognition, social cognition should be the starting point for their instruction. It is counterproductive to ask students to withhold social judgments until they "know more," since they are already dealing with
the issue from a social cognitive domain. Thus, future research should reexamine the traditional emphasis on content knowledge in science education.

In Part II of his investigation into reasoning in science and technology based issues, Fleming (1986b) explored how adolescents use nonsocial cognition when analyzing science and technology based issues. This second part of the investigation used the same participants and methodology as the previous study.

Fleming's analysis of the data generated three categories of statements within the nonsocial domain from the interview transcripts. These included (a) physical world (science content) statements, (b) science terminology statements, and (c) nature of science and scientists statements. It should be noted that the "nature of science" statements in the third category were more aligned with the characteristics and motivation of scientists than with the nature of science as defined at the beginning of this review. So few participants made statements about the physical world that Fleming considered these responses insignificant. To compensate for the possibility that lack of science content knowledge limited students' responses about the physical world, Fleming provided information packets for the participants' use during the interviews. However, none of the students chose to use these packets.

Student arguments involving science terms as a major component were categorized as science terminology statements. A large majority of students (91%) used these types of arguments. When Fleming questioned about the source of the terminology, every student identified school as the source of the terms that they used. However, every student qualified their responses by answering in the negative when
asked whether school was the source of useful information. Fleming also probed students' perceptions of the accuracy and completeness of scientific data. Ninety-four percent of the students believed that they had complete data (i.e., they did not need to use the information packets), yet in contradiction, 96% said they needed more information. Fleming believed that students rejected the information packet while wanting more information because they viewed the current data as incomplete and inaccurate. More information would result in more accuracy, but the factual knowledge must be completely true. In other words, students were only willing to alter their decisions if the added data were 100% true, with "true" being equivalent to information that the students perceived as useful in addressing the issue at hand.

In defending their positions on the science and technology based issues during the interviews, large percentages of participants (96%) also used statements about science and scientists. In general, the students appeared to view scientists as the finders and keepers of true (i.e., useful) facts. When Fleming asked the students what they thought scientists would say about the two issues, they were fairly evenly split in saying that the scientists would favor or oppose them. The scientists were viewed as being in favor of the nuclear power and genetic engineering plants for two reasons: career (67%) and the advancement of science and technology (33%). Students viewed scientists who opposed the two plants as having an understanding of the potential harm they could cause. When asked what professionals in nonscientific fields would say, the students unanimously replied that they would oppose both issues on the grounds that these professionals are more concerned with human effects than scientists are.
Based on these responses, Fleming concluded that students rarely, if ever, use knowledge of the physical world when analyzing and discussing science and technology based issues. School science, which emphasizes knowledge about the physical world, is not a source of useful information. Instead, students use their knowledge of scientists and the scientific enterprise in their considerations of science and technology based issues. The implication of these results is that to be useful to students, curricula dealing with science and technology based issues must emphasize the nature, strategies, and limitations of science. Further, the human qualities of science should be emphasized so that students can better understand science as a human endeavor.

Lederman and O'Malley (1990) explored secondary students' beliefs about the tentativeness of scientific knowledge, the sources of these beliefs, and the impact of these beliefs on their personal and societal decisions. The students of one class from each of the four science courses offered in a small, rural, western Oregon high school were selected to participate in the study. A total of 69 participants spanning grades 9-12 were selected; however, complete data were available for only 55 of these participants.

Students in the selected classes were asked to complete an open-ended questionnaire during the second week of the school year. The seven item open-ended questionnaire was designed to assess beliefs about the tentative nature of scientific knowledge with respect to each of the four "dichotomies" previously documented by Cotham and Smith (1981). The researchers analyzed the questionnaire responses by categorizing them with respect to their relation to tentative or absolutist views of science. In order to identify any changes in the students' beliefs, participating students
were asked to complete a posttest of the same questionnaire during the last month of the school year. Interestingly, the researchers did not ask the science teachers to specifically address the tentative nature of scientific knowledge or to purposively alter their normal instruction in the four science classes. The posttests were simply used to identify students whose views might have changed, regardless of the specific teachers and/or instructional approach.

Next, the researchers reviewed the completed questionnaires and selected a sample of 20 students who matched the criteria of being highly verbal, representative of each grade/subject level, holding the tentative/absolutist views of science, and whose beliefs had/had not changed toward a more tentative view. This stratified sample was then interviewed in order to (a) validate the questionnaire, (b) identify the source(s) of each student's beliefs about science, (c) elicit descriptions of any experiences which may have changed each students' beliefs, and (d) assess how students' views of the tentative nature of scientific knowledge affect their personal and societal decisions. While the interviews were flexible, a common set of questions were asked regarding each of the specific items on the questionnaire. These questions focused on when the participants learned the answers they wrote, whether their views had changed, and what caused the change. Other questions focused on the participants' meaning of the word "prove" and what suggestions they could give teachers about how best to teach the participants' beliefs about science. Finally, students who had expressed a tentative view were presented with a list of scientific claims that have recently changed and asked whether such scientific claims ever caused them to change what they eat, drink, or do.
The pretest data indicated that the participants' views were mixed. Responses to the first and fourth questions tended toward a tentative view, while responses to questions two and three were more aligned with an absolutist view (Table 6). The researchers suggested that the equivocal results indicated that students had compartmentalized their views with respect to the type of scientific knowledge, that their views were in a state of transition, or that the paper and pencil questionnaire by itself was invalid. Responses to the posttest indicated a shift to a more tentative view of scientific knowledge, especially in regard to question #2.

During the course of the interviews, the participants were asked to explain their answers to the questionnaire items and whether they would change any of their responses. None of the 20 interviewed students chose to make any changes. Lederman and O'Malley concluded that students had correctly interpreted the intent of the

<table>
<thead>
<tr>
<th>Question</th>
<th>Absolute</th>
<th>Tentative</th>
<th>Unclear</th>
<th>No Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre%</td>
<td>Post%</td>
<td>Pre%</td>
<td>Post</td>
</tr>
<tr>
<td>1</td>
<td>21.8</td>
<td>4.3</td>
<td>74.5</td>
<td>92.8</td>
</tr>
<tr>
<td>2</td>
<td>54.5</td>
<td>34.8</td>
<td>18.2</td>
<td>47.8</td>
</tr>
<tr>
<td>3</td>
<td>5.09</td>
<td>52.2</td>
<td>5.5</td>
<td>8.7</td>
</tr>
<tr>
<td>7</td>
<td>12.7</td>
<td>14.5</td>
<td>50.9</td>
<td>58.0</td>
</tr>
</tbody>
</table>
questionnaire items and, therefore, it possessed face validity as a measure of students' beliefs about the tentative nature of scientific knowledge.

On the other hand, it became apparent during the interviews that the researchers did not always correctly interpret the students' responses. For example, the researchers had concluded from the questionnaire data that many of the students possessed absolutist views of scientific laws due to their use of the "proven." When asked about their usage of this term in the interviews, it became clear that students did not mean to imply that scientific laws were proven in the literal sense of the word. Rather, they used the word to indicate that laws had more empirical support than theories. The critical implication for this finding is that differences in language usage by researchers and subjects may lead to misinterpretations, putting into question the results of all nature of science assessments that used paper and pencil instruments as the sole data source.

Most students were unable to provide specific sources when asked about the pre- to posttest change, if any, in their views of the tentative nature of scientific knowledge. What sources were listed included reflection on subject matter, outside reading, examples presented in class, and completing the questionnaire. This last source indicated a testing effect. Additionally, several students indicated that they were unable to comprehend the tentative nature of scientific knowledge until they had the opportunity to learn specific examples in high school. Thus, students believed that they needed a substantial knowledge base about science before they would be able to consider questions about the nature of science.
When asked how they responded to scientific claims, given their understanding of the tentative nature of scientific knowledge, each of the interviewed students indicated that they would need more proof or certainty before they would change their eating habits or lifestyles. As one student put it, "I won't go out and play with nuclear waste, but I will still eat my twinkies." The students apparently did not base decisions about how to conduct their daily lives on relevant subject matter knowledge (in this case, the tentative nature of scientific knowledge). This finding, which is consistent with that of Fleming (1986b), calls into question the ultimate goal of nature of science instruction and scientific literacy; i.e., to produce citizens capable of making reasoned choices on STS based issues.

Discussion and Conclusions

The studies examined in this review provide a fairly consistent assessment of adults' conceptions of the nature of science that spans three decades. The overall percent mean scores that the various groups achieved on the instruments ranged from a low of 60% to a high of 90%, with a median of 70% (Table 7). Following is a brief analysis of the individual groups assessed in these studies.

In the comparison studies, undergraduate science majors generally scored higher on quantitative assessments of their understandings of the nature of science than did nonscience majors (Cotham & Smith, 1981; Rubba & Anderson; 1978). One exception was philosophy majors, who often outscored both science majors and nonmajors (Cotham & Smith, 1981; Kimball, 1967-68; Rubba & Anderson; 1978). Scientists often fared well on these assessments and in fact, were sometimes used as the standard to
Table 7
Comparison of Results of Assessments of Adults' Understandings of the Nature of Science

<table>
<thead>
<tr>
<th>Researcher(s)</th>
<th>Adult Sample (n)</th>
<th>Instrument</th>
<th>Total Mean Score as a Percentage of Points Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behnke (1961)</td>
<td>scientists (70) physical science teachers (200)</td>
<td>researcher-developed 50-item survey</td>
<td>n/a</td>
</tr>
<tr>
<td>Miller (1963)</td>
<td>biology teachers (421)</td>
<td>TOUS 60 items, 60 points possible</td>
<td>biology teachers = 73%</td>
</tr>
<tr>
<td>Schmidt (1967)</td>
<td>preservice secondary teachers (29)</td>
<td>TOUS 60 items, 60 points possible</td>
<td>preservice secondary teachers = 80%</td>
</tr>
<tr>
<td></td>
<td>secondary science teachers (n/a)</td>
<td></td>
<td>secondary science teachers = 76%</td>
</tr>
<tr>
<td></td>
<td>preservice elementary teachers (43)</td>
<td></td>
<td>preservice elementary teachers = 68%</td>
</tr>
<tr>
<td></td>
<td>scientists (116)</td>
<td></td>
<td>scientists = 85%</td>
</tr>
<tr>
<td>Kimball (1967-68)</td>
<td>science teachers (78)</td>
<td>NOSS 29 items, 58 points possible</td>
<td>science teachers = 61%</td>
</tr>
<tr>
<td></td>
<td>philosophy majors (87)</td>
<td></td>
<td>philosophy majors = n/a</td>
</tr>
<tr>
<td></td>
<td>1969 (24)</td>
<td></td>
<td>1984 = 67%</td>
</tr>
<tr>
<td>Pomeroy (1993)</td>
<td>scientists (71)</td>
<td>researcher-developed 50-item questionnaire</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>elementary teachers (60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>secondary teachers (49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carey &amp; Stauss (1970)</td>
<td>preservice secondary teachers (35)</td>
<td>WISP 93 items, 93 points possible</td>
<td>preservice secondary teachers = 73%</td>
</tr>
<tr>
<td></td>
<td>preservice elementary teachers (221)</td>
<td></td>
<td>preservice elementary teachers = 64%</td>
</tr>
<tr>
<td>Wood (1972)</td>
<td>preservice elementary teachers (365)</td>
<td>WISP 93 items, 93 points possible</td>
<td>preservice elementary teachers = 70%</td>
</tr>
<tr>
<td></td>
<td>preservice secondary teachers (78)</td>
<td></td>
<td>preservice elementary teachers = 74% range = 48% - 87%</td>
</tr>
<tr>
<td>Lederman (1986)</td>
<td>secondary biology teachers (18)</td>
<td>NSKS 48 items, 240 points possible</td>
<td>secondary biology teachers = 81%</td>
</tr>
<tr>
<td>Gallagher (1991)</td>
<td>secondary teachers (27)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
which other groups were compared (Schmidt, 1968; Welch and Pella, 1968). However, this finding was not supported in the Kimball (1967-68) and Pomeroy (1993) investigations, in which the scientists achieved lower scores than other groups. Preservice elementary teachers consistently scored lower than the groups they were compared to (Carey & Stauss, 1970; Cotham & Smith, 1981; Schmidt, 1967; Wood, 1972). Inservice elementary teachers, on the other hand, were found in the Pomeroy (1993) study to possess understandings more in line with contemporary views of the nature of science than either secondary teachers or scientists. Secondary science teachers scored above 70% on their respective nature of science assessments in all but the Kimball (1967-68) investigation.
The science teacher scores on the various instruments warrant further attention. Ever since these assessments began, science educators have used these studies to criticize science teachers' knowledge of the nature of science (e.g., Billeh & Hassen, 1975; Carey & Stauss, 1970; Miller, 1963; Schmidt, 1967). While the science teachers' scores of about 70% on these instruments certainly leave room for improvement, they do not reflect the crisis or deplorable state of affairs that many commentators (and even the researchers in these studies) have used them to support. As Wood put it, "no specific area concerned with the nature of science or processes of science is grossly misunderstood" (Wood, 1972, p. 78). Curiously, some researchers were critical of their participants' knowledge of the nature of science, even when they achieved mean scores well over 70% on their respective assessment instruments (Schmidt, 1967; Miller 1963).

The readiness of such researchers to criticize teachers' achievement on these instruments seemingly no matter what they score appears to reflect a bias. Lederman (1986) blamed the problem on the failure of researchers to specifically define what they mean by "adequacy." He went on to describe two criteria for any definition of "adequacy" in regard to teachers' knowledge of the nature of science: "First, the actual beliefs of teachers must be evaluated... Secondly, the sine qua non of instruction [teachers can only teach what they understand] should lead one to compare teachers' conceptions with those of their students" (Lederman, 1986, p. 97). Using this comparison as a criterion for adequacy, the situation does not appear so bleak. In fact, every study comparing students' and teachers' beliefs about the nature of science has
reported higher scores for teachers than for the students in their own classrooms (i.e., Lederman, 1986; Miller, 1963; Schmidt, 1967).

Thus, it appears that inservice science teachers, philosophy majors, and practicing scientists consistently achieved respectable scores on past assessments of nature of science beliefs. It is important to remember, however, that most of these assessments used paper and pencil instruments as the sole data source. With the education research community's current embrace of qualitative techniques, the validity of such quantitative assessments has come into question. (Lederman, Wade, & Bell, 1998). Specifically, paper and pencil instruments have been criticized on the grounds that each one assumes its interpretation of science to be an enlightened view, despite the lack of consensus among scholars as to the definition or characterization of the nature of science (Cotham & Smith, 1981; Lederman, Wade, & Bell, 1998). Another critical concern about "traditional" assessments of nature of science conceptions has to do with both respondents' interpretation of items and researchers' interpretations of their responses. For example, Aikenhead, Ryan, and Desautels (1989) noted that with most paper and pencil instruments used to assess the nature of science it is simply assumed that respondents will interpret the test items in a manner consistent with the instrument developers. To the extent to which this assumption is untrue, the validity of the instrument comes into question. Although not a new insight, the Lederman and O'Malley (1990) investigation clearly highlighted the other side of this problem. They documented discrepancies between their own interpretations of students' written responses and the interpretations that surfaced from actual interviews of the same
students. This finding was timely, as it occurred when educational researchers were making a serious shift toward more qualitative, open-ended approaches to assessment of individuals' beliefs and understandings in general.

What appears to be recognized is that while paper and pencil instruments can reveal something about individuals' views of the nature of science, they cannot tell researchers everything they would like to know. Often, the significant question is not whether a person's view of the nature of science conforms to a particular espoused viewpoint, but rather, what are the limits of the person's understandings and how do their understandings affect their decisions and behaviors. It is now generally accepted that these questions require more detailed descriptions of a person's beliefs than paper and pencil instruments alone are able to provide.

Instrumentation is not the only concern with these investigations. Many researchers over-generalized their results, despite the fact that they used small, nonrepresentative samples. Over-generalization is especially common for the studies involving preservice and inservice teachers, where researchers typically described science teachers as a whole as possessing "inadequate" understandings, despite the use of samples as small as a single science methods course. It may make more sense to treat these isolated, nonrandom samples as populations in themselves, rather than samples of the population of science teachers as a whole. This view would better reflect current understanding of the impact of the individual instructor (Lederman, 1992; Trent, 1965) and the idiosyncrasies of the classroom experience on students' conceptions.
Most importantly for the purposes of this review, it should be noted that not one of these investigations into adult conceptions of the nature of science addressed the reason for learning the nature of science in the first place. As far as the current literature is concerned, the goal of adults using their understandings of the nature of science to inform their decisions on science and technology based issues remains an untested assumption.

The four investigations on decision making regarding science and technology based issues provided somewhat conflicting views of the role of content knowledge. In the Fleming (1986a, 1986b) studies, secondary students rarely, if ever, used science content knowledge in their analyses and discussions of science and technology based issues. Instead, their discussions focused on their perceptions of the goals and motivations of scientists. In the Zeidler and Schafer (1984) study, science majors reasoned at higher levels on environmental issues than did nonmajors. This was partly related to their greater comprehension of ecology. However, their reasoning levels appeared to be closely related to positive attitudes and greater commitment toward the environment, as well.

Lederman and O'Malley's (1990) investigation is the only one that specifically explored the role of the nature of science in making decisions on science and technology based issues. In their study, even students who had good understandings of the tentative nature of scientific knowledge wanted absolute knowledge before they would make changes in their daily lives. Thus, students' knowledge of the nature of science did not appear to impact their decision making.
The results of these studies provide preliminary evidence that, while content knowledge may play a role, it is not the primary determinant of one's decision making on science and technology based issues. If the nature of science is considered content knowledge as argued in Chapter I, then these investigations leave room for doubt regarding the role that the nature of science plays in decision making on science and technology based issues, especially in light of the Lederman and O'Malley (1990) investigation. Whether individuals actually use their knowledge of the nature of science when making decisions on complex science and technology based issues is a critical question that requires further investigation.

Recommendations

The literature examined in this review indicates a need for research assessing the influence of the nature of science on science and technology based issues. First, few studies have explored decision making on science and technology based issues. Those that have explored such decision making either have not addressed the influence of individuals' understandings of the nature of science, or in the case of the Lederman and O'Malley (1990) study, have only investigated the influence of a single aspect of the nature of science. Second, the research regarding adults' understandings of the nature of science has produced mixed results, possibly due to the prevailing use of quantitative assessments. Before any confidence can be placed in the anticipated outcome of nature of science instruction, more valid assessment both of adults' conceptions of the nature of science and the role these conceptions play in decision making is needed. Of course, if understandings of the nature of science are found to have little or no impact on decision
making, the efficacy of scientific literacy toward decision making will also come into question.

If such research is to avoid the problems of past investigations, several specific methodological changes are apparent. First, the issue of sample selection needs to be addressed. It is not acceptable to use the results of small, nonrandom samples to generalize to the population as a whole. If generalization is the goal, then large, representative samples are required. Given the difficulty of obtaining such samples, purposive selection of a relatively small group of adults to be treated as a population may be a more reasonable approach. It would be particularly illuminating to stratify the sample with regard to level of understanding of the nature of science. In that way, conceptions and decision making of people who may be expected to possess highly developed views of the nature of science (e.g., research scientists, science educators, and science philosophers) may be compared to those who have less-well developed views (e.g., liberal arts majors).

Second, changes should be made in the assessment of adults' understandings of the nature of science. Questionnaires should be open-ended so that respondents are free to express their individual views completely and accurately, as opposed to being forced to choose among limited alternative views preselected by the researcher. Additionally, follow-up interviews should be used to check the respondents' comprehension of the questionnaire items, to verify the researcher's interpretation of the responses, and to provide opportunities for clarifying remarks and probing questions.
Third, the influence of understandings of the nature of science on decision making regarding science and technology based issues should be directly assessed. Such assessment will require opportunities for participants to make decisions on issues that bridge the interface between science and society, most likely in the form of a questionnaire. As with the nature of science assessments, questionnaire responses should be followed up with interviews exploring participants' decision making in detail. In this way, reasoning patterns and factors which influence decision making (including knowledge of the nature of science) may be assessed.

As described in Chapter I, the anticipated goal of nature of science instruction is closely linked to that of scientific literacy. Both are assumed to be critical factors in producing a citizenry capable of making reasoned choices on science and technology based issues. The research recommended here constitutes the first test of this assumption, providing science educators with information critical for making reasoned choices about how best to equip citizens with the resources they need to respond to the local or national science and technology based issues that concern them.
CHAPTER III
DESIGN AND METHOD

Purpose

Current science education reform documents advocate more complete and authentic nature of science instruction (AAAS, 1990, 1993; NRC, 1996; NSTA, 1982). As discussed in Chapter I, the time and effort required to teach the nature of science typically is justified by the democratic argument; i.e., students who possess current views of the nature of science will be better prepared to make decisions on complex, science and technology based issues. This justification has yet to be empirically tested, and, therefore, remains an assumption.

The primary purpose of this study was to test this assumption by assessing the influence of people's understanding of the nature of science on decisions they make about science and technology based issues. The study also aimed to delineate factors and reasoning that individuals use when making decisions on science and technology based issues. The research questions guiding the investigation were as follows:

1. What is the relationship, if any, between understandings of the nature of science and decisions regarding science and technology based issues?

2. What is the relationship, if any, between understandings of the nature of science and the factors used to reach decisions on science and technology based issues?

3. What is the relationship, if any, between understandings of the nature of science and the reasoning used to reach decisions on science and technology based issues?
Method

This investigation employed both quantitative and qualitative methods to answer the research questions of interest. The research questions, which sought to explicate differences in decision making made by individuals with disparate understandings of the nature of science, were quantitative in nature. These questions were based upon the *a priori* hypothesis that the nature of science should impact decision making on science and technology based issues. Additionally, selecting individuals for, and placing them within, the two disparate groups involved comparing their understandings of the nature of science to a predetermined standard. This comparison also constituted a quantitative procedure, because the standard was selected from the literature, rather than derived from the participants themselves. Delineating the factors and reasoning involved in making decisions on complex science and technology based issues required a more open-ended approach. Given the exploratory nature of these objectives, inductive, qualitative methods of data collection and analysis were employed (as in Bogden & Bilken, 1992), such as the use of open-ended questions and interviews. Responses to these questions and interviews were looked at holistically to construct trends, patterns, or categories of information.

The investigation proceeded in four phases (Figure 1). The first phase entailed the selection of participants and collection of their vitae as sources of background information. In the second phase, participants' decision making was explored via an open-ended questionnaire in conjunction with follow-up interviews. In the third phase,
Phase 1:
Selection of 10 - 20 Participants
&
Collection of Vitae

Phase 2:
Administration of
Decision making Questionnaire
&
Follow-Up Interviews

Phase 3:
Administration of
Nature of Science Questionnaire
&
Follow-Up Interviews

Phase 4:
Group Assignments
Answering the Research Questions

Figure 1. Schematic of Research Procedures.

participants' understandings of the nature of science were assessed with a second set of
open-ended questionnaires and follow-up interviews. Postponing the assessment of the
participants' understandings of the nature of science until after administration of the
decision making questionnaire reduced the possibility of participants biasing their
responses recognition of the focus of the study.
Data analysis occurred in the fourth and final phase of the investigation. First, analysis of the nature of science questionnaire responses and follow-up interview transcripts were used to assign the participants to one of two groups: those whose views of the nature of science were consistent with contemporary views of science philosophers and science educators and those whose views were inconsistent with current thinking. Once this step was completed, the researcher answered the research questions by comparing the decisions, factors influencing the decisions, and decision making strategies of the two groups and searching for references to the nature of science in their responses.

Phase I: Participant Selection

A sample of convenience consisting of two groups of adults likely possessing disparate conceptions of the nature of science was purposively selected for participation in the study. Adults, rather than students, were selected for several reasons. First, scientific literacy is a goal for adults. The *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) provided separate but similar visions of K-12 development of scientific literacy. Thus, only high school graduates could be expected to have completed the education necessary for the development of scientific literacy and its nature of science constituent as delineated in these documents. Second, it was necessary to select the sample from populations with the highest likelihood of possessing the desired nature of science understandings. There is consensus among the many nature of science assessments that school-aged children do not possess the level of understandings this project requires (Aikenhead, 1973, 1987;
Bady, 1979; Gilbert, 1991; Lederman & O'Malley, 1990; Mackay, 1971; Mead & Matraux, 1957; Rubba & Anderson, 1978; Wilson, 1954, among others). Finally, adults, rather than students, were selected because they are in the best position to make the personal and political decisions included in the democratic argument for teaching the nature of science (Shamos, 1995).

The first group was comprised of individuals with doctoral degrees in science education, history of science, or philosophy of science. Individuals in these fields may reasonably be expected to have developed desired understandings of the nature of science through their research and other opportunities to contemplate the scientific enterprise. Because previous research has indicated that some scientists possess desired understandings of the nature of science (Schmidt, 1967; Welch & Pella, 1968), scientists were also included in this group. Members of the second group were selected to be comparable to those of the first, except for their level of understanding of the nature of science. The group was composed of individuals with educational backgrounds similar to the members of the first group; i.e., people with doctoral degrees, but in fields in which they were less likely to have contemplated the nature of scientific knowledge, e.g., American literature, history, and education.

Due to the probability that many contacted individuals would choose not to participate in the project, many more potential participants were contacted than were needed to participate. In all, more than 50 college faculty and scientists were contacted before a large enough pool of volunteers (21) had been gathered. This sample size was large enough to identify trends from the analysis of collected data, but not so large that
locating the required number of individuals possessing the desired levels of understandings of the nature of science was overly difficult. Additionally, the data generated from two groups of individuals was manageable to collect and analyze.

During the fall of 1998, initial inquiries to attract individuals willing to participate in the investigation were sent to university professors and research scientists. Some of these individuals were located on the researcher's campus; others were at various universities across the nation. Some of the professors were acquaintances of the researcher. Early e-mail contacts (Appendix A) were made to assess each individual's willingness to participate in the investigation. The general intent of the study, types of data to be collected, and time commitment required for participation were all explained. To avoid sensitizing participants to the focus of the investigation, potential participants were told that they would complete questionnaires and interviews as part of an investigation to determine the impact of their science background and knowledge on their decision making.

Once names of specific individuals who had expressed interest in participating in the project were obtained, the researcher mailed a second letter (Appendix B) to confirm their willingness to participate. This format provided a low pressure environment to allow individuals to disengage from further participation if they chose. The letter asked each participant to return a vita along with a signed consent form. The vita was used as a source of background information for each participant.
Phase II: Decision Making Questionnaire and Follow-Up Interviews

Open-ended Questionnaire. In order to assess any differences in their decision making strategies on science and technology based issues, participants were administered an open-ended questionnaire (Appendix C). This Decision Making Questionnaire (DMQ) originally contained five different scenarios, each describing a particular issue or dilemma related to science and/or technology. The individual scenarios were followed by a set of three to five questions asking the respondent to provide opinions or decisions directly related to the preceding scenario. These questions were open-ended and required the respondent to justify and/or elaborate on the reasons behind his/her decisions.

Five science education experts critically reviewed each scenario and item set of the DMQ regarding their appropriateness and relevancy to the research questions. Comments from the reviewers were used to modify the DMQ until at least 80% agreement was reached for each scenario and item. Agreement by these experts provided evidence for the face and content validity of the DMQ.

One round of review was all that was necessary to reach the required 80% agreement. In fact, the reviewers were in 100% agreement that four of the five DMQ scenarios and question sets were appropriate for collecting decision making data necessary to answer the research questions. The single dissension came from a reviewer who commented that Scenario 3 was disjointed as written, and required minor restructuring to enhance clarity. This suggestion was incorporated into the final version
of the DMQ, along with several other minor suggestions to reduce redundancy and improve readability and grammar.

A second reviewer drew attention to the length of the original DMQ, which consisted of five scenarios and 20 questions. The concern was that the amount of time and writing required to complete the DMQ might discourage respondents from providing the detail necessary for subsequent data analysis. This reviewer also identified several similarities between Scenario 2, which focused on the relationship between global warming and greenhouse gas emissions and Scenario 5, which focused on the endangered species act. For example, both dealt with complex environmental issues, both involved public, rather than private, decisions, and both involved the dilemma of protecting the environment versus incurring high economic cost. Because of these similarities, the reviewer suggested that eliminating Scenario 5 would reduce the length of the questionnaire without sacrificing the quality of data collected.

The validity of this suggestion was confirmed in a small pilot study in which the DMQ was administered to five subjects. Analysis of the responses to Scenario 2 and Scenario 5 questions supported the proposition that eliminating Scenario 5 would not adversely affect the quality of decisions, decision making factors, or decision making strategies elicited by the questionnaire. Additionally, the responses of the pilot study participants were more elaborate for Scenario 2 (global warming) than Scenario 5 (the endangered species act), suggesting that they were more familiar with the issue of global warming. Scenario 5 was, therefore, eliminated from the DMQ, resulting in a final version consisting of 4 scenarios and 15 items (Appendix C).
Since participants were from diverse geographical regions with a high probability of scheduling conflicts, participants were permitted to complete the questionnaire at their convenience, rather than in a controlled environment. To ameliorate the concern that participants would solicit answers to the questions from others or otherwise research their answers, the questionnaire was designed as more of an opinion survey than a test with specific "right" or "wrong" answers. Furthermore, the chance that respondents might choose to gather background information to inform their decisions was not considered problematic. Such information gathering could well have been a significant factor in their decision making process and, therefore, should be explicated rather than discouraged.

Analysis of DMQ Data. The DMQ responses were analyzed in order to (a) determine the percentages of "yes" and "no" decisions, (b) construct categories of the factors influencing the participants' decisions, and (c) delineate the reasoning participants used to arrive at their decisions on each of the scenarios.

First, the researcher tallied the "votes" and calculated the percentage of "yes" and "no" decisions for each individual's responses on the entire questionnaire. These data were then used during subsequent comparisons among the two groups during Phase IV of the research. Next, the respondents' written explanations for their respective decisions were scrutinized in order to generate categories of factors that influenced the participants' decision making. The researcher began by reviewing each participant's DMQ in order to obtain a general impression of the factors influencing his/her decisions on the science and technology based issues. The documents were then
reviewed to generate a list of the factors cited as influencing the participant's decisions. This process continued until the researcher was confident that all of the participant's decision making factors were listed. The entire procedure was then repeated for the other participants. The resulting lists of decision making factors were set aside for subsequent comparison to the lists generated from the follow-up interviews.

The analysis of the participants' reasoning was based on the explanations they provided for their decisions on the decision making questionnaires. It was not known in advance whether participants' arguments would be in sufficient detail to enable the use of a predetermined framework for the analysis. Originally, it was thought that conventions of logic would provide a tool for the analysis of the participants' reasoning (Salmon, 1973; Zeidler, Lederman, & Taylor, 1992). For example, the two groups' use of valid argument patterns (e.g., affirming the antecedent, denying the consequent, and use of dilemma) could be compared, as could their use of fallacious argument patterns (e.g., affirming the consequent, argument against the man, false dilemma, and hasty generalization).

Analysis of the participants' responses to the DMQ, however, revealed that their reasoning could not easily be categorized or characterized by conventions of logic. Instead, a more qualitative procedure of searching for general patterns of reasoning in the participants' responses was employed. This procedure involved reviewing each participant's responses to the DMQ in order to develop a general impression of the forms of argument used to support his/her decisions. The documents were then reviewed a second time to generate a preliminary list of the forms of argument used.
This process continued until the researcher was confident that all of the participant's arguments were identified and/or described. The entire procedure was then repeated for the other participants. The resulting preliminary lists of argument forms were set aside for subsequent comparison to the argument forms generated from the analysis of the follow-up interview transcripts.

Follow-up Interviews. Following the initial analysis of the DMQ responses, each participant was individually interviewed. The purposes of the interview were to provide opportunities for respondents to clarify and elaborate on their written responses and for the researcher to explore the reasoning and factors the participants used in reaching their decisions. These interviews occurred in person in some cases or via phone when the participant lived too far away. All interviews were audiotaped and transcribed. During these semistructured interviews, participants were provided with a copy of their DMQ and responses (in the case of phone interviews, the questionnaire and responses were faxed or mailed prior to the interview). They were then asked to explain their responses to each item and to respond to requests for clarification or elaboration. Any additional information not recorded on the audiotape (discussions occurring before or after the taped session, facial expressions or inflection, etc.) were recorded in a field notebook and subsequently added to the interview transcripts. This information was critical for assessing any differences in the quality of responses to the in-person interviews versus the phone interviews. The interviews lasted approximately 45 minutes.

Prior to the start of the interview, each participant was reminded of the general goals of the investigation, the types of data to be collected, and the overall time frame.
Participants were also reminded that their participation was voluntary and that information collected during the investigation was coded in order to mask their identities. Furthermore, none of the information was used for evaluative purposes outside the investigation. Finally, the researcher asked permission to audiotape the interview session.

Initially, the interview focused on the participants' academic and professional backgrounds. The innocuous nature of these initial questions was intended to alleviate any apprehension on the part of the respondent, as well as provide background information in addition to what was provided in participants' vitae. The following questions were used to guide the interview:

- When and why did you decide to become a (occupation)?
- How many years have you been a (occupation)?
- How would you describe your overall academic preparation?
- What schools did you attend?
- What were your areas of content specialization?
- What are your hobbies/interests outside your occupation?

The next part of the interview consisted of questions that targeted the participants' knowledge of and decision making experience with science and technology based issues in general:

- Do you follow scientific issues in the news?
- Did you vote in the last election? Why/why not?
How would you characterize your knowledge of the issues described in the questionnaire?

Have you ever had the opportunity to make a decision on a science and technology based issue?

Please describe the situation and the decision you made. Why did you make this particular choice?

The final part of the interview focused on the participants' responses to the DMQ. During this portion of the interview, participants were given a copy of their questionnaires and provided with the opportunity to clarify and elaborate on their written responses. The following questions guided this portion of the interview:

Did you understand the issue in scenario (scenario #)?

How would you rate your background knowledge of this issue?

What are your overall feelings about the issue?

Would you change any of your responses to the questions that follow this scenario?

What did you mean by your response to (question #)?

How did you reach that decision?

Was your decision based upon any particular experiences, strategies, or knowledge?

What single factor played the greatest role in reaching your decision?

**Analysis of Interview the DMQ Interview Data.** Analysis of the follow-up interview transcripts proceeded in a manner similar to that of the DMQ responses. First,
the respondents' explanations for their respective decisions were scrutinized in order to generate a second list of factors that influenced each participants' decision making. Then the lists of factors generated from the separate analyses of each participant's DMQ and corresponding interview were compared and combined. The entire procedure was repeated for each individual. The resulting set of factors was set aside until Phase IV of the investigation, when the participants were placed into groups according to their understandings of the nature of science.

Analysis of the reasoning the participants used to arrive at their decisions resembled that of the DMQ responses. First, each respondent's explanations for his/her respective decisions was scrutinized in order to generate a second list of argument forms. Then the two lists of argument forms generated from the separate analyses of each participant's DMQ and corresponding interview were compared and combined. The entire procedure was repeated for each individual. The resulting set of argument forms was then set aside until Phase IV of the investigation.

Phase III: Nature of Science Questionnaire and Follow-Up Interviews

Open-ended Questionnaire. Next, an open-ended questionnaire (Appendix D), in conjunction with a follow-up interview, was used to construct a profile of each participant's understandings of the nature of science. This approach was employed in order to avoid some of the difficulties with paper-and-pencil assessments described in Chapter II. The Nature of Science Questionnaire (NOSQ) consisted of six open-ended items adapted from Abd-El-Khalick (1998), Abd-El-Khalick, Bell, and Lederman.
The characteristics of the nature of science addressed by the questionnaire included:

1. Scientific knowledge is based upon both observation and inference.

2. Scientific laws and theories serve different functions and are derived from observational and inferential knowledge, respectively.

3. All scientific knowledge is tentative, due, in part, to its reliance on inference, the accumulation of knowledge, and/or the logic of hypothesis testing.

4. Scientific knowledge is ultimately based on empirical evidence.

5. Creativity and imagination are inherent to all aspects of the development of scientific knowledge, including hypothesis generation, research design, and especially, data interpretation.

6. Cultural and societal influences play significant roles in the development of scientific knowledge.

7. Scientific observations are inherently subjective due, in part, to the influence of culture and society and the fact that they are always interpreted in light of prior theories, ideas, or assumptions.

(See "The Researcher's Understandings of the Nature of Science" section at the end of this chapter and Appendix D for further elaboration on these characteristics of scientific knowledge). These particular aspects of the nature of science were chosen due to their accessibility to nonspecialists and the general level of agreement existing among philosophers and educators about these characteristics of science (Lederman & Abd-El-Khalick, 1998; Smith, Lederman, Bell, McComas, & Clough, 1997).
Establishing face and content validity for the questionnaire proceeded in a manner similar to that used for the DMQ. First, five experts in the fields of science education and/or philosophy of science were asked to critically review each item of the questionnaire regarding its clarity, appropriateness and relevancy to the aforementioned characteristics of the nature of science. The panel suggested minor improvements regarding the wording and order of the instructions and items. Implementation of these suggestions resulted in the final version of the NOSQ (Appendix D).

As with the DMQ, participants were permitted to complete the questionnaire at their convenience, rather than in a controlled environment. Again, the concern that participants may solicit answers to the questions from others or otherwise research their answers was partially ameliorated by the nature of the questionnaire itself, since the instrument was more an opinion survey than a test with specific "right" or "wrong" answers. Additionally, participants were assured that their viewpoints were important to the researcher, not their ability to answer the items "correctly."

**Analysis of NOSQ Data.** Responses to the open-ended questionnaire were analyzed to construct preliminary profiles of the participants' views of the nature of science. The analysis proceeded in a similar fashion to that of the DMQ responses and follow-up interviews. First, completed questionnaires were reviewed to generate summaries of each participant's views. Next, the summaries were searched for patterns and/or categories. These categories were then checked against confirmatory or otherwise contradictory evidence in the data and modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily
reduce and organize the data. These categories were used to generate the profiles of the participants' conceptions of the nature of science.

Some unclear or incomplete responses were encountered during the analysis of the questionnaire in addition to interesting responses in need of elaboration. The researcher kept a record of these instances and gave each participant the opportunity to clarify or elaborate on such responses during the follow-up interviews.

Follow-Up Interviews. After the analysis of the questionnaire responses was completed, participants were individually interviewed in order to validate their responses to the questionnaire and to provide them with opportunities to clarify and elaborate on their written responses. Depending on the participant's location, these interviews were conducted in person or via telephone. Respondents were reminded that information collected during the investigation was being coded in order to mask their identities and that none of the information would be used for evaluative purposes outside the investigation. Finally, the researcher asked permission to audiotape the interview session.

During these semistructured interviews, participants were provided with a copy of their nature of science questionnaire and responses (in the case of phone interviews, the questionnaire and responses were faxed or mailed prior to the interview). They were then asked to explain their responses to each item and to respond to requests for clarification or elaboration. Any additional information not recorded on the audiotape (discussions occurring before or after the taped session, facial expressions or inflection,
etc.) were recorded in a field notebook and subsequently added to the interview transcripts. The interviews lasted approximately 45 minutes.

After the respondents discussed their responses to the nature of science questionnaire, one final question was asked:

In the second questionnaire you described your conceptions of several aspects of scientific knowledge, e.g., scientific knowledge is tentative, it has a subjective component, (or any other aspects of the nature of science indicated in the participant's response to the questionnaire). Did your beliefs about science impact the decisions you made on the first questionnaire in any way?

Digressions were common during the interviews, as the participants’ lines of thought were followed and probed in depth. All interviews were audiotaped and transcribed for analysis.

It should be noted that participants were each given the opportunity to volunteer the nature of science as a factor influencing their decision making without prompting before the researcher specifically addressed the nature of science in the last interview question of the investigation. This strategy was designed to reduce the concern that the respondent would become sensitized to the researcher's focus early in the investigation and respond accordingly.

Analysis of the NOSQ Interview Data. The analysis of the interview transcripts proceeded in the same manner as the previously described analysis of the nature of science questionnaire responses. The transcripts were first reviewed in order to generate a second set of summaries of each participant's views. Next, these summaries were
scrutinized for patterns and/or categories, which were then checked against the data and modified accordingly. After several rounds of category generation, confirmation, and modification, a set of profiles of the participants' understandings of the nature of science was generated. Finally, the profiles generated from the separate analyses of the questionnaires and corresponding interviews were compared. When discrepancies between the two profiles were evident, the data were reexamined to determine which profile best reflected the participant's views.

Phase IV: Comparison of the Two Groups

Group Assignments. Once the previous analyses were completed, the researcher assigned each participant to one of the two groups according to the views of the nature of science reflected in his/her nature of science knowledge profiles. Participants whose profiles reflected the current thinking of philosophers of science and science educators were assigned to Group A. Participants whose profiles were inconsistent with currently accepted conceptions were assigned to Group B. This level of consistency was determined by comparing participants' profiles with the seven characteristics of the nature of science presented in Chapter II. That is,

1. Scientific knowledge is based upon both observation and inference.
2. Scientific laws and theories serve different functions and are derived from observational and inferential knowledge, respectively.
3. All scientific knowledge is tentative, due, in part, to its reliance on inference, the accumulation of knowledge, and/or the logic of hypothesis testing.
4. Scientific knowledge is ultimately based on empirical evidence.
5. Creativity and imagination are inherent to all aspects of the development of scientific knowledge, including hypothesis generation, research design, and especially, data interpretation.

6. Cultural and societal influences play significant roles in the development of scientific knowledge.

7. Scientific observations are inherently subjective due, in part, to the influence of culture and society and the fact that they are always interpreted in light of prior theories, ideas, or assumptions.

Of the 21 respondents to the NOSQ, 9 participants held views consistent with current understandings on six or seven of the assessed aspects of the nature of science, 3 participants held views consistent with five aspects, and 9 participants held views consistent with only two to four aspects. Based on these results, the 9 participants with contemporary views of the nature of science were assigned to Group A, and the 9 whose views were least consistent with contemporary views were assigned to Group B. The 3 participants in the middle (consistent on five aspects) were dropped from consideration to create a greater distinction between the two groups. This procedure resulted in two groups of participants with distinct views of the nature of science. Group A participants' conceptions of the nature of science were consistent with contemporary views on an average of 6.8 of the 7 assessed aspects. Group B participants' views, in contrast, were consistent with an average of only 3.3 of the characteristics of the nature of science assessed by the NOSQ.
Answering the Research Questions. The first research question of the investigation was "What is the relationship, if any, between understandings of the nature of science and decisions regarding science and technology based issues?" Answering this question involved tallying the total "yes" and "no" decisions for the members of each group. These totals were used to calculate the percentages of "yes" and "no" decisions as a function of the total number of decisions possible. Finally, the percentages of the two groups were directly compared. It should be noted that inferential statistics are not appropriate for this comparison. Chi-square is the appropriate statistical tool if inferential statistics were being performed on a representative sample. However, as explained earlier in this chapter, the participants constituted the population of interest, so there was no need to make inferences.

The second question called for delineating the factors influencing individuals' decision making regarding complex science and technology based issues. Answering this question required the lists of factors generated in Phase II of the investigation. First, the researcher reviewed the lists of factors for the members of Group A and attempted to reduce the data by grouping similar factors into common categories. These categories were then compared to the DMQ and follow-up transcript data in order to identify inconsistencies and make any necessary modifications. Several rounds of category generation, confirmation, and modification were necessary to satisfactorily reduce the data. The entire process was then repeated for Group B participants. Finally, the Group A and Group B categories were compared and contrasted.
The third research question asked "What is the relationship, if any, between understandings of the nature of science and reasoning on science and technology based issues?" Answering this research question required a procedure similar to that used to answer the second question. First, the researcher reviewed the lists of forms of argument for the members of Group A generated in Phase II of the research in order to generate a summary of the group's reasoning. These summaries were scrutinized for patterns and/or categories, checked against the data, and modified accordingly. Several rounds of category generation, confirmation, and modification were necessary to satisfactorily summarize the data. Finally, the categories generated from the separate analyses of the questionnaires and corresponding interviews were compared. When discrepancies between the two category lists became evident, the data were reexamined to determine which list better reflected the participant's views. The entire process was then repeated for Group B participants, after which the reasoning of Group A and Group B participants were directly compared.

The Researcher's Understandings of the Nature of Science

As described earlier in this chapter, the researcher characterized and evaluated the participants' understandings of the nature of science from their written and verbal responses to open-ended questions. The researcher's personal conceptions of the nature of science inevitably influenced these interpretations. For example, the procedures used in this investigation required the researcher to decide whether participants' responses match currently accepted views of the nature of science as described by philosophers, educators, and science reform documents. Obviously, the validity of such decisions are
contingent upon the researcher's understandings of these currently accepted views. A well-developed understanding of the nature of science was also required for the researcher to identify subtle references to aspects of the nature of science in the participants' responses and to inform follow-up questioning. Therefore, to increase confidence in the researcher's interviewing, data analyses, and interpretations, it is requisite to first delineate the researcher's beliefs about the nature of science. This information may also be useful as a framework through which to interpret the researcher's conclusions.

As described in Chapter II, the nature of science is a complex construct that defies simple definition. In fact, philosophers of science, historians of science, science educators, and scientists have not agreed on a specific definition of the nature of science. Although the nature of science has been defined in various ways, it generally refers to the epistemology of science; i.e., "the values and assumptions inherent to scientific knowledge" (Lederman, 1986). The following is a characterization of the scientific enterprise related to the eight characteristics of the nature of science referred to in this study.

First, scientific knowledge is never absolute, rather, it is characterized as tentative, or subject to change. This characterization includes all forms of scientific claims, including hypotheses, models, theories and laws. The tentative nature of scientific knowledge derives from several factors. For instance, scientific knowledge is the product of both observation and inference. Observations constitute the empirical basis of scientific knowledge and are descriptions of natural phenomena that may be
directly perceived by the senses (or instrumental extensions of the senses). For example, "This star is brighter than that one" is an observation. Inferences, on the other hand, are conjectures that go beyond what is directly accessible to the senses. "This star is brighter than that one because it is significantly closer to earth" is an inference. The distances to stars cannot be directly measured. Rather, our estimates of stellar distances are inferences based upon interpretations of geocentric parallax and other indirect evidence. Obviously, since inferences are conjectures beyond observable data, any claims based upon inferences are inherently tentative. Additionally, errors in measurement and perceptual illusions give rise to uncertainty in observational data. Furthermore, because no one can ever be certain of observing all instances of a phenomenon (there is always the possibility of a black swan), scientific claims based upon observation are also tentative (see Popper, 1963).

The distinction between observations and inference in science is significant because these two types of scientific knowledge give rise to different kinds of scientific claims. For example, scientists are sometimes able to recognize (create?) patterns and relationships among observations. Once established and recognized by scientists, these patterns and relationships are known as scientific laws. For example, Charles' law depicts the relationship between the temperature of a gas and its volume as volume equals a constant times temperature. In other words, temperature and pressure are directly proportional. The law expresses what happens under specific conditions, but offers no explanation for why it happens. Explanations for why the relationship expressed in Charles' law exists must go beyond what is observable, and are, therefore,
inferential in nature. These inferential explanations, when well supported and accepted by scientists, are known as scientific theories. For example, the kinetic molecular theory explains Charles' law in terms of the inherent motion of the molecular particles that make up gases.

Two critical misconceptions are dispelled by understanding the respective observational and inferential basis of laws and theories. Because scientific laws and theories are based on different kinds of evidence, the common misconception that laws are proven theories is unfounded. Theories and laws are different kinds of knowledge and play different roles in science. As such, one can never become the other. Additionally, because both laws and theories are based on tentative knowledge (i.e., observations and inferences), neither is absolute. Laws are no more "proven" than theories. Both are subject to change.

Another reason scientific knowledge is tentative is that new evidence is constantly imposed on existing claims. An example is taken from a recent headline in a local newspaper: "New Evidence of Moon Water Found." The article goes on to explain that new data from unmanned spacecraft indicate the presence of water deposits in the form of ice at the north and south poles of the moon (Recer, 1998). The old "fact" many of us were taught in school that "there is no water on the moon" has been replaced with a new estimate of as much as 10 billion tons of water at the lunar poles. However, the accumulation of new evidence is not the only way that scientific knowledge changes. Occasionally, new ways of looking at current knowledge come to light as a result of paradigm shifts (Kuhn, 1970a). For example the shift from a geocentric to heliocentric
model of the solar system did not occur simply due to the accumulation of new data (although data from the newly developed telescope did play a role), but was also the result of a change in the mindset of scientists and philosophers. This new mindset, or paradigm, was influenced by social and cultural changes, such as religious and political views, and resulted in an entirely new way of looking at existing data (Kuhn, 1957).

Third, scientific knowledge is inherently tentative because it is based upon human imagination and creativity. Science is not simply the product of logic and rationality. There is no single "scientific method" that scientists follow in order to produce scientific claims. Rather, science involves the creative invention of explanations and the imaginative construction of patterns and relationships. Darwin's synthesis of the theory of natural selection required the creative work of pulling together data and ideas from several diverse sources, including observations and samples from his tenure on the H.M.S. Beagle, the geologic principles of Lyell, and Malthus' theory of populations.

The role of creativity and imagination in the development of scientific knowledge has implications for the supposed objectiveness of science. In fact, even so-called objective facts in science are not really free from subjectivity. Consider the early sketches of Galileo and others who first used the telescope to observe the planet Saturn (Figure 2). Obviously, early observers did not know what to make of their observations of the planet and its changing appearance from year to year. Not until 1659, when Christiaan Huygens published a theory (or model) of the Saturnian system (Figure 3) did the observations of Saturn finally begin to make sense. R. L. Gregory noted that the "drawings do not represent how the object appears through a telescope at any one time."
They are the synthesis of very many observations. They represent a belief in what it is 'really' like" (Gregory, 1970, p. 119). Before the explanation provided by Huygens' model of Saturn, observers had no theory with which to interpret the data provided by their senses.
Figure 2. Early telescopic views of Saturn collected by Christiaan Huygens and published in his *Systema Saturnium* in 1659.
Figure 3. Huygens' diagram from *Systema Saturnium*, illustrating how the hypothesis that Saturn is surrounded by a "thin flat ring, nowhere touching," could account for its various telescopic appearances.
CHAPTER IV
RESULTS

Introduction

The purpose of this investigation was to assess the relationship between understandings of the nature of science and decision making on science and technology based issues. The study focused on delineating the decisions, influential factors, and reasoning patterns of two groups of highly educated adults possessing disparate views of the nature of science. By comparing these three aspects of decision making for the two groups, as well as specifically looking for aspects of the nature of science in the participants' descriptions of their decision making, the validity of the democratic argument supporting nature of science instruction could be assessed.

To facilitate the presentation of the varied and complex data of the investigation, this chapter is organized in four sections. The first section presents general background information for the participants in each of the two groups. The second section provides a detailed profile of the participants' views of the nature of science judged to be consistent with current conceptions of science (as determined by participants' responses on the NOSQ and in the follow-up interviews). These participants were assigned to Group A. The third section provides a profile of the beliefs of the participants assigned to Group B. The fourth and final section presents the two groups' decisions and decision making strategies as explicated by the DMQ and follow-up interviews.
Participant Descriptions

Participants assigned to Group A consisted of 9 college professors, 5 female and 4 male, from universities in six states in the US. Two were full professors, 5 were assistant professors, 1 was a research associate, and 1 was a visiting associate professor.

Four of the participants in Group A had received their doctoral degree in science education, 2 in education, 1 in history of science, 1 in forest science, and 1 in conceptual foundations of science. All 9 had either bachelors or masters degrees (or both) in one of the science disciplines, including biology, zoology, physical science (geology/astronomy), or chemistry (see Table 8).

Six were currently employed in schools of education or curriculum and instruction departments. One professor worked in a department of history and one in a department of philosophy. The single scientist in the group worked in a forest science department.

All of the participants listed on their vita one or more presentations, publications, or courses taught on the subject of the nature, history, or philosophy of science. Eight of the 9 Group A participants reported voting in the most recent election. Only 4 participants reported ever voting on science and technology based issues. All said they had made personal decisions related to science and technology based issues. The 9 participants in Group B (7 males, 2 females), had more diversity of profession. Located in five states throughout the US, they had earned a doctoral degree in a variety of fields (see Table 8). Eight participants were employed by an institution of higher
Table 8
Summary of Participant Background Information

<table>
<thead>
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<th>Field in which doctoral degree earned</th>
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<th>No. in Group B</th>
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</tr>
<tr>
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<tr>
<td>Conceptual foundations of science</td>
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</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Mechanical engineering</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Special education</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>English</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Philosophy/history</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Intercultural studies</td>
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<td></td>
</tr>
<tr>
<td>Soil chemistry</td>
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<td></td>
</tr>
<tr>
<td>Near Eastern studies</td>
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<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
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<td></td>
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<table>
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<tr>
<td>Soil chemistry, nuclear engineering, mechanical engineering</td>
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</tr>
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<td>Philosophy/history</td>
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<tr>
<td>History dept.</td>
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<tr>
<td>Information Management dept.</td>
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<tr>
<td>Engineering dept.</td>
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<tr>
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<tr>
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<tr>
<td>School of Religion</td>
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<td>Near Eastern studies</td>
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</table>

<table>
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<th>Listed presentations, publications or courses taught on the nature, history or philosophy of science</th>
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<th>No. in Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
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</table>

education. One was the director of a school of education. One was an associate professor, and 3 were assistant professors. Two participants were full professors. The colleges or departments with which they were associated included English, religion,
education, history, information management, and engineering. A ninth participant was employed as a research soil scientist by the US Environmental Protection Agency.

The 6 participants with doctoral degrees in nonscience disciplines had earned no other degrees in a science-related discipline, according to their curriculum vita. None of the participants in Group B listed any publications, courses taught, or presentations related to the nature, history, or philosophy of science. All Group B participants reported voting in the most recent election, 4 reported that at some point in time they had voted on science and technology based issues, and all said they had made personal decisions relating to science and technology based issues.

Group A Views of the Nature of Science

The following is a detailed profile of the nature of science conceptions of the 9 participants subsequently assigned to Group A. They were assigned to Group A due to the consistency of their views with the contemporary views of the nature of science expressed in the literature by science educators, science philosophers, science historians, and science reform organizations. (After each quotation in the remainder of this thesis will be found in parentheses the identifying number—A 1-9 or B 1-9—assigned to the participant making the statement, along with the name of the instrument or interview in which the statement was made.)

The Empirical Nature of Scientific Knowledge. The construction of scientific knowledge is ultimately, but not solely, based on observations of the natural world. Scientists are no different from others in that they do not have direct access to natural phenomena. Rather, observations must necessarily be filtered through the senses and/or
theory-based instrumentation. Nevertheless, empirical data are critical to the processes of science, because "sooner or later, the validity of scientific claims is settled by referring to observations of phenomena" (AAAS, 1990, p.4).

All participants assigned to Group A wrote responses to the first and/or fourth items on the NOSQ containing references to the empirical nature of scientific knowledge. Additionally, these participants discussed their views of science's empirical basis during the follow-up interviews. Group A participants used several different terms to express this view. Some participants mentioned "empirical" or "empiricism." More typically, Group A participants indicated that science is based on natural phenomena, evidence, data, information, and observation.

Simply put, any idea in science may change if and when better data are available or more effective explanations of old data are presented. (A2, NOSQ)

Most would say that [science differs from art] in its empirical base, the use of evidence. Other disciplines use evidence, but not to the same degree. (A5, NOSQ)

Nature constrains science. That doesn't mean that there's only one idea that works, but you can't say that anything goes...Well, you know, you can be as creative as you want to and say a rock goes up, but it just doesn't by itself. (A6, NOSQ-interview)

Many Group A participants attempted to describe science as a way of knowing by contrasting it with art or religion. These participants tended to focus on science's reliance on empirical data and reason, in contrast to art's focus on aesthetics and religion's reliance on faith and revealed truth:

I would agree that the creativity and imagination required of scientists is much like that needed in art. The difference is that, in the end, a
scientist's creativity is constrained by nature. I believe Thomas Huxley said something about a beautiful theory slayed by an ugly fact. (A6, NOSQ)

Religion involves a very strong dose of faith and willingness to suspend reason. Scientists are generally unwilling to suspend reason. (A4, NOSQ-interview)

I've separated science from other ways of knowing, such as religion, where truth is usually revealed truth, or where one looks inward to find truth, rather than look for conformity with the world around us. (A9, NOSQ-interview)

None of the Group A participants spoke of science using observations or evidence to "prove" its conjectures. Rather, they tended to view empirical evidence as supportive of scientific claims, but not able to prove them in any absolute sense. Additionally, their responses indicated that they did not see physical evidence as being the sole determinant in choosing between competing ideas or theories. Rather, they viewed scientific claims as being based upon a mix of observational, personal, social, and cultural influences.

**Inference and Theoretical Entities in Science.** The second item on the NOSQ was intended to elicit participants' understandings of the role of models and other theoretical entities in science, as well as the distinction between observation and inference. This item asked participants how certain scientists are about the structure of the atom and what kinds of evidence scientists use to develop their understandings of atomic structure. Responses to the questions were used to determine whether the participants understood that scientists' views of the atom are based on indirect evidence and inference, or whether they incorrectly attributed scientists' views to direct observation.
Group A participants' responses to the second NOSQ item and their responses to subsequent questioning during the follow-up interviews clearly reflected their understandings of the inferential nature of scientific models. While all were confident that scientists understand much of what atoms are like, none appeared to believe that scientists "know" the structure of the atom in any absolute sense of the term. Rather, they used qualified language to describe scientists' certainty about atomic structure. Furthermore, they were careful to point out that scientists have confidence in the model because it "works," rather than that it reflects reality:

Scientists are sure enough that a person would have to be a cantankerous fool to deny the model has captured a great deal of what the atom is like. Of course, we cannot be certain, but we need not be. The model is based on the best available evidence, is corroborated in a number of ways, and works extremely well. (A6, NOSQ)

Scientists use this picture as an approximation or as one of several different pictures or representations of the atom. This picture works under limited circumstances. (A4, NOSQ)

Group A participants rejected the notion that scientists obtained their understandings of atoms through direct observations of atomic structure. Instead, each of the Group A participants ascribed a role for indirect evidence and/or inference in the construction of atomic models:

All this evidence is admittedly indirect regarding the structure of undisturbed atoms or molecules. But inductively, if you hit them and banged then into each other for a long time and have seen mostly these particles emerging, it is a pretty good indication that those are the primary components. (A3, NOSQ)
Thus, through their discussion of atomic structure, Group A participants demonstrated adequate understandings of the inferential nature of theoretical entities. Additionally, they demonstrated an instrumentalist view of atomic models by emphasizing their usefulness and predictive power over any notion that such models are meant to be reflections of reality.

**Scientific Theories.** The first item on the NOSQ asked whether scientific theories change and the reasons they might change. All 9 of the participants placed in Group A indicated that scientific theories change. Four of the 9 Group A respondents spoke of theory change in a general way. The other 5 further qualified the concept of theory change to include refinement and modification in addition to outright change:

Of course scientific theories change. The words atom, molecule, and cell all mean something different than in earlier usages, because what we mean by these terms has changed as our theories about them and about the natural world have changed. Theories are malleable and open to challenge and revision, and that is their strength. (A4, NOSQ)

Theories can remain, be modified, or be replaced over time. To describe the universe, geocentric theory was eventually replaced by heliocentric theory. To describe the earth's surface, the notion of immobile continents and oceans was replaced in the 1960s by plate tectonics. The theory of evolution was first made popular by Darwin in the mid-1800's. Scientists today rarely debate whether evolution occurs, but continue to modify their description of the mechanism by which it proceeds. (A5, NOSQ)

Additionally, 3 of the 9 Group A participants further explicated the role of new data by describing the role of anomalies in theory change. For these participants, theories change as new information comes to light that is not consistent with current theory. These anomalies create dissatisfaction with current theory and new interest in the development of new, more comprehensive theories:
Theories change as a result of anomalies, which cause dissatisfaction with existing theory. This dissatisfaction leads to further investigation, which eventually leads to new theories. (A4, NOSQ-interview)

While all of the Group A participants indicated that theories change as a result of new evidence, discoveries, or technology, most did not attribute theory change solely to new information. Eighty-nine percent of these participants cited factors in addition to new data and technologies as reasons theories might change. Cited factors included new insights, consistency with other theories, and social and cultural influences:

Simply put, any idea in science may change if and when better data are available or more effective and complete explanations of old data are presented. (A2, NOSQ)

Theories change because of new and creative insights by scientists, model-building, the identification of anomalies unexplainable by current theory, new observations, new experiments, and/or the reinterpretation of already collected data. Theories also change because of changing social, cultural, and political circumstances. Science is embedded in and reflects society. (A5, NOSQ)

Participants placed in Group A further demonstrated their understandings of theory change by providing many valid examples of theories that have changed due to new evidence or new ways of looking at existing evidence. Each participant provided at least one accurate example of theory change, and some provided as many as five examples. Evolution theory and the shift from a geocentric to heliocentric model of the solar system were the most common examples cited, accounting for 26% and 13% of the examples, respectively. The principle example of theory change from geology was the acceptance of plate tectonics, which accounted for 13% of the examples. Other cited examples included changes in the theory of heredity, DNA structure, atomic models,
and theories of dinosaur extinction. In all, the Group A participants provided 23 examples of theory change:

In addition to recognizing the tentative nature of scientific theories, Group A responses reflected other aspects of scientific theories consistent with current understandings. Several participants described theories as robust, well-supported systems of explanations based on substantial evidence. For these participants, theories may be tentative, but not fickle. Thus, their understandings of scientific theories contrasted with the common vernacular sense of the word, in which theory is defined as a simple guess or unsubstantiated idea:

While theories are not immutable, they also do not change on a daily basis; they strive to explain general principles and are usually based on lots of data and changing them is a slow process that will also need to be based on an accumulation of information. (A7, NOSQ)

I called scientific theories "useful fictions" because they are not true in any absolute sense. To some degree they are made up, and that's what fiction is. However, they are not made up in the sense of some arbitrary concoction, but in the sense of what we think works based on evidence. (A1, NOSQ-interview)

The second part of the first item on the NOSQ asked why it is worth learning scientific theories if they are going to change. This question was designed to elicit participants' understandings regarding the explanatory function of theories, as well as the role that theories play in generating research programs and guiding investigations. The responses to this question of Group A participants further substantiated that their views of the nature of scientific theories were consistent with current conceptions.
Eight of the 9 participants cited the explanatory function of scientific theories in their responses to the question concerning the usefulness of learning scientific theories. For these participants, scientific theories provide explanations for natural phenomena, or are simply the best explanations available:

We teach and learn scientific theories because they are the best explanations available, not because they are set in stone for all time. (A2, NOSQ)

Just because theories change doesn't mean they are any less useful or interesting or beautiful. I guess one good example is evolution by natural selection, which is a very powerful story to explain change in living organisms over time. It is the best story available, and students should know something about it. (A1, NOSQ)

Most Group A participants (78%) also justified the utility of learning scientific theories by arguing that they provide a framework for current knowledge and/or for future investigation. In this view, theories provide guidelines for the integration and interpretation of data. Additionally, theories are fruitful in that they generate research programs, and guide further investigations:

One of the characteristics of theories is that they tie together and explain many facts that may have appeared unrelated; they unify many pieces of information and often times have predictive power. (A7, NOSQ)

Regarding the role of theories in inquiry, theories tell us what the questions are, how to go about answering questions, what data to collect, and how to interpret data. (A6, NOSQ)

The participants' views of theories as frameworks that guide data interpretation and future investigations was further explored during the follow-up interviews by asking "Which comes first in scientific investigations, theory or observation?" In response to
the question, most of the Group A participants (78%) indicated that theory precedes observation:

Theory, by all means. Observations make no sense at all without some kind of theoretical framework. (A1, NOSQ-interview)

Theory comes first, because the questions you ask are going to be influenced by the way you see nature, the way you set up your experiments, how you interpret your data, the kinds of data you'll even accept are all influenced by your prior theory. (A6, NOSQ-interview)

Two of the 9 Group A participants discussed a role for serendipitous discovery in which observation precedes theory. However, even for these respondents, it was more typical for theory to precede observation in scientific investigations:

It varies. Often theory comes first, but sometimes surprising observations lead to new discoveries. In practice, the two are closely linked: observation is not done in the absence of theory and theory is not done in the absence of observation. (A3, NOSQ-interview)

This is debated by philosophers, but I think all observation is theory-laden. Sometimes, however, unexpected discoveries are made that fall outside of the theoretical framework. (A5, NOSQ-interview)

Distinctions and Relationship Between Scientific Theories and Laws. Nearly all of the participants assigned to Group A expressed views of scientific laws and the relationship between scientific theories and laws consistent with current thinking among science educators and philosophers. All of these participants viewed scientific theories and laws as different kinds of knowledge; thus, the misconception of a hierarchical relationship between theories and laws was nonexistent. Only one of the participants viewed scientific laws as being certain in any absolute sense of the word—for most
members of Group A, tentativeness applied to laws just as it does for other forms of scientific knowledge. In short, the Group A participants viewed theories and laws as being distinct but equally valid forms of scientific knowledge:

A law is a specific relationship, often mathematical in science, between two or more entities that has been verified to be essentially true. It becomes a pretty firm generalization. A theory is a broader explanation behind a specific law, which helps to explain the WHY of the relationship known as a law. (A8, NOSQ)

The distinction that has worked well for me both in teaching this issue and in interpreting the work of scientists is that a law is a generalization (for some aspect of nature) and a theory is an explanation for how a law works. (A2, NOSQ)

A few of the Group A participants (33%) described scientific theories and laws less specifically. These participants viewed theories as being more general, less quantifiable propositions than scientific laws, with no further elaboration in regard to the relationship between the two kinds of knowledge. All of the participants assigned to Group A viewed scientific laws as tentative. Scientific laws might change less often than theories, but the changes were due more to the simplicity and specificity of laws than their being proven in any absolute way. For these participants, it was important to note that in science, the potential for change always exists, whether the proposition is a theory or a law:

Laws do change, but because they are simpler than theories, they don't change as often. (A6, NOSQ-interview)

[Laws] would have to have the potential to be wrong or else they wouldn't be science. Some may be so well-accepted that it's hard to imagine them being potentially refuted. Then again, the whole idea of gravity and motion Newton had, in large part, really was twisted and
changed almost beyond recognition by Einstein, so maybe it does happen. (A9, NOSQ-interview)

Laws are not more proven than theories. Both are guesses about the organization of the natural world. Laws also change and get discarded. There is no distinction in that sense. (A3, NOSQ-interview)

Further evidence that Group A participants did not give scientific laws higher status or importance over scientific theories was evident in their follow-up interview responses. The participants were asked, "Would you rank theories and laws in terms of status or significance?" If the respondent indicated that they would rank them, they were asked to describe how and to explain their reasoning. If they chose not to rank them, they were simply asked to explain their reasoning. In response to this line of questioning, none of the Group A participants chose to rank theories and laws. The consensus was that both theories and laws are equally important and crucial to science.

All of the Group A participants provided adequate examples of scientific laws. Twenty examples were provided in total, with the number provided by each participant ranging from one to five. Most of the examples came from physical science. Newton's laws of motion, Boyle's and Charles' gas laws, the laws of thermodynamics, and gravity made up 60% of the provided examples. Other physical laws included Kepler's laws of planetary motion, the Heisenberg Uncertainty principle, and Maxwell's four equations. The only examples provided of biological laws were the law of independent assortment and the law of segregation. No inappropriate or misidentified examples were provided by Group A members.

The Creative and Imaginative Nature of Scientific Knowledge. Group A participant responses to the fourth and sixth items of the NOSQ were remarkably
consistent in their views of roles of creativity and imagination in science. All believed that creativity permeates the scientific process, from the earliest conceptions of a research question to the ingenuity required to set up and run an investigation to the ultimate interpretation of the results of the investigation. None of the Group A participants adhered to a rigid interpretation of a single scientific method, but allowed for various approaches to answering the wide variety of possible research questions. In all of these responses, Group A participants' understandings were consistent with current conceptions of the nature of science. Additionally, the Group A participants provided several valid examples of how creativity is integral to science process, including both personal experiences and historical vignettes.

A common view among those who ascribe a role for creativity in science is that it is limited to resourcefulness or ingenuity (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & Lederman, 1998). People tend to see creativity in the way scientists design experiments and deal with unforeseen problems during an investigation, but they often miss the role that creativity data plays in interpretation and the invention of ideas. Group A responses to the third and fourth items of the NOSQ demonstrated that all viewed creativity in science both in terms of resourcefulness in carrying out experiments and in inventiveness in interpreting data and coming up with inferences and theories:

It's critical to understand that scientists are not slaves to the data. The creative part of science is creating meaning from data. Rutherford had to make sense of rebounding charges in his investigation. But keep in mind, the data were simply blips on the screen—they didn't directly say anything about the atom having a dense, positively charged core. (A6, NOSQ-interview)
It seems to me that scientists use creativity and imagination in all states of research. In fact, my understanding is that most of the creative work takes place in the interpretation and writing up of data. (A1, NOSQ)

Scientific research rarely runs as smooth as desired—in fact, many times the next step in an experiment can only be determined when the result from the previous steps are in. There is always space for a researcher to come up with a new way of looking at the data, or new connections that need to be probed. Throughout the research, the scientist is continually looking for or thinking about links to other experiments, techniques, or findings that would complement his/her research, and trying to see connections with other related research. (A7, NOSQ)

Given the seminal role Group A participants assigned to creativity in science, it is not surprising that they all rejected the notion of a single scientific method:

[There are] different methods for different purposes and different methods for different fields. Biologists certainly don't use the same methods as physicists. Even within biology there's a lot of diversity. (A1, NOSQ-interview)

There is no single method that all scientists follow. A lot of people have taken the format of the scientific paper and applied it to the process of science. (A6, NOSQ-interview)

The worst thing we can do in teaching kids about science is to write "the method" on the board and suggest that this is how scientists do science, period. What we see in textbooks as "the method" can serve as a guide, but the danger is the linear method of that presentation. Like, observation always comes before theory—we know that's not true. There's nothing wrong with the individual components that are in "the method," but if we're going to claim a method, we need to also describe how dynamic science really is. (A8, NOSQ-interview)

Finally, only 2 of the 9 Group A participants (22%) failed to provide examples of how creativity is used in science. The other 78% provided vignettes from the history of science that exemplified the role of creativity and imagination in developing scientific knowledge:
The only example I can think of off-hand is Miliken's oil drop experiment. While doing his work, he clearly was playing with the data and ideas and this colored the manner in which he collected and interpreted data. (A6, NOSQ)

Watson in his book, *The Race to the Double Helix*, described how a model of the DNA helix arose out of a chaotic process: a commitment to elegance and simplicity in science, trial- and-error model building, conversations with other scientists, and the (re)interpretation of data collected from various sources. (A5, NOSQ)

The Subjective Nature of Scientific Knowledge. Scientific knowledge has an empirical base but is not based solely on objective, empirical data. Previous knowledge, experiences, training, theoretical commitments, and expectations combine to form a framework that determines what data scientists collect and how they analyze and interpret this data. The fifth item on the NOSQ presented a scientific controversy in cosmology. Participants were asked to explain how scientists could arrive at different conclusions regarding the ultimate fate of the universe when they were looking at the same data. In responding to the question, Group A participants focused on differences in interpretation due to different background factors, as described above. In doing so, they ascribed a role for subjectivity in the construction of scientific knowledge.

In explaining the different conclusions reached by the astronomers, Group A participants focused on neither differences in the evidence being looked at or incomplete evidence. As one participant explained, "Evidence is the arena in which these different ideas challenge one another, but evidence is not the only thing disagreed on—the ideas themselves tend to be the area of disagreement." (A9, NOSQ-interview)
All of the Group A participants attributed the divergent conclusions reached by the astronomers in Item 5 of the NOSQ at least partly to different interpretations. According to the Group A participants, different interpretations can result from astronomers working within various frameworks. These frameworks can vary with the scientists' educational backgrounds, training, philosophical perspectives, theoretical commitments, personal experiences, and beliefs.

In addition to different interpretations of the data, two of the Group A participants emphasized the inaccessibility of the objects being studied as reasons for divergent ideas about the fate of the universe:

Astronomy is an example of a science where you can never touch what you're investigating. All of the data is indirect. There's a lot of possibility for different stages of interpretation along the way. (A8, NOSQ-interview)

The expansion of the universe is further complicated by the fact that it is not something you can test in the laboratory under controlled conditions. From what I understand, astronomers collect lots of different sorts of observations and then must create models and analysis of data to develop or support their theory. (A7, NOSQ)

One important consideration related to the subjective nature of scientific knowledge is the degree of subjectivity involved. Is science viewed as a totally subjective enterprise in which anything goes? To answer this question, Group A participants were asked during the follow-up interview to elaborate on their answers to Item 5 of the NOSQ in order to clarify the degree of subjectivity they meant to convey. The responses to this line of questioning clearly indicated that none of the Group A respondents viewed science as totally subjective.
The majority of Group A participants (67%) described subjectivity in science as constrained by the scientific community. The notions that "any thing goes" or that all ideas are equally viable because "everyone has their own opinion" were rejected:

Scientists use all sorts of plausible assumptions in the process of coming up with a conclusion. Different scientists may use different plausible assumptions and come to a different conclusion. That doesn't mean that it's merely whatever anyone thinks. Each of those different options has to be recognized by the larger scientific community as a viable option. But the data underdetermine which of the options should be chosen. (A3, NOSQ-interview)

It's not that everyone has their own opinion. In astronomy, or any other science discipline, there is a limited repertoire of accepted theory. This tends to constrain what is acceptable to the science community. (A4, NOSQ-interview)

Social and Cultural Influences on Scientific Knowledge. Science is a human endeavor that operates within particular cultures and societies. Science profoundly impacts, and is impacted by, the culture and society within which it operates. For example, a culture's politics, economics, religions, beliefs, and values all influence what science is and how it is done. The culture, in turn, is impacted by the scientific knowledge and technology it generates.

The fourth and fifth items of the NOSQ provided opportunities for respondents to discuss their beliefs about cultural and societal influences on the generation of scientific knowledge. Participants assigned to Group A described two cultures in their responses. The first of these involved the culture within science itself, including such factors as peer review and consensus. The second way culture was dealt with was how societal factors (such as politics, economics, and religion) impact science.
Eight of the 9 Group A participants (89%) described a culture of science and how it influences the generation of scientific knowledge. Most of these descriptions were provided as respondents contrasted science and art in response to Item 4 of the NOSQ. Common among these responses were discussions of a culture or community within science that establishes rules of practice and evidence, essentially acting as judge for what is acceptable in science:

There is also the question of how work is accepted and critiqued by the community. Scientists have established a fairly standard (though continually changing) canon of rules for protocols and methods that should be followed in order to "count" as science. Like artists, scientists are always creatively developing new techniques and methods, but ultimately, their work and its merit is judged by a group of their peers. (A7, NOSQ)

Both [science and art] are groups of disciplines with long histories and identifiable bodies of knowledge and practices. They are practiced by members of an identifiable community or culture. Members share particular values and norms, speak a common language, and have undergone years of rigorous study, training, and apprenticeship. Both science and art require the use of individual creativity and social consensus. Within a given science or art discipline, for example, members negotiate and reach consensus on what is "good" or "bad" science or art. (A5, NOSQ)

A second set of responses focused on objectivity and subjectivity in science. In answering Item 4 of the NOSQ and probing questions during follow-up interviews, respondents described the community of science as playing a crucial role in limiting subjectivity by application of peer review and group consensus:

Scientific work emphasizes community of assent and duplication of effort, in contrast to an emphasis in art on the unique. (A4, NOSQ)

Individual subjectivity can, in part, be constrained by "public" science. There's lots of potential subjectivity in the way an individual does
science. But, as science critically examines ideas, problems are hashed out. Through the social process, the individual creativity and subjectivity is constrained, in part, by the interaction with others. The final product will not be objective, but will be less subjective. (A6, NOSQ-interview)

No, [science is not totally subjective], it's objective in terms of community. You have to convince many people of your idea, and this provides a kind of objectivity. (A7, NOSQ-interview)

Finally, 2 Group A participants (22%) described cultural influences of the society in which science is conducted on the science that is done. These participants listed various factors, including economic and political contexts, funding for science, and gender and racial issues:

Both science and art tell stories of some kind. The stories are the result of what the individual brings in terms of experience, knowledge, interests, and preferences. These are shaped by the larger culture the individual lives in. For example, if it's not deemed fundworthy, it's not going to go anywhere. (A1, NOSQ-interview)

Both [science and art] are socially constructed disciplines that shape and are shaped by their larger social, economic, cultural, and political contexts....Cultural views of racial hierarchy and gender difference shape whether scientists look for patterns of similarities or differences in the data collected. (A5, NOSQ)

Group B Views of the Nature of Science

The following is a detailed profile of the nature of science conceptions of the 9 participants assigned to Group B. These assignments were made subsequent to the analysis of their responses to the NOSQ and follow-up interviews, and based on the consistency of their views with the current views of the nature of science expressed in the literature by science educators, science philosophers, science historians, and science reform organizations.
The Empirical Nature of Scientific Knowledge. Like the responses of participants assigned to Group A on the first and fourth items on the NOSQ and follow-up interviews, the responses of participants assigned to Group B reflected a belief in an empirical basis for scientific knowledge. In fact, 8 of the 9 Group B participants (89%) indicated that scientific claims ultimately rely on physical evidence. These participants used terms such as *empirical evidence, measurable, quantifiable, data, facts*, and *physical truth*.

Unlike the Group A participants, however, a sizable fraction of Group B participants (44%) indicated that scientific knowledge is based *solely* on the evidence. In their view, the reliance on empirical evidence makes science an objective endeavor. Thus, they emphasized empiricism to the exclusion of the more personal attributes of interpretation, speculation, and opinion. It is as if these respondents believed that scientific knowledge is read directly from the book of nature:

Science is demanding empirically measurable evidence of reality. It is very rational and uses empirical, quantifiable, evidence and logic to prove our hypotheses. (B2, NOSQ-interview)

Science is a process, a way of objectively, carefully studying our environment and ourselves. Science relies more on what is seen; art more on what is felt. Science deals more with facts; art, imagination. I see them as a continuum, with science at one end and art at the other. (B4, NOSQ)

Other Group B participants spoke of science as a search for objective "truth."

For example, one Group B participant stated, "Science and art are different in that science is tasked with creating truth....Art is free of this constraint" (B8, NOSQ). These
Group B participants also emphasized the empirical nature of scientific knowledge as a way to bypass human subjectivity in the quest for physical reality, or truth.

In all, 6 of the 9 Group B participants (67%) emphasized the empirical nature of scientific claims to the exclusion of subjective factors, such as human bias and values. The remaining 33% of Group B responded in ways that were more consistent with contemporary views of science. These participants expressed less absolutist views of the relationship between evidence and scientific knowledge. For this minority of Group B participants, physical data could support, but not necessarily prove scientific claims.

**Inference and Theoretical Entities in Science.** A misconception commonly elicited by Item 2 of the NOSQ is that atomic structure is directly observable, rather than the product of indirect evidence and inference. Most, but not all, Group B responses indicated that they understood the inferential nature of scientific models, such as those describing atomic structure, although their responses were not as detailed in regard to the technical aspects of the evidence used to develop models of atomic structure. Thus, their understandings of the inferential nature of scientific models did not differ significantly from those of Group A.

The first item on the NOSQ asked whether scientific theories change and the reasons they might change. Only 2 of the 9 Group B participants (22%) indicated that theories do not change. These 2 participants believed that, while theories might be added to or refined, the theory itself does not change. The rest of the Group B participants (78%) stated that theories do change. Each of these participants cited a single reason for theory change, the accumulation of new evidence:
New phenomena will always put some theory to the test. Basically, theories change as new data comes to light. (B9, NOSQ)

As more research and observations are made, this information can be used to modify, enhance, or disprove the original theory. (B5, NOSQ)

Theories change because we continue to collect data. If new data don't fit, we have to modify the theory. (B4, NOSQ)

During the follow-up interviews, each of the participants was asked whether new evidence was the only reason theories change. In response to this question, 3 of the 7 who cited new evidence as the sole source of theory change on the NOSQ maintained that new evidence was the only reason theories would ever change. These participants failed to explicate a role for new ways of looking at existing evidence, such as paradigm shifts as a reason theories might change. On the other hand, 4 of the 7 described a role for new ways of looking at existing evidence as a reason theories might change. For these Group B participants, the social and cultural context in which data are collected is as important as the data itself when it comes to theory refinement/change. It is important to note that this aspect of the 4 Group B respondents' beliefs about why theories change would have been missed without detailed probing during the follow-up interview.

Another indication of a person's understanding of the concept of theory change is the ability to provide valid examples. Group B participants provided substantially fewer examples of theories that have changed than did the Group A participants. In total, Group B participants provided only six accurate examples of theory change, compared to the 24 that Group A participants provided. The shift from a geocentric to a
heliocentric model of the solar system accounted for half of the Group B examples. Other examples included the shift from Newtonian mechanics to Einstein's theory of relativity and the change from Lamarckian to Darwinian views of evolution. Two of the Group B participants provided inaccurate examples, including calling the recent discovery of new planets a theory and equating the four food groups and food pyramid with theory.

Unlike the Group A participants, none of the members of Group B spoke directly of the well-substantiated nature of theories. In fact, the only direct references to the level of evidence for theories were made by 2 Group B members, who clearly indicated that they viewed the term in the vernacular sense of the word; i.e., a scientific theory is "just a theory." In this view, a scientific theory is more a guess or unsubstantiated idea than a well-supported concept:

I believe that theories can change. Theories are just that, theories. (B5, NOSQ)

Yes, theories change. By definition, a theory is not a law. (B2, NOSQ)

Group B participants' responses to the question of why it is worth learning about scientific theories indicted that they had less sophisticated understandings of the nature of scientific theories than did the Group A participants. For example, only 1 of the 9 Group B participants (11%) discussed the explanatory power of theories in any detail. The rest of the Group B participants (89%) could only describe theories as "best thinking" or "the extent of current knowledge." In doing so, the Group B participants
appeared to downplay the empirical, well-supported nature of theories, viewing them, instead, as being incomplete:

It is important to teach theories because they represent the extent of our current knowledge. I think it is important to tell students we don't know everything. For example, the theory of evolution is almost taught as the gospel (law) of evolution. The theory has taken on a life of its own. (B5, NOSQ)

We teach theories because they are the best thinking of the day. As we accumulate evidence and information, some of that thinking will be found to be lacking or to be based on incorrect assumptions. Therefore, it is important to continue to update what we teach. (B6, NOSQ)

Interestingly, three of the Group B respondents (33%) emphasized practical reasons for learning scientific theories:

We teach and learn theories because it is important to know the latest for making decisions today. (B4, NOSQ)

Scientific theories...are the tools used by humans to understand nature and to develop methods to support and enhance human existence. (B9, NOSQ)

We teach science theories because they provide our best understanding of the universe we inhabit. As an engineer, we use current theories to develop products that work. (B8, NOSQ)

Only one Group B participant indicated a role for scientific theories as guiding frameworks for investigation. "We also use [theories] to derive further hypotheses for testing. Thus, theories are very important to any scientific inquiry." (B2, NOSQ). The vast majority of the Group B participants (89%) provided no evidence that they understood that theories play an important role in generating research questions and guiding scientific inquiry.
Additional support for this conclusion was provided by Group B's responses to the question of what comes first in conducting scientific investigations, theory or observation. While none of the Group A participants viewed observation as independent of theory, but recognized the theory-laden nature of observation in scientific investigations, 6 of the 9 Group B participants (66%) indicated that observation precedes theory in science investigations. These responses reinforce the conclusion that most of the Group B participants did not have complete understandings of the role of theories in guiding scientific research:

In most cases it's observation that comes first. Observation in scientific investigations is what scientists use to generate theories. (B3, NOSQ-interview)

It starts with observation. In our research, we typically see a phenomenon that we weren't expecting, and then based on that observation we try to come up with an explanation for why that occurred. (B9, NOSQ-interview)

In science, it's observation that comes first. For example, Gregor Mendel looked at his observations and then developed his ideas about heredity. (B5, NOSQ-interview)

The other four participants noted that it could go either way. While these participants rejected the idea that all observations are theory-laden, their responses indicated that they believed that scientific theories play a role in generating investigations and selecting what to observe. It was evident from their responses that the Group B participants who believed theory precedes observation were less sure about their answers than those that viewed observation comes first. The use of qualifying words like "My guess" and "it could be the other way around" indicate low confidence
in these responses. Perhaps the reason for this trepidation lay in the view that observation *should* precede theory. For at least one Group B participant, the fact that theory might influence observation is more indicative of human nature than the way science is "supposed" to be done:

People are not supposed to go in with preconceived ideas, but certainly folks go in with some idea of what they're going to find. Ideally, though, I think observation would come first, because we all like to have the notion that knowledge is objective. We would rather not think about the fact that we impose our biases and thought patterns into whatever we're looking at, but that we look at something and create theories or laws about it. (B1, NOSQ-interview)

**Distinctions and Relationship Between Scientific Theories and Laws.** All of the participants assigned to Group B expressed inadequate views of scientific laws and the relationship between theories and laws. The majority of Group B participants believed laws to be true in the absolute sense of the word and embraced the misconception that theories become laws when proven through repeated testing. For the Group B participants, scientific theories are based on less evidence and are, therefore, less valid than "proven" laws.

Seven of the 9 Group B participants (78%) explicitly stated in their responses to the NOSQ and/or probing during the follow-up interviews the misconception that scientific theories become laws when proven, or when they have "passed" repeated testing:

Yes, but I don't know how someone decrees that. I think the way that happens is when you have a mathematical model that works every time for the widest range of conditions. At that point, they consider it a law. (B9, NOSQ-interview)
The very reason it is considered a theory (rather than a law) is the humble (at times) recognition that, given the advancement in testing or research, this conclusion could be challenged in the future...I have always held a theory is a law in process. If it becomes so obvious that the theory is confirmed, it will be a law. (B3, NOSQ)

I think there is a difference, but it's one based on degree of proof...When you have something you would state into law, that's basically when you have a theory that's been tested to the point that you have so much confidence that you really believe it is 100% truth. (B8, NOSQ)

The other two respondents (22%) did not specifically describe a hierarchical relationship between theories and laws. However, their responses still indicated that they believed laws to be proven true and theories to be tentative, either because not enough data are available, or because scientists are unable to design the necessary experiments or apparatus to adequately test theories:

We have a theory of evolution, but a law of gravity. Gravity seems in every test to be a constant of the universe. Evolution seems true; it's the best explanation we have for the physical evidence we have. But evolutionary theory has been changed and modified as more information is found. (B2, NOSQ)

Scientific laws are generally accepted and demonstrated as being true. On the other hand, scientific theories are not yet proven, possibly because of an inability to design instrumentation or experiments that would absolutely demonstrate a theory (for example, in astrophysicists, where scientists speculate about the big bang theory of creation and black holes, but may be unable to categorically prove these theories. (B7, NOSQ)

Group B participants' views of laws as proven knowledge was further probed during the follow-up interview by specifically asking if scientific laws ever change. In response to this question, two thirds of the Group B participants indicated that scientific laws do not change:
I can't see a law changing without nature changing. (B3, NOSQ-interview)

Laws may be interpreted a little bit differently, but they do not change. I think it's more a question of when something becomes a law. (B9, NOSQ-interview)

Laws do not change in natural science, but they do change in social science. There are simply too many assumptions in social science for the laws to ever be proven. (B2, NOSQ-interview)

Laws start out as theories. In my lifetime, I don't know that I've ever watched any theory become a law, but I suppose that's the way it happens. (B6, NOSQ-interview)

The other four Group B participants (44%) indicated they believed that scientific laws could change. At first, these responses might appear surprising, given their previously described responses regarding the proven nature of scientific laws. However, closer scrutiny of several of their responses indicated that their expressions of the tentative nature of scientific laws may not be all that tentative after all. For example, one participant described scientific laws as capable of change, but only when "what somebody thinks is a law really isn't." Another seemed willing to accept that laws could change, but waffled between this tentative view and the notion that "laws are carved in stone." When pressed for examples of laws that had changed, the participant simply responded that he did not know of any. Finally, a third participant indicated that scientific laws are proven, but not necessarily for all time. Given enough time, data may accumulate that causes a law to change. However, for all practical purposes this respondent viewed laws as absolute, since they could be "proven" within the context of one's lifetime:
A law is not proven transhistorically, but within a given context. It may not change in a hundred years while someone is alive, but certainly in longer periods new data can accumulate that does cause it to change. (B1, NOSQ-interview)

Only one of the Group B participants appeared to understand that scientific laws can change for much the same reason as other scientific postulates:

Laws have the potential to change for the same reasons other things change. You get new data and you have to modify that. My belief is that certain laws will remain throughout the lifespan of the human race or the universe. Certain laws may not. (B8, NOSQ-interview)

Participants' beliefs concerning a hierarchical relationship between theories and laws was further explored during the follow-up interviews by asking the question: "Would you rank theories and laws in terms of status or significance?" If respondents indicated that they would rank them, they were asked to describe how and to explain their reasoning. If they chose not to rank them, they were simply asked to explain their reasoning. Only 2 of the 9 Group B participants ranked laws as being most important in response to this line of questioning:

Laws are the ultimate goal, but theories are what scientists work on day to day. (B5, NOSQ-interview)

We use laws a lot in the work we do. In general, I think that theories are still being tested. A theory is a postulate that has not been widely tested and therefore is not widely accepted. (B9, NOSQ-interview)

Two other participants ranked theories as being more important/significant, but only because laws are proven and, therefore, require no additional investigation.
Theories were viewed as being more interesting to scientists because they are works in progress:

Law is the place to be for a scientific idea, but theories may be more important because they spawn more research—no one's concerned that the law of gravity is going to go away at this point. (B2, NOSQ-interview)

Theories may be more significant than laws because they're still working with them, but scientists depend more on laws. (B3, NOSQ-interview)

The rest of the Group B participants either chose not to rank theories and laws (22%), or did not answer the question (33%).

None of the Group B participants contrasted the descriptive role of scientific laws with the explanatory nature of scientific theories. Thus, Group B respondents differed markedly from the majority of Group A respondents, who viewed scientific theories as nonobservable explanations or inferences and scientific laws as descriptions of patterns or relationships among observable phenomena.

While Group B participants were able to provide examples of scientific laws, they were not able to do so with the same frequency or accuracy as Group A members. Only 66% of the Group B participants provided accurate examples of laws, for a total of 8 (compared to 21 in Group A). Gravity and the laws of thermodynamics accounted for 60% of the Group B examples and no examples of biological laws were provided. One-third of the participants provided inaccurate examples of scientific laws. These participants confused scientific laws with such things as the observation that falling objects accelerate at 32 feet per second squared, the discovery of the Van Allen radiation belts, and the geocentric model of the universe. This latter example is
interesting in that it clearly reflects the misconception of a hierarchical relationship between scientific theories and laws:

I have a feeling that when people thought the earth was the center of the universe, it was probably taken as a law at the time. Then, when they observed things that didn't fit the pattern, they formed a new theory. (B6, NOSQ-interview)

In summary, all of Group B participants expressed absolutist views of the nature of scientific laws. Unlike their Group A counterparts, most believed scientific theories and laws to be the same type of knowledge, only proven to a different degree. A large majority of the Group B participants expressed the view that theories become laws when enough evidence is accumulated in their favor. Finally, Group B participants were able to provide few adequate examples of scientific laws, and one-third of the examples they provided were inaccurate.

The Creative and Imaginative Nature of Scientific Knowledge. Like their Group A counterparts, participants assigned to Group B ascribed roles for creativity and imagination throughout the scientific process. Their views of creativity went beyond the notion of ingenuity in devising and trouble-shooting experiments, and included data interpretation, pattern recognition, and devising new theories. Group B provided descriptions of the use of creativity in science, but, as the representative quotes that follow will show, not with the same frequency or detail as members of Group A. Furthermore, despite their commitment to the roles of creativity and imagination in science, all of the Group B participants adhered to the notion of a single scientific method.
Possibly, this inconsistency in Group B views is indicative of conceptions that are incomplete or not well conceived. On the other hand, it may simply reflect the fact that Group B participants' conceptions of creativity in science differ in specific ways from those of Group A. Either way, it appears that Group B participants' views of the creative and imaginative aspects of the generation of scientific knowledge were in some ways inconsistent with the views currently espoused by science philosophers and educators.

Group B responses to the third and fourth items of the NOSQ demonstrated that most (78%) viewed creativity and imagination as integral to the process of science. Like their Group A counterparts, these respondents viewed creativity in science both in terms of resourcefulness in carrying out experiments and in inventiveness in interpreting data and identifying inferences and theories:

Scientific thinking requires an element of creativity—an ability to think "outside the box" and to be open to new ideas—and to see patterns that emerge that may not be the pattern one thought was going to emerge....Pattern recognition requires a lot of creativity and imagination, and often the patterns that emerge do not match prior expectations. It takes imagination to step back and allow new patterns to emerge. Those, then, become new theories to be tested in future experiments. (B6, NOSQ)

Two of the 9 Group B participants (22%) held a much more limited view of creativity and imagination in science. The first of these respondents held a restricted view of creativity in science: "My view is that there isn't a lot of creativity in science. It's not like a jazz musician who's into improvisation; science is much more methodological." (B7, NOSQ-interview). For this respondent, creativity in the early
stages of an investigation was avoided as scientists rigorously adhered to their experimental design and replicated their results:

My stereotypical view of a scientist is that they have one good idea (i.e., the subject of an experiment) and then they laboriously perform the experiment over and over, collecting data. There may be room for creativity and imagination in the interpretation of the data at the end of the process, but I would think that scientists would want to keep to their research plan. (B7, NOSQ)

The second of these respondents viewed creative thinking in science in a negative way. For this participant, scientists sometimes used their creativity to twist the data to conform to preconceived ideas and biases, especially in regard to evolutionary theory:

As scientists lock onto one particular theory, they tend to use their creativity to prove it rather than an openness to other possibilities. Evolution seems the best example of this to me. Too much evidence is lacking for that one theory to dispel any other explanation of the universe. (B3, NOSQ)

A little more than half of the Group B participants (56%) provided valid examples of the influence of creativity and imagination in science. Their responses contrast with those of the Group A participants, where 80% provided adequate examples. Like those of Group A participants, these examples consisted of vignettes from the history of science. However, the Group B examples did not contain the same level of detail as those of Group A:

The one example I can think of is Richard Feynman. Feynman was a wild man. He was energetic, creative, and he loved art. Feynman was also a math and physics whiz and was able to take it to the next level and developed shortcuts and advanced techniques to reduce the amount of
computational effort required to solve problems. His advancement may have shortened W.W.II. (B5, NOSQ)

I think it was Einstein who said "imagination is more important than knowledge." After learning the laws and debates in any given field, one must then imagine the possibilities that go beyond those laws. It seems to me, for instance, that the Copernican revolution was about such imaginative capabilities. (B1, NOSQ)

Despite the large degree of consensus that creativity and imagination are integral to scientific processes, all Group B participants expressed belief in a single scientific method. One of the common themes among these responses was the need for hypothesis testing in science:

Science can be defined by the scientific method, which means you generate hypotheses and design experiments to test the hypotheses to see if you can come up with theories and/or laws. At some level, all scientists use the scientific method. There must be testing of hypotheses, for example. (B1, NOSQ-interview)

Science is the study of the world around us, based on forming hypotheses to test theories. You have a theory and you formulate a hypothesis, and then you test that hypothesis, and then you reject it or not and advance... Yeah, I would say that all scientists use the scientific method. I can't think of an example in science where they wouldn't. (B6, NOSQ-interview)

The scientific method involves asking questions and developing and testing hypotheses. It's what I do and what science is to me. People can do science without testing hypotheses, but it's really just a less formal application of the scientific method. In my work, I'm always testing hypotheses, but I'm not always writing them out. (B5, NOSQ-interview)

While hypothesis testing is an important method for discriminating among ideas in science, it is not the only method of doing science. Essentially, Group B participants viewed all of science as following the scientific method, which they equated with
hypothesis testing, or experimentation. As one Group B participant explained, "Science uses an experimental method, that's what makes it science and separates it from art, religion, and history, which are all more interpretive." (B7, NOSQ-interview) In doing so, Group B participants left out the possibility of counting descriptive and correlational designs as science.

The idea that there exists a single way of doing science appears to be at odds with the notion of science as a creative endeavor. As one Group A participant had explained earlier:

I don't agree with this [5-step] view of scientific method. It's part of a recipe that fits within science, but the larger, creative approach of how one comes up with an idea, how it's embedded in the ideas of people around us and before us—that's a fundamental part of science that wouldn't be captured in that kind of description. (A9, NOSQ)

Clearly, Group B views of a single scientific method were incompatible with their descriptions of science as a creative endeavor. On the one hand, they could describe science as a creative, imaginative endeavor, but on the other hand, they limited science to a fairly rigid view of hypothesis testing. One explanation for this inconsistency is that Group B participants viewed creativity as applying only to particular steps or stages within the framework of the scientific method. This view is supported by the comments of several Group B participants on the NOSQ and during the follow-up interviews:

I think there's a kind of formula to science, and it goes back to the scientific method. Creativity comes in mainly when you're pushing the envelope beyond what is currently known. It also can be in the design of experiments and interpretation of data, but figuring out something like how to measure the moisture level of the duff layer is low-level
creativity. Figuring out the ecosystem or something like global warming is high-level creativity. (B5, NOSQ-interview)

When you look at the scientific method, creativity comes in when you postulate what causes a particular phenomenon. You're trying to deduce from data what causes it. There's a hardcore logic to it, but it's also creative, because you have to use your imagination to fill in the gaps. "Now let's develop an experiment that will determine or not if that's what really happened." (B9, NOSQ-interview)

The scientific method requires that you do experiments that distinguish between theories. The theorists are coming up with theories. Now it's up to the scientific method to determine whether it's right. (B8, NOSQ-interview)

It is clear in these responses that at least some of the Group B participants separated creativity to a large extent from the process of doing science. For these participants, most creativity in science occurs before and after the scientific method is employed, as theories are postulated and ideas are developed. After that, the scientific method is used to determine whether the scientist's postulates were correct.

The Subjective Nature of Scientific Knowledge. As described earlier, the fifth item on the NOSQ presented a scientific controversy in cosmology. Participants were asked to explain how astronomers could arrive at different conclusions regarding the ultimate fate of the universe when they were looking at the same data. Unlike Group A participants, who focused on differences in interpretation, participants assigned to Group B, tended to focus on inadequacies in the data or differences in the data the astronomers were using. As one respondent stated, "Boy, if the astronomers were all looking at the same data, I don't know how they could reach different conclusions" (B6, NOSQ-interview). Responses like this reflect a more objective view of science.
Two of the Group B participants ascribed the controversy regarding the ultimate fate of the universe to problems with the data:

Perhaps those who decided the universe is shrinking were looking at a specific part of the universe—for example, planets that are gradually being pulled closer to their suns by gravity. (B6, NOSQ)

The answer is very simple. The observational and experimental evidence available 50 years ago did not put a lot of constraints on the theories. In the absence of measurements, scientists, like everybody else, are free to dream about possibilities. (B8, NOSQ)

Five of the 9 Group B responses (56%) allowed that subjectivity is a part of science, especially in regard to interpreting data. However, these participants believed that subjectivity, while a factor of human nature, is to be avoided in science:

Science is not totally objective and value free, even though it is supposed to be. (B3, NOSQ-interview)

There's no way to escape human bias—there's always some subjectivity in any human endeavor. But in science, it's something to overcome as much as possible. Science methodology says you set aside your subjective views and let the evidence speak. (B2, NOSQ-interview)

There are some pretty rigorous steps you go through in the whole scientific process, formulating a hypothesis and how you test the data and how you sample and that sort of thing. But where everything falls apart is where you interpret the data. (B6, NOSQ-interview)

Two of the Group B participants (22%) appeared to have adequate understandings of subjectivity in science. These participants emphasized the theory-laden nature of observations by describing how different backgrounds can influence how scientists view and interpret data:
A lot of the interpretation depends upon where one went to school, which theories are more important, what the research leader thinks, and on and on. That's just the way science is. (B5, NOSQ)

Like in history, the story being told is greatly affected by the person telling the story. There are just competing theories about how to read the evidence. Science I suspect, is not as objective as many scientists would like us to believe. (B1, NOSQ)

Social and Cultural Influences on Scientific Knowledge. As described in the Group A Views of the Nature of Science section, Items 4 and 5 of the NOSQ were intended, in part, to elicit views of social and cultural influences on the development of scientific knowledge. In responding to the questions contained in these items, Group B participants did not refer to social and cultural influences at nearly the same depth or frequency as did Group A. In fact, only three Group B participants (33%) made any reference to social/cultural influences. While Group B provided much fewer references to these influences overall, the nature of these references was parallel to that of Group A. For example, during the follow-up interview, one participant described how peer review within the culture or community of scientists provides a safeguard against total subjectivity:

Bias and pride can be a bad thing. It's set back the progress of science in certain areas. In the end, though, the evidence becomes more and more overwhelming against them. Additionally, peer review is a safeguard against this—it helps weed out some of the subjectivity. (B9, NOSQ-interview)

A second participant briefly described how the culture/society at large can impact science. This participant, in answering questions about his response to Item 5 of
the NOSQ, mentioned without much detail how society can influence the way scientists make and interpret observations:

Sure, facts can be seen differently; I've seen it cross-culturally. We are all shaped by the context/environment in which we are raised. Things like gender differences can have an impact, too. Men and women are different, and so they see things differently. (B3, NOSQ-interview)

A third Group B participant provided a brief historical example of how society can impede the development of new and unpopular scientific ideas:

People with alternate information or opposing theories are not listened to. They're labeled and discounted. Galileo ran into similar problems with his observations and theories of the solar system. It didn't fit popular dogma. (B5, NOSQ)

It should be noted that this respondent provided the example in support of his view that evolution has been accepted by society to the point that those who question it are labeled "heretics."

Apparently, Group B participants viewed the influence of science on society as more significant than societal influences on science. The majority of the Group B participants (67%) made no reference to social or cultural influences on the development of scientific knowledge, contrasting markedly with the 89% of the Group A participants who ascribed a role for such influences.

Assessment and Analysis of Decision-Making

Participants' decisions regarding four science and technology based issues were elicited through administration of the DMQ at the beginning of the study. Analyses of
the DMQ responses, in conjunction with participants' responses to follow-up interview questions about their responses to the DMQ, were used to compare the decisions of Group A and Group B. Furthermore, for each group the DMQ responses and interview transcripts were scrutinized for factors that influenced the decisions and the strategies the participants used to arrive at their decisions. Participants cited factors more in their DMQ responses, while discussing their reasoning strategies more in the follow-up interviews. The results of these analyses were used to answer the research questions of the investigation:

1. What is the relationship, if any, between adults' understandings of the nature of science and the decisions they make on science and technology based issues?

2. What is the relationship, if any, between adults' understandings of the nature of science and the factors they use to reach decisions on science and technology based issues?

3. What is the relationship, if any, between adults' understandings of the nature of science and the reasoning they use to reach decisions on science and technology based issues?

Comparison of Group A and Group B Decisions

The first step in analyzing the decision-making of Group A and Group B participants was to compare the total number of "yes" and "no" decisions for each group. The DMQ contained four scenarios, each based on a particular science and technology based issue. The four issues covered a range of current socio-scientific
problems, followed by three to five questions eliciting yes/no decisions from the participants.

1. Fetal tissue implantation - Five questions.
2. Greenhouse gas emissions and global warming - Four questions.
3. The relationship between diet, exercise and cancer - Three questions.
4. The relationship between smoking and cancer - Three questions.

"Yes" and "no" decisions were tallied for each group and summed separately for each question, scenario, and the total DMQ. The vast majority of responses included the words "yes" or "no," and were tallied accordingly. Other common positive responses included "I agree," "They are justified," "I think so," "Absolutely," and "I agree."

Typical negative responses included such phrases as "I would not support," and "I disagree." A few DMQ responses were unclear or the respondents were unwilling to commit to a decision for a particular question. These responses were noted and the respondents probed during the follow-up interviews to clarify their decisions. In a few cases, such probing did not result in the respondent making a clear decision. These responses were categorized as "undecided."

Table 9 illustrates a comparison of the Group A and Group B decisions for each question on the DMQ. It is clear that there is little difference in the two groups' overall decisions. None of the responses, whether "yes," "no," or "undecided," differed between Group A and Group B by more than two. Furthermore, the vast majority of responses (93%) differed by one or fewer, and a sizable minority (29%) did not differ at all.
<table>
<thead>
<tr>
<th>Question</th>
<th>Yes Group</th>
<th>No Group</th>
<th>Undecided Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>1</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>(Fetal Tissue Implantation)</td>
<td>2</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>(Global Warming)</td>
<td>2</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>1</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>(Diet/Exercise &amp; Cancer)</td>
<td>2</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Scenario 4</td>
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<td>2</td>
</tr>
<tr>
<td>(Smoking &amp; Cancer)</td>
<td>2</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

When the two groups' decisions were examined at the scenario level, a similar pattern emerged (Table 10). Forty-two percent of the comparisons of total numbers of "yes," "no," or "undecided" responses for each scenario between the two groups differed by one or fewer. None of them differed between the two groups by more than two, except in Scenario 4. In Scenario 4, which dealt with cigarette smoking and cancer,
Table 10

Comparison of Group A and Group B Responses By DMQ Scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>No. of Questions/Responses</th>
<th>Yes Group A</th>
<th>Yes Group B</th>
<th>No Group A</th>
<th>No Group B</th>
<th>Undecided Group A</th>
<th>Undecided Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>5/45</td>
<td>33</td>
<td>35</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>(Fetal Tissue</td>
<td></td>
<td>(73%)</td>
<td>(78%)</td>
<td>(22%)</td>
<td>(22%)</td>
<td>(4%)</td>
<td></td>
</tr>
<tr>
<td>Implantation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>4/36</td>
<td>28</td>
<td>28</td>
<td>7</td>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(Global Warming)</td>
<td></td>
<td>(78%)</td>
<td>(78%)</td>
<td>(19%)</td>
<td>(19%)</td>
<td>(3%)</td>
<td>(3%)</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>3/27</td>
<td>18</td>
<td>16</td>
<td>9</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(Diet/Exercise &amp;</td>
<td></td>
<td>(67%)</td>
<td>(59%)</td>
<td>(33%)</td>
<td>(41%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancer)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td>3/27</td>
<td>16</td>
<td>20</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>(Smoking &amp; Cancer)</td>
<td></td>
<td>(59%)</td>
<td>(74%)</td>
<td>(37%)</td>
<td>(26%)</td>
<td>(4%)</td>
<td></td>
</tr>
</tbody>
</table>

16 "yes" statements were tallied for Group A out of a possible 27 (3 items x 9 participants), or 59%. A total of 20 "yes" responses were tallied for Group B, which computes to 74% of all the Group B responses to the three items that followed Scenario 4. The reciprocal pattern was evident for the "no" responses, where there were a total of 10 (37%) for Group A and 7 (26%) for Group B.

It should be noted that the set of questions following each of the DMQ scenarios did not represent subscales. That is, they were not meant to measure particular aspects of decision making. For example, there was no particular correspondence between scenarios. Even the numbers of questions differed between the four scenarios. The only
relationship existing among the questions was the topic of the scenario they were associated with. Therefore, it makes most sense to compare Group A and Group B responses to individual questions and, perhaps, the entire DMQ, than it does to treat the four scenarios as units or subscales.

Given this, there appears to be no difference in the decisions reached by the members of Group A and Group B. Not only is there little difference in responses to individual questions (Table 9), but there is also little difference in the decisions of the two groups when their responses to the DMQ as a whole are considered (Table 11). A difference of 4 "yes" responses out of a possible of 135 (3%) is not substantial enough to warrant the conclusion that the two groups' decisions differed in any practical sense of the word. In fact, the difference in the "yes" response rate for the DMQ could largely be explained by the three additional "undecided" decisions of the Group A participants.

Table 11
Comparison of Group A and Group B Responses for the Entire DMQ

<table>
<thead>
<tr>
<th>No. of Questions/Responses</th>
<th>Yes Group A</th>
<th>No Group A</th>
<th>Undecided Group A</th>
<th>Yes Group B</th>
<th>No Group B</th>
<th>Undecided Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15/135</td>
<td>95 (70%)</td>
<td>36 (27%)</td>
<td>35 (26%)</td>
<td>4 (3%)</td>
<td>1 (1%)</td>
</tr>
</tbody>
</table>

participants' decisions. To encourage the listing of such factors, the questions following each of the four scenarios instructed respondents to list the reasons for their decisions. The intention was to use the list of factors provided by the two groups to determine (a)
the relative influence of the nature of science in reaching these decisions, and (b) whether there were any differences in the kinds of factors listed between the two groups.

The first step in the analysis of factors was to examine each participant's answers to individual DMQ items for references to factors influencing their decisions. Identified factors were then listed separately for each group per scenario. In most cases, participants listed multiple factors. Next, the four resulting lists of factors were grouped into common categories, such as the nature of science, moral/ethical issues, pragmatism, and personal choice. In all, eight categories were created for the 26 factors identified in the DMQ responses. Definitions and representative quotes for each of these categories are provided in Appendix E.

Note that the first primary category reported in each of the data tables (Nature of Science) was included because of its relevance to the research questions of this investigation, rather than the frequency with which it was cited. Remaining factors were placed in a second broad category (Other). Under "Other," factors mentioned by 3 or more participants in one of the groups were listed separately. For clarity of presentation, factors that were cited by only one or two participants in a scenario were grouped under the "Miscellaneous" heading.

Scenario 1: Fetal Tissue Implantation. The first scenario dealt with an experimental procedure involving the use of fetal tissue implantation for the treatment of Parkinson's disease. While this scenario contained a strong ethical/moral component, it also provided opportunities for respondents to comment on a variety of nature of
science issues, including the subjective nature of whether the fetus is alive, in what ways science can inform ethical dilemmas, and whether the treatment needed to be proven as effective before participants were willing to recommend it.

Table 12
Scenario 1 Categories of Decision Making Factors for Group A and Group B

<table>
<thead>
<tr>
<th>Group A Factors</th>
<th>No. of Respondents</th>
<th>Group B Factors</th>
<th>No. of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of science</td>
<td>0</td>
<td>Nature of science</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Moral/ethical issues</td>
<td>9</td>
<td>Moral/ethical issues</td>
<td>9</td>
</tr>
<tr>
<td>Values</td>
<td>9</td>
<td>Values</td>
<td>7</td>
</tr>
<tr>
<td>Social/political issues</td>
<td>5</td>
<td>Social/political issues</td>
<td>2</td>
</tr>
<tr>
<td>Support of Science</td>
<td>3</td>
<td>Support of Science</td>
<td>1</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5</td>
<td>Miscellaneous</td>
<td>1</td>
</tr>
</tbody>
</table>

Obviously, from the data presented in Table 12, the nature of science was not a major contributing factor in the decisions reached by either Group A or Group B. In the first scenario items, none of the Group A or Group B participants referred to any of the characteristics of scientific knowledge in their discussions of why they decided what they did. In fact, the only participant who referred to science at all indicated that it was not appropriate for answering the principle questions of the scenario:

On a final note, just like science alone cannot and should not provide society with a definitive answer regarding when human life begins, it cannot and should not alone decide if and how fetal tissue should be donated. (A5, DMQ)
Noticeably absent from the participants' responses were any references to scientific evidence or the subjective nature of the definition of life. Furthermore, none of the Group A participants indicated that the experimental nature of the treatment influenced their decisions when explicitly asked during the follow-up interviews.

That is not to say that the participants failed to refer to science at all. Three Group A participants referred to the pursuit of science as a factor that influenced their decisions. These participants appeared to view science, in relation to the fetal tissue implantation issue, as a means to a better social or more ethical end. All of these were in response to Item 5, which asked if Dr. Harrison's work involving fetal brain tissue transplantation as a treatment for Parkinson's disease should continue:

This research will remain "experimental" unless further research is done to determine its safety and effect. (A1, DMQ)

Why [should Dr. Harrison's research continue]? Because the research may open up lines of rehabilitation that do not use fetal cells. (A3, DMQ)

Experimental research is part of science. Although there will need to be committees that rule on the ethical considerations, I think that such research should occur. For example, from this research scientists might discover a chemical or process that retards or reverses Alzheimer's that they then might be able to produce synthetically...such advances (that avoid the complex ethical issues surrounding abortion) might not be discovered if scientists are not allowed to experiment at all. (A7, DMQ)

The vast majority of factors identified in Group A and Group B responses to Scenario 1 items fell into the "Other" category. These responses focused on moral/ethical issues, personal values, and social/political issues:

The desire to stay alive and the desire to assist a family member in staying alive is strong and in itself justified if that chance of a cure doesn't negatively impact anyone else in a significant fashion...I can't see
any ethical reason why such a treatment regime would not be permitted or even recommended. (A2, DMQ)

I believe the right to an abortion (before the fetus becomes human) should not be restricted by law…I believe that this group of cells is part of the woman's body and should be treated accordingly. (B8, DMQ)

If society (and by extension, the legal and medical professions) continues to view a fetus as part of a woman's body, then like organs, donors should be able to request donation of fetal tissue to specific people. (A5, DMQ)

Appendix E provides additional examples of these factors. Some miscellaneous factors mentioned by only a few of the participants included the nature of the disease, condition of father, success of treatment, and safety.

In summary, Groups A and B appeared to use similar factors in their decision making in Scenario 1, most of which focused on ethical considerations and personal values. Furthermore, the decisions reached by participants in both groups did not appear to be influenced by their views of the nature of science.

Scenario 2: Global Warming and Green House Gas Emissions. The second DMQ scenario dealt with the connection between greenhouse gas emissions and global warming. The questions following the scenario asked respondents to make decisions having both personal and public impacts, such as whether they would be willing to pay for technology to reduce automobile pollution and whether the US should adopt binding limits on greenhouse gas emissions. The lack of consensus among scientists regarding the reality and potential impact of global warming provided an opportunity for respondents to list aspects of the nature of science as influencing their decisions.
The self-reported factors that influenced the respondents' decisions in the second scenario are listed in Table 13. Less than half of the participants' in both groups cited decision making factors that may be interpreted to reflect their views of the nature of science. Two Group A participants mentioned the use of scientific evidence in decision making:

Yes, [the US should agree to legally-binding limits on greenhouse gas emissions], because the one side that says human influenced global warming is a near certainty have the evidence in their favor. (A3, DMQ)

Yes, although I am no atmospheric scientist, the evidence that I have seen makes it clear that the science on global warming warrants some action. It makes no sense to ignore good science for political gain. (A2, DMQ)

Table 13
Scenario 2 Categories of Decision Making Factors for Group A and Group B

<table>
<thead>
<tr>
<th>Group A Factors</th>
<th>No. of Respondents</th>
<th>Group B Factors</th>
<th>No. of Respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of science</td>
<td>4</td>
<td>Nature of science</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Social/political issues</td>
<td>7</td>
<td>Social/political issues</td>
<td>8</td>
</tr>
<tr>
<td>Pragmatism</td>
<td>5</td>
<td>Pragmatism</td>
<td>3</td>
</tr>
<tr>
<td>Personal issues/values</td>
<td>6</td>
<td>Personal issues/values</td>
<td>1</td>
</tr>
<tr>
<td>Personal philosophy</td>
<td>4</td>
<td>Personal philosophy</td>
<td>5</td>
</tr>
<tr>
<td>Economics</td>
<td>2</td>
<td>Economics</td>
<td>6</td>
</tr>
<tr>
<td>(cost/benefit)</td>
<td>1</td>
<td>(cost/benefit)</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td>Miscellaneous</td>
<td>2</td>
</tr>
</tbody>
</table>
Two other Group A participants referred to the inconclusive nature of the scientific evidence:

I recognize that research on the relationship between gas emissions and global warming is equivocal: The scientific community has yet to reach consensus on this issue. (A5, DMQ)

Uncertainties about the potential of greenhouse gases to alter climate are still substantial, though a wise reading would indicate a likely connection. (A9, DMQ)

In contrast to these responses, two Group B participants mentioned the certainty of scientific knowledge as factors in their decisions.

This is potentially the greatest issue we face, and I discount all propaganda from the energy industries that this is as yet unproven. (B2, DMQ)

No, the US should not agree to legally binding limits until research conclusively shows that the global warming phenomenon is real. (B9, DMQ)

A third Group B participant seemed to hold a belief more in line with currently accepted views of the tentative nature of science:

Yes, I think that the risk of global warming is real. Even if actual global warming cannot be scientifically determined, this is not a gamble we should make. (B7, DMQ)

While there appear to be differences in the ways some Group A and Group B participants viewed the certainty of the evidence for global warming, few mentioned scientific evidence at all. As is shown in Table 13, social/political issues and personal philosophy—even pragmatism—were reported by the participants much more
frequently as factors in their decision making. (See Appendix E for example statements regarding other factors.) The most frequently cited factors were also cited about equally between the two groups, although economics was mentioned more often in Group B. Miscellaneous factors included long-term consequences and morals/ethics.

Even the participants who acknowledged that the scientific evidence was equivocal said their decisions were not strongly influenced by this knowledge. They indicated that their decisions were based on other issues, including conservation, social/political, and moral factors. For example,

On moral/ethical grounds, the United States has an obligation to lead the way in reducing the amount of energy used and the amount and kinds of emissions produced. After all, the United States is one of the world's largest consumers of energy. (A5, DMQ)

I'm skeptical that limits can be achieved—the connection between CO₂ and energy production is too strong, as is the link between energy production and human welfare. (A9, DMQ)

Scenario 3: Diet, Exercise, and Cancer. The third DMQ scenario dealt with the probable links between diet, exercise, and cancer. The three questions following the scenario asked how the participants' knowledge of the benefits a particular dietary program and exercise had impacted their lives and whether they would support legislation prohibiting the sale of certain foods associated with cancer. These questions were designed to give the participants an opportunity to describe what factors influence their personal choices when the scientific evidence is equivocal.
Factors related to the nature of science were cited more frequently in this scenario than in the first two, although nature of science factors were still cited by less than half of the total participants of the two groups (Table 14). In most of these cases, participants recognized that scientific evidence exists in some form:

Just recently, I have taken some measures to eat less red meat. This is directly related to my understanding that cancer has a genetic component (bad news in my case), and the evidence indicates that red meat and fats in the diet can increase the occurrence of cancer. (A2, DMQ)

When one considers the evidence linking nutrition, not only to cancer but to other major diseases, one would have to be "deaf and dumb" to ignore suggested guidelines for nutrition. (A3, DMQ)

Two participants discussed the strength of the evidence in connection with the question about legislating against foods connected to cancer.

In addition, researchers (and governments!) often draw conclusions that are not based on strong evidence (indeed, many epidemiological studies cannot, by their very nature, produce strong evidence) and I'd hate to proliferate science based on weak evidence (or on evidence of weak impacts). (A9, DMQ)

<table>
<thead>
<tr>
<th>Table 14</th>
<th>Scenario 3 Categories of Decision-Making Factors for Group A and Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A Factors</strong></td>
<td><strong>No. of Respondents</strong></td>
</tr>
<tr>
<td>Nature of science</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Values</td>
<td>9</td>
</tr>
<tr>
<td>Moderation</td>
<td>4</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4</td>
</tr>
</tbody>
</table>
While I find current studies on diet and cancer compelling enough to change my own habits, I am uncertain there is enough scientific research or consensus among members of the scientific community to support legislation on foods associated with cancer. (A5, DMQ)

However, not even these participants used their understanding of the nature of science exclusively in their decision making.

I also recognize that science can and should be only one of many voices in deciding how and what legislation is passed: I wonder if current scientific evidence would outweigh economic losses and public outcry. (A5, DMQ)

The two participants in Group B who mentioned science at all (both in response to Item 3 about legislation) seemed to blame science for being inadequate to produce a clear-cut answer.

I must admit, however, that given the scientific flip-flopping over the years about the merits and demerits of certain foods, I am somewhat skeptical about the research results. (B1, DMQ)

No—this is an imperfect science at best. We don't know exactly how diet, exercise, heredity, and stress interact to cause cancer, so it is premature to focus on one factor. (B6, DMQ)

This reaction is expected given Group B participants’ more absolute views of scientific knowledge. What is surprising is that more Group B participants did not respond this way.

Values, including factors such as convenience, self-image, and especially, personal benefit, were cited by every participant in this scenario. A small but roughly equal number of participants in both groups had a philosophy of moderation in regard to
diet ("I can't believe all of these 'bad' things are necessarily bad if taken in moderation"
B7, DMQ). The miscellaneous category included factors such as societal rights and
social issues, economics, and morals/ethics. All factors were mentioned with similar
frequency in both groups. (Appendix E contains examples of quotes in the Other
category.)

In both groups, even when they were convinced of the benefits of proper diet
and exercise, participants admitted to having trouble acting on their convictions.

I like to think that as a type A guy I am always on the go, but in all
honesty I do not have a regular exercise plan. This is one area where my
knowledge of the facts say one thing and my actions do not conform to
what I know to be true. (A2, DMQ)

Yes, I try to eat broccoli and fish more often and red meat less often. I
am not as good about this as I would like, due to laziness, but I have
tried to improve. (B8, DMQ)

When pressed in the interview about what kind of evidence would convince
them to change their diet and exercise habits, many participants indicated that the issue
for them was not weak science, but weak willpower:

I don't know if science could do anymore at this point. I think it's a
matter of saying, "Okay, this is something that needs incorporated in my
own personal lifestyle. I need to be exercising and eating right." It has to
be more of a personal concern, like a family thing, you know, "We're
worried about you and your cholesterol. We want you around for a
while." It has to be a more personal level to lead to that kind of
motivation. (B9, DMQ)

I think the evidence that regular exercise is beneficial is pretty
unarguable, as I understand it from a wide range of features, such as
cardiovascular health, happiness with what level of activity you're having,
and ability to do the things you enjoy — all those things are persuasive
that exercise regularly is a good idea. And the reason I don't is just a
little irrational, I suppose, but not having found any regular exercise that
is enjoyable, has made it easy to be a little slothful and not do the optimal thing. (A9, DMQ)

Scenario 4: Cigarette Smoking and Cancer. The last DMQ scenario dealt with the probable links between cigarette smoking and cancer. The questions following the scenario asked about prohibiting smoking, limiting the availability of cigarettes for minors, and banning smoking in public buildings.

Three Group A participants and one Group B participant mentioned the existence of scientific evidence, or data (Table 15). Two seemed to verbalize a "correct" notion of the tentative nature of science, although evidence was not the primary factor in their decision.

Additionally, the "alleged" dangers of passive cigarette smoke concern me. There is significant evidence that outlines the potential problems, and though scientists may not agree on the effect, I would rather not take chances with my health. (A7, DMQ)

Table 15
Scenario 4 Categories of Decision Making Factors for Group A and Group B

<table>
<thead>
<tr>
<th>Group A Factors</th>
<th>No. of Respondents</th>
<th>Group B Factors</th>
<th>No. of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOS</td>
<td>3</td>
<td>NOS</td>
<td>1</td>
</tr>
<tr>
<td>Other Other</td>
<td>9</td>
<td>Other Values</td>
<td>9</td>
</tr>
<tr>
<td>Pragmatism</td>
<td>7</td>
<td>Pragmatism</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5</td>
<td>Miscellaneous</td>
<td>7</td>
</tr>
</tbody>
</table>
If one were to use only scientific criteria in deciding whether or not to render smoking illegal, there appears enough rigorous research and consensus within the scientific community to support such anti-smoking legislation. Proponents of tobacco who claim "lack of proof" distort the purposes, language, and practices of science to further their own agenda. Of course, legislators can and should not look solely to science to make this decision; they must consider economic issues, social norms, and lessons of history (to name just a few). (A5, DMQ)

The other two merely mentioned science in a general way:

The science is clear that secondhand smoke impacts the health of those around smokers. (A2, DMQ)

However, given the data on passive smoking, I think it is unfair to make employees work in a place where they are exposed to secondhand smoke on a continual basis. (B7, DMQ)

For the Other category in this scenario, values such as personal choice and personal convenience were cited most frequently in both groups. Five participants in Group A and 8 in Group B held values about protecting minors from cigarettes, even though it meant limiting their freedom. Pragmatism ("it wouldn't work") was cited as a factor about twice as often in Group A, mainly in response to Item 1 about making cigarette smoking illegal.

In the miscellaneous category, a few participants in both groups cited social and economic issues. Two participants in Group B cited morals/ethics as factors.

Overall, the lists of factors generated from the Group A and Group B responses indicated that the nature of science played, at best, a minor role in participants' decision making on the science and technology based issues of the DMQ. In the relatively few times the participants referred to factors related to the nature of science, typically they
simply acknowledged the existence of scientific evidence. Other factors, including
social/political issues, ethical considerations, and personal values, were cited both more
frequently and elaborately. No factors related to the nature of science were listed for the
first scenario, which was ethically charged. In the other three scenarios factors related to
the nature of science were mentioned by a minority of respondents. The second
scenario, which was situated in the public realm, elicited more social/political concerns
than the other scenarios. Scenario 3 was more personal and queried participants about
how they actually followed up on decisions they had made. No longer speaking in the
hypothetical realm, participants made it clear that, at least in the area of diet and
nutrition, they do not always do what they decide is right. In the fourth scenario, factors
focused on personal values and reflected participants' nearly unanimous distaste for
cigarette smoking.

Comparison of Group A and Group B Reasoning

As described in Chapter 3, both the DMQ and the follow-up interviews were
intended to provide opportunities for participants to describe and elaborate on their
reasoning on science and technology based issues. The interviews, in particular, were
designed to elicit the participants' reasoning related to their decision making. In this
regard, participants were asked two or three questions emphasizing the equivocal nature
of the science related to one or more of the scenarios.

For example, in Scenario 1, participants were asked how the experimental nature
of the fetal tissue treatment affected their decisions. In Scenario 2, participants were
presented with an alternative explanation for global warming (land-form alterations),
based on the most current science. In view of this conflicting evidence, participants were asked how they could make decisions about regulating carbon emissions. In Scenario 3, the researcher asked participants how they could make decisions about nutrition when researchers, based on scientific evidence, have altered their recommendations, as in the case of the inclusion of Omega-3 fatty acids in the diet. The Scenario 4 probing question asked whether participants would change their decisions based on some scientists' assertions that the links between tobacco and cancer have never been proven. It was hoped that, in addition to eliciting participants' reasoning on controversial science and technology based issues, these probing questions would prompt the participants to illuminate how their views of the nature of science impacted their reasoning.

The DMQ responses and interview transcripts were searched for participants' reasoning patterns as they responded to the probing questions. While it was originally thought that forms of formal logic could be used as a framework for the analysis of the participants' reasoning, this turned out not to be the case. To do so would have required much inference on the part of the researcher to fill in gaps in the participants' responses. These responses, while elaborate enough to identify general patterns, were not formal enough to apply rules of formal logic. Not all participants clearly elucidated their reasoning, but most provided multiple decision making strategies that could be classified.

In all, six different reasoning patterns were identified and were remarkably similar between the two groups (Table 16). This similarity was consistent with the other findings of this study regarding decisions made and factors used in decision making.
Table 16
Group A and B Decision Making Strategies

<table>
<thead>
<tr>
<th>Strategy</th>
<th>No. of Group A Participants</th>
<th>No. of Group B Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider the Evidence</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Conservatism</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Risk Analysis</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cost/Benefit Analysis</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Values-Based</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Fallacious Reasoning</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Group A General Reasoning. All 9 participants in Group A said they considered the “evidence” when making decisions on science and technology based issues. While they realized scientific evidence on such issues is often equivocal or incomplete, they found it useful in informing their decisions and often spoke of using the “best available evidence”:

Currently, the best evidence we have indicates that there is a link—a link between smoking and cancers and other diseases. We could be wrong, but our best evidence over a long period of time seems to indicate the opposite. (A3, DMQ-interview)

I don’t necessarily feel you might always need nutritional supplements. There are occasions where they may be needed. I do take Calcium, because I don’t drink much milk. That is important for women, studies have shown it’s good for the bones. (A7, DMQ-interview)

Respondents also referred to historical evidence in the first item of Scenario 4 of the DMQ to argue that banning cigarette smoking would not work. They often compared banning cigarette smoking to the prohibition of alcohol in the 1920s. These
arguments emphasized the similarities between banning alcohol consumption and banning cigarette smoking, as well as the negative outcomes of prohibition:

I do not believe such legislation should be passed. Even if smoking could be made illegal, smokers would find ways of getting tobacco. I imagine a situation similar to Prohibition would arise. (A6, DMQ)

Although all referred to considering evidence, none of them claimed to use evidence alone in their decision making. Four referred to a personal philosophy of conservatism, including three different aspects, depending on the participant and/or the scenario discussed. For these participants, if the evidence did not provide a clear-cut answer, they decided the issue by maintaining the status quo, deciding in favor of safety, or using moderation:

Researcher: And what do you do when you look at the empirical evidence and scientists are saying that greenhouse gas emissions are causing global warming and others saying that either it isn't happening, or if it is happening, we have no way of knowing whether it's the greenhouse gases that are causing it?

Subject: Take two scientists and call me in the morning. I want to hear from more people. I think before you ask an entire nation to change their diet, for instance, you need to be pretty darn sure that it is a reasonable way to proceed. So, as far as I'm concerned, we just need more data.

Researcher: And if you're asked to make a decision before you have "enough data?" What do you do?

Subject: Status quo. My general rationale about these initiatives, for instance, is to maintain the status quo, unless there is clear evidence that one should alter the status quo. So, back to the leg-hold trap issue, I was willing to give the status-quo, like a 60% shot. I would have been willing to vote [to make leg-hold traps illegal] if the evidence had been pretty compelling on the reverse. (A2, DMQ-interview)
Risk analysis was cited by four participants as a strategy for decision making when the evidence was equivocal:

For example, living in a cave would greatly reduce my chances of being killed by a meteorite. The risk is real, the outcome severe—but the probability is incredibly slight. Similarly, if I aim to reduce my risk of cancer by 20%, I’d need to know the actual probability of cancer. If 1 in 20 people get cancer, then a 20% reduction in risk would be worth a large sacrifice. If 1 in 2000 get this type of cancer, then less sacrifice would be rational. (A9, DMQ)

Related to that, two others talked about making a cost/benefit analysis, including the costs of being wrong, additional benefits whether wrong or right, and/or a balance of evidence and values:

You can almost always find differing points of view. There is always going to be someone who says A and someone who says B. Once again, it’s kind of like, you know, that not smoking is never going to be harmful to your health. On the other hand, when smoking there is a much-increased risk of developing something. I don’t want to put that risk to my health, to my environment. So, if you know one thing is not harmful and the other could be potentially harmful, again I am going to side with the one that is not harmful to my health. (A7, DMQ-interview)

Three participants specifically said they tempered the scientific evidence with their values or emotions on the issue. In some cases values or emotions weighed more heavily than the evidence, which is consistent with the responses on the DMQ:

I think scientific evidence in any new area is going to be equivocal. Because that’s just the way science is done. Look at the history of science. There’s always lots of ideas brought forth when there’s a new area under investigation. It takes a while for scientists to reach consensus on what are the one or two views they're going to have on that topic. So, I think that as a citizen, you take the scientific information, but then you also have to make decisions based on values and societal, cultural, and
personal goals. And that's true of any sort of everyday decision that relates to science and technology. I don't think anybody takes scientific information, whether it's equivocal or unequivocal and incorporates it whole clause into their everyday experience. (A5, DMQ-interview)

Researcher: So what about decision making in this realm, when you're saying it's an honest debate, the scientists are equivocal on both sides of the issue. As a consumer in the democratic process, how do you go about making decisions?

Subject: It comes back to values again. I see us as being stewards of the earth; we have to ensure that we leave our ancestors the best that we can. Therefore, we have to make decisions that will most likely leave them with a habitable earth. So, here is a case where I am willing to undergo some hardship personally and for society to ensure there is a future that is going to be enjoyable and sustainable. (A6, DMQ-interview)

No clear examples of fallacious reasoning were evident in Group A responses to either the DMQ or the follow-up interview questions. Instead, respondents carefully qualified their discussions of how they reached decisions on the various scenarios. For example, one respondent avoided generalizing the results of a single study beyond what is warranted (hasty generalization):

Women don't have a lot of breast cancer in Japan. But, in America, Japanese-American women have a higher incidence of breast cancer, but a lower incidence of ovarian cancer than women in Japan. So, they think it has to do partly with culture, lifestyle, but also partly with diet. So, I think that there are some generalizations that have been made, but there's still a lot of research to be done. (A5, DMQ-interview).

Another respondent carefully avoided the fallacy of normative reasoning as he discussed the use of personal experience in decision making:
Researcher: Some people give up on science when the evidence is equivocal and use personal experience.

Subject: I'm less willing to do that. I do have some personal experience as in the case of the diet—I did have an uncle pass away at age 29.... There are personal anecdotal pieces of evidence or considerations that are involved in all my decisions, but I think it's also important to compare one's anecdotes to the preponderance of the evidence and try not to allow one's anecdotal evidence to override what the best available evidence is. (A3, DMQ-interview)

**Group B General Reasoning.** All participants in Group B claimed to consider evidence when making decisions on science and technology based issues as well. There were differences, however, in the ways they viewed the evidence. Three participants talked about looking at “both sides of the issue” and 2 mentioned evaluating the “credibility” of the studies. Like the Group A participants, 4 Group B respondents compared banning cigarette smoking to Prohibition. On the other hand, while the Group A participants viewed the evidence as imperfect and equivocal but still useful, Group B participants tended to look for long-term consistency and absolute “proof.” They were skeptical of science when these could not be provided.

Researcher: In Question #3 in the second paragraph, you had a really interesting comment. Here you said, “I must admit however that given the scientific flip-flopping over the years about the merits and demerits of certain foods, I am somewhat skeptical about the research results.” What do you mean by flip-flopping?

Subject: I have been hearing these types of things since I was ten years old when they start educating you about food and milk in school. It seems to me they have gone back and forth on a number of foods. For a considerable amount of time they said caffeine was bad for you, I just read recently that in moderation it can be very good for stimulating blood circulation.... Yeah, it's stuff like that;
it's the same with wine, eggs, etc. It seems to me in all the fields, that is the one with the most flip-flopping back and forth, what's healthy and what's not healthy. That makes me skeptical. (B1, DMQ-interview)

Otherwise, reasoning patterns were remarkably similar to those of Group A. Five participants said that when the evidence was equivocal, they fell back on a conservative philosophy, acting in favor of safety or using moderation (phrases like "balanced diet" and "variety" came out especially in Scenario 3 on nutrition). One participant, the nuclear scientist, said he used risk analysis, trying to determine what was "most likely to happen." Two looked at costs versus benefits. One reasoned that understating the problem could be catastrophic, while overstating the problem had less significant consequences. The other compared impacts on freedom to impacts on health and safety.

Three participants cited values and emotions in their reasoning process, things like a "gut feeling," "common sense," and a "familiar way of life." One participant who was trying a vegetarian diet because he believed it was good for his health admitted that sometimes he deviated for reasons having nothing to do with evidence:

I don't know, I'm in a quandary about this. My daughters want to be vegetarians and when they're at home, I generally make vegetarian meals for them. I think that there are reasons for becoming vegetarian, and then, on the other hand, every two to three weeks I'm feeling low on energy, so I go out and buy a steak. (B8, DMQ-interview)

A single example of fallacious reasoning emerged from the analysis of the Group B DMQ and follow-up interview responses. In this case, the subject made an unwarranted generalization from a small sample based on personal experience:
I don't have any doubt, particularly when it relates to lung and throat cancer, that there is a clear connection between smoking and cancer.

Is this from personal experience or from what you have read?

It’s from the people I have ministered to. Just in ministry. (B3, DMQ-interview)

In summary, both Group A and Group B participants used six different categories of reasoning to justify their decisions on the DMQ. While all the participants referred to the use of evidence in their reasoning, only a few specifically spoke of aspects of evidence related to the nature of science. All of Group A and most of Group B found evidence useful for making decisions even though the evidence was not absolute. This finding was consistent with Group A's responses to the DMQ, but inconsistent with Group B's more absolute responses. Even though all participants cited evidence as a consideration in their decision making, evidence was not the sole influence, nor did it appear to be the primary influence for any of the participants. Consistent with the decisions and decision factors, participants' reasoning patterns focused on social and values-based issues, such as values, personal philosophy, and economics.
CHAPTER V
DISCUSSION AND IMPLICATIONS

Introduction

This investigation assessed the relationship between understandings of the nature of science and decision making on science and technology based issues. The study focused on delineating the decisions, factors that influenced the decisions, and reasoning patterns of two groups of highly educated participants possessing disparate views of the nature of science. By comparing these aspects of decision making for the two groups, as well as specifically looking for aspects of the nature of science in the participants' descriptions of their decision making, the validity of the democratic argument for nature of science instruction was assessed.

This chapter discusses the findings reported in Chapter IV and situates these findings within the context of previous research on teaching and learning, with particular emphasis on the literature related to the nature of science. This discussion is presented in seven sections. The first section examines present results in light of previous research on adult understandings of the nature of science. The second section examines the similar decisions reached by the two groups. The third and fourth sections explore the relatively insignificant representation of the nature of science in the factors and reasoning that influenced the participants' decisions. The role of the nature of science in decision making as delineated by the answers to the research questions is explicated in the fifth section. The investigation's salient limitations and qualifications are presented in the sixth section. Finally, the implications of the present study's results for science
education are outlined in the seventh section, along with recommendations for future research.

Adult Understandings of the Nature of Science

If the nature of science plays a role in decision making, it is critical to know adults' conceptions of the nature of science. After all, the goal of K-12 education, scientific literacy, is to produce adults capable of making reasoned decisions on science and technology based issues. It is adults who participate in socio-political decision making, as well as who have the most autonomy in regard to personal choices and decisions. Interestingly, however, most of the research that has included assessments of the nature of science has focused on children, rather than adults. It appears that researchers do not know very much about the target population's understandings of the nature of science.

As reviewed in Chapter 2 of this thesis, there have been some assessments of adult understandings of the nature of science over the past several decades. However, these studies have examined only a rather narrow range of the adult population. Specifically, understandings of the nature of science have been assessed for college students (Anderson, Harty & Samuel, 1986; Carey & Strauss, 1970; Cotham & Smith, 1981; King, 1991; Rubba & Anderson, 1978; Schmidt, 1967; Wood, 1972), elementary teachers (Pomeroy, 1993), secondary science teachers (Behnke, 1961; Gallagher, 1991; Kimball, 1967-68; Lederman, 1986; Miller, 1963; Pomeroy 1993; Schmidt, 1967; Welch & Pella, 1968), and scientists (Behnke, 1961; Kimball, 1967-68; Pomeroy, 1993; Schmidt, 1967; Welch & Pella, 1968). To further complicate the issue, the samples used
in many of these studies have been quite small. Obviously, there is need for a more
complete picture of adults' conceptions, including both larger and more diverse samples.

The principle purpose for assessing adult understandings of the nature of science
in this study was to place participants into divergent groups in order to determine the
impact of the nature of science on their decision making. But by focusing on a different
segment of the population than previous assessments, the present study also makes a
significant contribution to the overall picture of adult understandings of the nature of
science.

The stratified, volunteer sample of college professors and research scientists
included in this study possessed divergent views of the nature of science. Not
unexpectedly, the views of those whose work fell primarily within the humanities did
not align with current understandings of the nature of science. Neither did the views of
3 of the 4 research scientists in the study align with current understandings. While
initially surprising, this latter result is in line with previous research indicating that
scientists' possess inadequate views of the nature of science (Kimball, 1967-68;
Pomeroy, 1993). Given the 4 scientists' backgrounds and current research programs, it
is safe to assume that all possessed strong knowledge of the content of their respective
disciplines. Furthermore, they were all actively involved in doing science. Thus, it
appears that for these participants, neither strong content knowledge nor active
engagement in scientific processes was enough to foster adequate understandings of the
nature of science.
It is noteworthy that the only scientist who performed well on the DMQ was involved in teaching a course about science to undergraduate ecology and philosophy majors. The discussions and required readings in the course, which included Kuhn's *Structure of Scientific Revolutions*, were designed to involve students in reflecting about the logic, philosophy, and nature of science. The act of reflecting on science in the process of putting this course together may have contributed to this individual's current understandings of the nature of science. If so, then these results support recent studies indicating that explicit reflection on the nature of science is necessary for the development of adequate understandings. (Abd-El-Khalick, et al., 1998; Bell, et al., 1998).

Finally, the divergent performance on the NOSQ by the Group A and Group B participants supports the construct validity of the combined instrument and interview. Various versions of the NOSQ have been used in previous studies (Abd-El-Khalick, 1998; Abd-El-Khalick, et al., 1998; Bell, Blair, Crawford, & Lederman, 1999; Bell et al., 1998; Lederman & O'Malley, 1990; Lederman, Schwartz, Abd-El-Khalick, & Bell, 1999; Zeidler, et al., 1999), during which face and/or content validity have been reported. Additionally, respondents' elaboration on their NOSQ responses during the follow-up interviews have supported the content validity of the questionnaire through triangulation. The fact that all of the participants who had extensive opportunities to reflect on the nature of science performed much better on the instrument than those who had little opportunity to reflect on the nature of science supports the contention that the
instrument measures a construct that differentiates the two groups, i.e., the nature of science.

Decisions on Science and Technology Based Issues

As described in the previous chapter, the decisions reached by the two groups on the NOSQ did not differ substantially, despite significant differences in the groups' views of the nature of science. As Table 9 previously indicated, a large majority of the decisions of both groups were in favor of the issues suggested in the questionnaire items. While the NOSQ was not designed to measure a single construct such as liberalism or conservatism, it is clear that most of the items have a liberal bent. For example, the items in the first scenario centered around the issue of pro-choice. In the second scenario, respondents were asked if they would support increased taxes and regulations to protect the environment. The fact that the majority of participants in both groups demonstrated a similar commitment to the environment contrasts with the Zeidler and Shafer (1984) investigation in which non-science majors had less positive attitudes toward the environment than did science majors.

The third scenario dealt with issues that were more personal than political. However, participants' responses to these items had a distinct liberal flavor to them (i.e., less red meat, more vegetables), with several indicating that they had adopted vegetarian diets. The fourth scenario items focused on increasing legislation regarding smoking. By agreeing with the majority of items on the questionnaire, both Group A and Group B participants appeared to share relatively liberal views of the socio-political issues encapsulated within the scenarios.
Only 2 of the 15 NOSQ items resulted in split decisions (approximately equal numbers of “yes” and “no” votes within a group). Both of these split decisions occurred in the first scenario, which dealt with fetal tissue implantation. Items 3 and 4 were the most controversial items of the questionnaire and dealt with the issue of whether the couple should be permitted to designate the recipient of the fetal tissue they donate. It is not surprising that the “yes” and “no” responses of both Group A and Group B participants were fairly evenly split in regard to this ethically charged issue. Even then, the responses were fairly consistent between the groups, just as with the rest of the issues on the DMQ.

There were only two DMQ items that elicited a “no” response from the majority of respondents, Item 3 of the third scenario and Item 1 of the fourth scenario. The two items were similar in that they proposed banning potentially harmful practices. Nearly all participants disagreed with such bans, citing the value that they believed people should have freedom of choice, even if their choices reduced the quality/quantity of their lives. To regulate such decisions appeared too invasive and Draconian to both groups of participants:

People need to know how dangerous, addictive and deadly [cigarettes] are, but “big brother” forbidding it is not the way I want to live. (A8, DMQ)

No, I would support information, but not restriction. I think what we eat should not be the government's business. (B8, DMQ)

Somewhat surprising was the consistency of decisions among participants within each group. Given the diverse backgrounds even within groups, more mixed decisions
might have been expected. This consistency points to some similarity in the two groups’ reasoning on these issues. The similarity could not have resulted from their understandings of the nature of science, since their understandings were so different. Neither could the similarity have resulted from their science content knowledge, which was nearly as disparate between the groups as their nature of science understandings. A possible answer is their level of intellectual development (Perry, 1970), since all were academics and had opportunities for high levels of intellectual development. This possibility is discussed further in the implications section.

While a few respondents were unable to make up their minds on a particular issue, overall there were few responses in the “Undecided” category. As Table 9 indicated, there were no more than two “Undecided” responses on any particular scenario. This is interesting because it indicates that lacking current views of the nature of science did not hamper the ability of Group B participants to make decisions on these scientific and technology based issues. This finding is consistent with Fleming's (1981a) work, in which high school students tended to focus their decisions on the social aspects of socio-economic issues, rather than science content. Apparently, as will be discussed in the next two sections, all respondents tended to rely on factors other than their understandings of science when making difficult choices on these issues.

Factors Influencing Decisions on Science and Technology Based Issues

Based on their responses to the DMQ and follow-up interview responses, participants’ understandings of the nature of science did not appear to be a major contributing factor to either Group A or Group B participants. To be sure,
characteristics of the nature of science were identified in the responses to three of the four scenarios, but only by a minority of the participants.

If understandings of the nature of science did not play a major role in the participants' decisions, what did? This question can be answered by considering the factors listed by a majority of the respondents. The short list of these influential factors includes items such as personal values, social/political issues, and due consideration to concerns of practicality. Again, these factors were in line with the results of previous research on socio-scientific decision making (Fleming, 1981a, 1981b; Zeidler & Shafer, 1984).

For most respondents, personal values, rather than their understandings of science, tempered their decisions. Whether it was clean air, the right to choose what happens to one's body, or personal body image, values-related issues dominated participants' discussions about their decisions. In the social-political realm, participants were concerned about whether economically disadvantaged families could afford increased taxes and automobile prices. The fact that abortion is legal in our society was commonly cited in Scenario 1 items. And, as previously mentioned, limiting "Big Government" regulations of personal choice was a paramount consideration among the participants. Certainly, pragmatic concerns were a big issue for the participants. In all of the scenarios, participants were concerned about what can be done, what is enforceable, and what works:

I don't think you can eliminate all fat from your diet....Besides, it's not going to work. I think I put in my questionnaire it didn't work with alcohol when the Women's Temperance League decided that they were going to make that illegal. All it did was turn everybody into a criminal
and they continued to drink. The same is going to happen with junk food. You'd just turn everybody into a criminal. (B6, DMQ-interview)

The consistency and frequency with which both groups cited factors other than the nature of science supports the conclusion that their understandings of the nature of science did not play a major role in the participants' decision making processes. The respondents' relatively few references to specific characteristics of science further supports this conclusion.

Reasoning on Science and Technology Based Issues

Contrary to expectations, no clear formal strategies were used by either group to reach decisions on the DMQ. Based on previous investigations (Zeidler & Schafer, 1984; Zeidler, et al., 1999), it was thought that fallacious reasoning might play a significant role in the participants' decision making. This turned out not to be the case.

Previous studies (Zeidler, et al., 1992; Zeidler & Schafer, 1984; Zeidler, et al., 1999) have identified a variety of common fallacious reasoning patterns in decision making on socio-scientific issues, including hasty generalizations, appeals to authority, and normative reasoning, among many others. Surprisingly, instances of such faulty reasoning were rare in both the Group A and Group B responses. In fact, only a single clear instance of fallacious reasoning was identified among all of the data.

Two possible explanations exist for the lack of fallacious arguments identified in the participants' responses. Possibly, the participants reasoned fallaciously, but neither the questionnaire nor interview protocol were sufficient to elicit their logical errors. Given the number of opportunities that participants had to discuss their reasoning, it is
unlikely that such fallacies would fail to emerge. The other, more likely, possibility is that the respondents did not make many common logical errors. As academicians and scientists, the participants were highly educated and experienced in making reasoned decisions and in justifying their reasoning. It is not surprising, therefore, that they exhibited fewer logical fallacies than the younger, less-educated participants in previous studies.

Despite the lack of fallacious or other a priori categories of reasoning, several general reasoning patterns emerged from the participants' responses, as presented in Chapter IV. These patterns were closely related to the decision factors identified for the participants, due to the fact that the factors and reasoning on the science and technology based issues were necessarily closely intertwined. The general pattern of no substantial differences between Group A and Group B participants remained true, with the same five categories of reasoning being applicable to both groups.

There were differences, however, in how some of the participants used evidence in their reasoning. The Group A participants recognized the equivocal nature of the evidence on the controversial issues of the DMQ, but still found it useful in making decisions. In other words, absolute knowledge, or even consensus among scientists, was not necessary before they could make reasoned decisions. It is important to note that most Group B participants shared this view. There was a minority of Group B participants, however, who indicated that the equivocal nature of the evidence and/or the "flip-flopping" of scientific opinion diminished the utility of scientific evidence in making personal and public decisions. In doing so, these participants expressed
reasoning patterns consistent with participants in the Lederman & O'Malley (1990) study.

Given that none of the participants who used such reasoning were Group A members, it appears that this need for absolute knowledge is related to the Group B participants' more absolute views of the nature of science. The equivocal nature of the evidence in the controversial scenarios of the DMQ were acknowledged by the Group A participants, but were a source of frustration for the Group B participants:

I think this is a real dilemma. I stopped eating butter, because it's high in cholesterol. Then they tell you all of the different fats you're supposed to eat, like to use canola margarine. Then, they go back and say, no, butter is better than margarine. That was a flip-flop. The latest I've heard is that there's no correlation between eating eggs, even though they're high in cholesterol, and in the actual cholesterol people have, which is the latest flip-flop. (B7, DMQ-interview)

Thus, for these Group B participants, it was "finished science" and not "science in the making" that was useful in decision making. This same view was reported for high school students in the Fleming (1986b). The significance becomes evident when one considers that most of the issues on which the public is asked to make decisions, as well as many personal decisions, are based on science in the making (Collins & Pinch, 1998). Citizens who view the progression of science negatively as "flip-flopping" between positions are unlikely to use such knowledge, even though it may help them make better decisions.

These differences between Group A and Group B participants' use of evidence are interesting because of their relevance to the participants' understandings of the nature of science. Yet, it is important not to overemphasize these differences. Most
Group B participants were not perturbed by the equivocal nature of the scientific evidence related to the various scenarios of the DMQ. For the most part, as is the case with the other aspects of their decision making, Group B participants' reasoning was remarkably similar to that of Group A. Group B participants' reasoning in light of equivocal evidence contrasts with their understandings of the nature of science, which as a whole was distinctly absolute. But why was Group B respondents' reasoning on these scientific and technology based issues less absolute than their views of the nature of science?

One possibility is that the decisions reflected the epistemologies of their particular disciplines more than their views of science epistemology. Group B participants consisted of 3 scientists and 6 academicians in the humanities. When responding to the science-specific items of the NOSQ, which required metacognition about the construction of scientific knowledge, participants' absolute views of science were evident. But, when responding to the DMQ, where the issues had a significant social component, the participants were better able to transfer their understandings of knowledge construction in their own fields. Such an explanation depends on a general, nonspecific epistemology of knowledge, which has been reported in the literature (Schommer & Walker, 1995).

There is another possibility for the inconsistency between the majority of Group B participants' views of the absolute nature of scientific knowledge and their acceptance of tentative scientific evidence in making decisions. It should be noted that the NOSQ assesses understandings of the nature of science. The instrument and interview
combination are effective in eliciting both accurate and erroneous conceptions of the scientific enterprise. It is not surprising that the NOSQ revealed many misconceptions of the participants who worked outside the realm of science history and philosophy and had little opportunity or inclination to reflect on the tenets and characteristics of scientific knowledge.

The DMQ, on the other hand, was designed to reveal details of the participants' decision making, rather than a particular construct, such as the nature of science. This difference is significant, because discrepancies between responses to the NOSQ and DMQ indicate that another construct is mediating the Group B decisions. One possibility for this construct is the participants' level of intellectual development. Perry (1970) described intellectual development in college students as progressing through four distinct stages. Each stage is characterized by different views of knowledge, starting with a positivist stance (Dualism) and culminating in a view of knowledge as constructed, contextual, and tentative (Commitment to Relativism). It is possible that while many Group B participants held absolute views of the nature of science, a topic that was relatively unfamiliar to them, their use of knowledge in general was mediated by the relativistic views associated with their high levels of intellectual development.

There is a third explanation for the apparent discrepancy between the Group B participants' more absolute views of the nature of science and their willingness to use equivocal scientific evidence in their decision making. It may be that their decision making was primarily impacted by factors other than the nature of science, such as values and ethics. This conclusion is supported by the results of the analyses of the two
groups' decisions, factors influencing decisions, and reasoning patterns, as well as consistent with science education literature on decision making (Fleming, 1981a, 1981b). In all of these, factors other than understandings of the nature of science appeared to play the major role in both Group A and Group B decision making. For example, members of both groups commonly spoke of using values to help in their decision making on the scientific and technology based issues of the DMQ. For the Group A participants, values were used in conjunction with their understandings of the relevant science:

So, I think that as a citizen, you take the scientific information, but then you also have to make decisions based on values and societal, cultural, and personal goals. And that's true of any sort of everyday decision that relates to science and technology. I don't think anybody takes scientific information, whether it's equivocal or unequivocal and incorporates it whole clause into their everyday experience. (A5, NOSQ-interview)

The Group B participants, most of who knew little science content, tended to rely on values instead of the science:

Researcher: How does this equivocal nature of the information you get from nutritionists and doctors affect your decision making?

Subject: I think I probably just kind of roll with the punches and use my good common sense. I'm sure that eating a lot of fat red meats and stuff like that is not good, but that doesn't mean I don't go out and have a whopper once a month, you know... I think I have a reasonably balanced diet, so I kind of don't worry about it one way or another. (B2, NOSQ-interview)
Either way, it was evident that personal values were much more prevalent in the
decision making of the members of the two groups than their understandings of the
nature of science. That being the case, moral development may be an important
consideration when assessing decision making strategies on science and technology
based issues. This conclusion is consistent with previous research focusing on college
students' responses to socio-scientific dilemmas (Zeidler & Schafer, 1984), although the
DMQ scenarios were not presented as dilemmas.

A final consideration about the reasoning of the participants in the study is
related to the hypothetical nature of most of the scenarios and items. Scenarios 1, 2, and
4 all described situations that, while realistic, had no current direct effect on the
respondents. It is possible that participants might respond differently to such
hypothetical situations than they would to situations that had a more personal and
immediate impact:

Well, it's easy for me an academic sitting in an ivory tower to talk about
increasing fines or emissions and increasing restrictions on businesses.
But, I suppose if my whole livelihood came from an energy industry, it
would be harder for me to be so cavalier. (A8, NOSQ-interview)

The first two items of the third scenario were intended to elicit the respondents'
reasoning on issues that were more personal and less hypothetical. Analysis of the
reasoning on these questions revealed no substantial differences from the reasoning on
the other scenarios, with one exception. While respondents appeared to come to logical
conclusions about what they thought was best for their health, they did not always carry
I think the evidence that regular exercise is beneficial is pretty unarguable, as I understand it from a wide range of features, such as cardiovascular health, happiness with what level of activity you're having and ability to do the things you enjoy—all those things are persuasive that exercise regularly is a good idea. And the reason I don't is just a little irrational, I suppose, but not having found any regular exercise that is enjoyable has made it easy to be a little slothful and not do the optimal thing. (A9, NOSQ-interview)

Researcher: On question #1 you said, "Your awareness of this issue hasn't really impacted what you choose to eat."

Subject: That unfortunately is true.

Researcher: You said that you do eat certain foods.

Subject: If anything, I haven't gotten rid of junk food, for example, but I have tried to add additional things. People say you should be eating oatmeal. I've started to eat oatmeal, but I still eat my candy bars. I'm just eating more and I think I'm starting to gain weight.

Researcher: You said that you believe diet does have a link and you cited medical evidence for that. Why hasn't this resulted in the changes that would be most appropriate?

Subject: I think you just get used to a certain habit of eating and lifestyle and it takes effort. So, if there was a group of us doing it, it might be a little easier. It's a matter of motivation and saying this is something I need to do.

Researcher: So, it's not related to the fact that you don't think the science is good enough?

Subject: Correct. I think there is more and more evidence coming in and every time I look there is somebody from another major institution saying diet is important and exercise is important.

Researcher: What would it take in science for you to make those changes?
So, once again, the scientific evidence alone did not decide the issue, but the science was mediated by what these participants valued and found motivational. Additionally, as these quotes indicate, the participants' reasoning did not always impact their behavior, a finding consistent with the high school students in the Lederman and O'Malley (1990) investigation. Actions may speak louder than words, but they are also more difficult to change.

The Role of the Nature of Science in Decision Making

The purposes of this investigation were to assess the influence of people's understanding of the nature of science on their decision making regarding science and technology based issues and to delineate the factors and reasoning people use when making these types of decisions. To explore this question, the decision making of two groups of college professors and research scientists who held disparate understandings of the nature of science was examined.

This examination found that there were few differences in the factors influencing the two groups' decisions on complex, controversial science and technology based issues. Factors associated with the nature of science played an insignificant role for a minority of the respondents and no clear role for the majority. Other factors, including
social/political issues, ethical considerations, and personal values, appeared to dominate the participants' decision making.

The reasoning processes the two groups used to reach their decisions were generally similar, although not always consistent with their views of the nature of science. However, in both groups an understanding of the nature of science regarding evidence emerged as only one of several reasoning patterns. Once again, it appeared to play only a minor role in influencing decisions.

Finally and perhaps most important, the actual decisions reached by the members of the two groups were not substantially different. Therefore, even if the minor differences in reasoning were viewed as significant, the differences have no practical significance because the two Groups' decisions were largely equivalent. The participants had to have been basing their decisions on factors other than their understandings of the nature of science to have come to the same conclusions.

Practically speaking, how many opportunities do people have to make decisions on science and technology based issues? Interestingly, less than half the participants in each group believed they had ever voted on a science and technology based issue. On the other hand, all the participants could list several personal decisions they had made that were related to science and technology based issues. These findings lend support to the utilitarian argument for teaching the nature of science, focusing on personal uses of scientific knowledge (Driver et al., 1996), rather than the democratic argument, which focuses on public decisions.
Limitations of the Study

All research involves an intricate balance between project goals and practical considerations. Resultant compromises constitute limitations that should be considered when interpreting and applying the results of the investigation. This study is no exception. Compromises due to such factors as limited time, availability of subjects, and other methodological limitations necessarily mitigate the interpretation and generalizability of the project results.

First, due to the nonrandom nature of the sampling, the results reported are not generalizable beyond the participants of this study. In fact, the participants were selected specifically to provide a best-case scenario for illuminating the relationship between understandings of the nature of science and decision making, not because they were representative of any larger segment of decision making adults. Hopefully, the investigation will spawn a line of research in which the decision making strategies of an ever-broadening segment of the adult population will be assessed in order that the external validity of the findings will be enhanced. Until then, the description of the selection criteria and procedures in Chapter III, as well as the detailed background information of the participants in Chapter IV, should assist readers in judging the applicability of the findings to other contexts.

However, it should be kept in mind that the sample used in the study represented extremes in terms of understandings of the nature of science. Choosing extreme cases may limit generalizability in one sense, but it also allows for some inferences to be made concerning adults with less extreme views. For instance, considering that few
differences were evident in the decision making in these extreme cases, it is unlikely that
differences would be found in other segments of the population. Additionally, neither
those who understood the nature of science well (Group A participants), nor those who
had poor understandings (Group B participants), used their understandings substantially
in decision making. Thus, it is reasonable to predict that adults with more moderate
views of the nature of science would be unlikely to use their understandings to any great
degree in their decision making on science and technology based issues.

Another limitation involved the validity of the DMQ questionnaire and follow-up
interviews. Certainly, pains were taken to construct instruments that adequately solicited
decisions, decision making factors, and decision making strategies on relevant science
and technology based issues. The face and content validity for the DMQ reported in
Chapter III support the success of these efforts. Furthermore, the fact that the DMQ
and follow-up interviews successfully elicited decisions, decision making factors, and
decision making strategies from all the participants in the present study further supports
their validity. However, it should be noted that the DMQ and follow-up interview
protocols are newly developed instruments that are not nearly as well established as the
NOSQ. Subsequent investigation and refinement will likely improve the validity of these
instruments. Until then, responses to the DMQ should be interpreted with caution.

Adding to these concerns is the self-report nature of the participant responses to
the DMQ and follow-up interviews. It is possible that the decisions respondents report
in the more-or-less hypothetical context of the DMQ may not be congruent with the
decisions they would make when confronted with the actual issues. This incongruity is
supported by the responses to the items of Scenario III, where several participants admitted that their actions did not always reflect what they had decided was best for their health. Despite this limitation, the self-reports of decision making solicited by the DMQ provide a useful first step in untangling the complicated web that constitutes decision making on science and technology based issues.

Additionally, the seven aspects of the nature of science that this investigation focused on should not be viewed as exhaustive. Rather, they are a subset of the multifaceted construct that science educators have identified as the nature of science. The nature of science subset used in this investigation is consistent with the recommendations of science educators (e.g., Duschl, 1990; Hodson, 1985, 1988; Lederman, Farber, Abd-El-Khalick, & Bell, 1998; Robinson, 1965; Smith, et al., 1997), recent reform documents in science education (AAAS, 1990, 1993; NRC, 1996), and the writings of science philosophers (e.g., Feyerabend, 1993; Giere, 1988; Kuhn, 1970; Lakotos, 1978; Popper, 1963, 1988, 1994). However, other aspects of the nature of science exist, such as the issue of parsimony in science and the existence and nature of reality independent of the observer. It is possible that unassessed aspects of the nature of science may be more salient to decision making on science and technology based issues than the subset addressed in this investigation. Such concern is largely mitigated, however, by the relatively minor role the nature of science played in the participants' decision making and the fact that the participants made no references to other aspects of the nature of science in their descriptions of their reasoning.
Finally, the researcher may also be viewed as a limitation in this study. As the principal instrument of data analysis, it is unavoidable that at least some components of the researcher's experiences, beliefs, and biases influenced the results and their interpretation. Certainly, the researcher's commitment to nature of science instruction guided the direction of this study. The impact of such biases is reduced by the systematic procedures used to collect and analyze data. Additionally, the "About the Researcher" section of Chapter III should provide useful information for judging the researcher's interpretations of the findings and conclusions.

Implications and Recommendations for Future Research

Because the results of this study do not lend support to the idea that the nature of science plays a major role in decision making on science and technology based issues, questions regarding two separate lines of research emerge: What is it that impacts decision making, and if the nature of science does not play a major role in decision making, is it worth teaching? This section will discuss implications and suggestions for future research for each of these questions.

What are the influences and strategies that impact decision making on science and technology based issues? For the participants in this study, values, morals, and ethics seemed to play the primary role in mediating their decisions. This finding implies that, if educators are concerned that schools graduate adults well prepared to make decisions on public and personal science and technology based issues, schools will need to develop curricula emphasizing the importance of values in decision making. This curricula should encourage teachers not to impose their values on students, but to help
students recognize the connections and identify their own values so they can use them effectively. Unfortunately, for the past several decades, there has been a movement to remove values-based instruction from school curricula. If the results of this study are found to be generalizable, then such goals will need to be reconsidered.

On the other hand, science educators may continue to value nature of science instruction and promote the potential that current understandings hold for decision making. In such case, explicit instruction on how to use current views of the nature of science in decision making may be warranted. Curricula promoting this kind of instruction would need to emphasize the relevance of the nature of science to students' everyday experiences and decisions, as well as provide opportunities for students to use their understandings to make decisions on controversial science and technology based issues.

Surprisingly most of the Group B participants did not need absolute scientific evidence before they could make decisions on science and technology based issues. This finding contrasts with previous studies in which those with less sophisticated understandings of the nature of science required more absolute knowledge from science before they could make personal and public decisions (Lederman & O'Malley, 1990; Miller & Wynne, 1988).

It can even be inferred from the results of this study that these participants were using a more general epistemology of knowledge in their decision making. Future research should focus on the relationship between general epistemologies of knowledge and decision making to see if this relationship is supported. Additionally, the impact of
epistemologies in particular fields could be explored. For example, the decision making of natural scientists and social scientists possessing equivalent absolute views of the nature of science could be assessed. The discipline-dependent epistemology of the natural scientists should be equivalent to their views of the nature of science. The social scientists, on the other hand, would possess separate, less absolute views of knowledge construction in their own fields. Comparison of the decision making factors and strategies of these two groups could shed light on whether epistemology transfer is taking place, as well as the level of its impact on decision making on science and technology based issues.

This concept could be extended to suggest that general literacy may be more important than scientific literacy in making decisions, even on science and technology based issues. The argument has been that the nature of science is a major component of scientific literacy, which is the construct that determines one's ability to make reasoned decisions on science and technology based issues. However, the highly literate participants in this study reached the same decisions regardless of their views of the nature of science. It is possible, therefore, that their decision making was more related to their level of intellectual development than to their understandings of the nature of science. If so, scientific literacy should be seen more as a component of the broader goal of general literacy than as an end in itself.

Such literacy should help citizens evaluate and make sense of media reports of scientific evidence. This is critical in light of the fact that nearly all of the participants in this study reported popular media as the sole source of information in deciding science
and technology based issues. The ability to discern between biased and objective treatment of controversial issues should prove helpful in a variety of disciplinary contexts.

Another inference stemming from these results is that intellectual development may play a critical role in science and technology based decision making. If a connection between intellectual development and decision making is established by subsequent studies, then elementary and secondary school students may not be developmentally ready for the type of nature of science instruction that this study implies. Students who are not ready for relativistic type thinking (Perry, 1970) may become frustrated or cynical when exposed to instruction about the tentative nature of scientific knowledge. Such instruction may do more harm than good (Winchester, 1993).

On the other hand, understandings of the nature of science and intellectual development may be linked in a manner possessing more positive implications for nature of science instruction. Future research may find understandings of the nature of science to be more important as a factor in decision making for those less intellectually developed than the academics who participated in this study. If so, it will be important to identify the level of intellectual development at which students view current understandings of the nature of science as interesting and helpful, rather than frustrating. Such research would allow nature of science instruction to be targeted at the most appropriate time in students' intellectual development.

While the nature of science did not appear to play a primary role in the participants' decision making, the majority of participants' views of the nature of science
were consistent with their use of evidence in reasoning on science and technology based issues. Thus, the present study provides some evidence for a role for the nature of science in particular aspects of reasoning on science and technology based issues, such as the use of scientific evidence. Future research should focus on the use of evidence in reasoning in order to further explicate the role of the nature of science and use of evidence in decision making.

There was some evidence in this investigation that participants' reasoning depended on whether the decisions to be made were personal or public. Future research regarding the use of particular aspects of the nature of science in decision making should involve a variety of personal and public issues to further investigate this potential relationship.

A second line of implications and direction for future research is centered on the question of why teach the nature of science? If the understandings of the nature of science do not significantly impact decision making, as the results of this study suggest, then is the goal of developing adequate conceptions of this complex and elusive concept worth the time and effort to pursue?

Before addressing this question, it is worth reiterating that the results of this study alone should not be seen as generalizable to the population of adult decision makers in general. The investigation was based upon a stratified, nonrandom sampling of a nonrepresentative segment of the voting adults. While the sampling and methodology allowed for a best-case test of the assumption that understandings of the
nature of science significantly impact decision making on science and technology based issues, the results of the investigation are not generalizable to the public as a whole.

A productive area for future research would be to extend the generalizability of these findings. Several suggestions for this goal are presented. For example, it would be useful to replicate this investigation with a more representative sample of the average American voter, rather than concentrating on the highly educated. The results of such an investigation would help illuminate whether the findings of the present study are primarily an artifact of the sample used. Another possibility would be to explore students' (high school or post-secondary) decision making before and after learning particular aspects of the nature of science. Such an investigation would provide experimental evidence for or against the results of the present investigation.

Another aspect that could be explored is decision-making on different types of scenarios and dilemmas. The issues in the present study were selected due to their applicability to the types of personal and public decisions a citizen might be asked to make. Perhaps other types of issues, while not typically voted on, may be impacted more directly by understandings of the nature of science. For example, the teaching of Darwin's theory of natural selection in public schools is a contentious issue in many communities. The issue of whether to accept Darwin's theory will not be decided upon by voting; it is a personal issue heavily mitigated by personal beliefs. It would be informative to explore whether understandings of the nature of science impact one's beliefs about evolutionary theory. Such research would be useful in identifying the types of personal decisions that may be impacted by the nature of science, and possibly, in
facilitating curriculum development and instruction for this critical component of biology.

Should the results of subsequent investigations support the generalizability of the negative results of the present study, the question of why teach the nature of science becomes even more critical. Answering this question provides implications for science education and direction for future research. For example, Driver, et. al (1996) have argued that an understanding of the nature of science is necessary for people to make sense of the science and technology they experience in everyday life. The significance of this assertion is supported by the interview responses of the present study, where all of the participants readily identified multiple examples of personal decisions on science and technology based issues they make on a day-to-day basis. However, does understanding the nature of science significantly impact such personal uses of scientific knowledge? Future research should specifically focus on this application of the nature of science in order to validate (or invalidate) its role in helping people cope in today's technological world.

Another argument for inclusion of the nature of science in the science curriculum is that it facilitates the learning of science content. Typically, students experience a wide range of direct instruction and conformational, cookbook-style laboratory experiences in their science instruction. It is not surprising that in such an environment, students often develop the misconception that scientific ideas, laws, and theories emerge directly from observational data. However, in the actual practice of science, scientific concepts and controversies are almost never decided by data alone (Collings & Pinch, 1996; Kuhn,
Without an appreciation of the conjectural nature of scientific knowledge, students may adopt an inefficient, passive learning style, or simply decide that science is not for them (Driver, et al., 1996). Indeed, science educators have argued that learning science content would be enhanced by drawing attention to the similarities between students' conceptual change and the nature of scientific revolutions (Hodson, 1988), and learning and reflecting on the history of the development of scientific knowledge (Solomon, 1991). Previous studies provide initial support for these ideas by suggesting a relationship between views of the nature of science and conceptual understanding in science (Kuhn, Amsel, & O'Loughlin, 1988; Shapiro, 1989, 1994; Songer & Linn, 1991). Future research should be directed at delineating any relationship between what students know about science and their understandings of science content.

It is possible, perhaps even likely, that results of the suggested empirical studies will not support the assertions, assumptions, and hopes that many science educators have for the nature of science. If such is the case, science educators may be forced to decide between empirical evidence and what they value and hold to be ethically sound. In other words, even if the nature of science is not typically used in decision making, the science education community may decide that it should be. After all, it appears intuitive that knowledge about science would be helpful in deciding science and technology based issues and dilemmas. Maybe people would make better decisions if they understood the nature of science and used it. Future research, therefore, should examine the impact current understandings of the nature of science can have on decision making.
On the other hand, it is important to remember that the construct of the nature of science consists of *values* and assumptions inherent to scientific knowledge. By imposing their values on students' decision making, do science educators want to cross the line from instruction to indoctrination? In the end, will the issue of nature of science instruction be decided upon by the science education community's understandings of the evidence, or like the participants in this study, will values and ethics be the determining factors? These are only two of the many questions that the science education community must address as it continues to explicate a role for the nature of science in the development of scientific literacy.
REFERENCES


Winchester, I. (1993). "Science is dead. We have killed it, you and I"—How attacking the presuppositional structures of our scientific age can doom the interrogation of nature. *Interchange*, 24, 191-198.


APPENDICES
Dear [Name],

My name is Randy Bell and I am a doctoral student in Science Education at Oregon State University. I am beginning my dissertation research soon and would like to ask for your help in my investigation.

My research project will focus on how people make decisions on science and technology based issues, such as global warming and fetal tissue research. I will be selecting participants with extensive backgrounds in science as well as those who have less formal knowledge about science. I should note that I am not interested in your knowledge of particular science subject matter. Instead, I will be exploring how you make decisions on issues of personal and public importance.

If you choose to participate in the study, I will ask you to provide me with a copy of your vita and to complete two questionnaires and two interviews. The first questionnaire contains four scenarios, each depicting a different science and technology based issue. Each scenario is followed by three to five questions that ask you to make decisions about some of the issues related to the scenario. There are not right or wrong answers per se to these questions, rather I am simply interested in your views. Next, I will ask to interview you about your responses to the questionnaire. This interview may be in person or over the phone, will last approximately 45 minutes, and will be audio-taped.

The second questionnaire consists of seven open-ended questions that I will use to assess your views on some additional issues about science. Again, there are no right or wrong answers. I will ask to interview you a second time regarding your responses to this questionnaire. This interview should also last approximately 45 minutes and will be audio-taped.

Confidentiality will be maintained through the use of coding, rather than names, on questionnaires and interview cassette tapes. Additionally, these data sources will be kept in a locked location at all times. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants. Please note that your participation in this research project is voluntary and you may withdrawal from the investigation at any time.

The information that you will provide through your participation in this project is extremely valuable to my research. I would like to thank you in advance for your consideration.
Please contact me at bellr@ucs.orst.edu or (541-737-2545) to let me know whether you choose to participate and whether you have any questions. I very much look forward to working with you.
Dear ___________,

My name is Randy Bell and I am a doctoral student in Science Education at Oregon State University. I am beginning my dissertation research soon and would like to ask for your help in my investigation. My research project will focus on how people make decisions on science and technology based issues, such as global warming and fetal tissue research.

If you choose to participate in the study, I will ask you to provide me with a copy of your vita and to complete two questionnaires and two interviews during the fall of 1998. The questionnaires will focus on your views of science and science and technology based issues, while the interviews will focus on your responses to the questionnaires. Each interview and questionnaire will require about 45 minutes to complete.

I will need to audiotape and transcribe the interviews for subsequent analysis. Confidentiality will be maintained through the use of codes, rather than names, on data sources and by keeping the audio-tapes and questionnaire responses in a locked location at all times. The only people who will have access to the questionnaires will be my major professor and myself. Any publications that result from this investigation will use pseudonyms to maintain the anonymity of the participants.

Please note that your participation in this research project is voluntary and you may withdrawal from the investigation at any time.

If you have any questions you can contact me at bellr@ucs.orst.edu (ph. 541-737-2545) or Professor Norman Lederman at lederman@ucs.orst.edu (ph. 541-737-1819).

Thank you for your consideration. I look forward to the possibility of working with you.

I agree to participate in this research project and understand the general intent of the study, types of data that will be collected, and the anticipated time commitments.

____________________________   _____________________
Signature                                        Date

(Please return a copy of your current vita with this letter).
Last six digits of your social security number: xxx - ____ - ______

Instructions

Answer the following questions, using the back of the page if you need more space. Please note that there are no "right" or "wrong" answers to these questions. I am simply interested in your views on a number of issues about science.

Scenario I

In the past decade, research has opened the doors to fetal tissue transplantation, a procedure that typically involves transferring tissue from an aborted fetus to another human. The procedure could potentially provide therapy for victims of a variety of debilitating diseases, including diabetes, Parkinson's disease and Alzheimer's disease. As in many areas of biotechnology, the development of this technique has outpaced the development of ethical policy. Please read the following scenario and thoughtfully answer the questions that follow.

Bill and Sally are a happily married couple in their late 30s. They enjoy a comfortable life style and a stable home life with their two teen-aged children. Recently, Sally's elderly father was diagnosed as having Parkinson's disease, a slowly progressive disabling ailment marked by tremor and increasing muscular stiffness. His symptoms are mild but his physician has explained that he will become more and more incapacitated with time.
Close to the time that she learns about her father, Sally reads an article in the local newspaper about a research project being run at a local university. A team of researchers, led by Dr. Harrison, have applied to the federal and state governments for permission to do a study with Parkinson's victims. She visits with Dr. Harrison to learn more about the disease. During the course of their discussions, she finds out that the progression of Parkinson's can be slowed and possibly reversed by implanting fetal brain cells in the brain of the patient.

Two months later Sally is surprised to learn that she has become pregnant. Due to the unexpected nature of the pregnancy, Sally considers aborting the fetus. Furthermore, as her father's condition begins to deteriorate, she and Bill consider some therapeutic options for him. Recalling her discussions with Dr. Harrison, Sally and Bill begin to discuss the option of using tissue from the fetus in her womb to donate the cells to cure her father.

Questions:

1. Given the experimental nature of fetal tissue transplant treatments, are Sally and Bill justified in considering the procedure for her father? Why or why not?

2. If Bill and Sally decide to abort the fetus, should they be allowed to donate the fetal tissue for transplantation? Why or why not?

1. Should Bill and Sally be allowed to designate Sally's father as recipient of the fetal tissue? Why or why not?

2. Should Sally be allowed to have the abortion if her primary reason for wanting it is to provide a source of tissue for transplantation into her father? Why or why not?
3. Should Dr. Harrison be allowed to continue his work on fetal brain tissue transplantation as a treatment for Parkinson's disease? Why or why not?
Today, global climate change is a major environmental issue facing the United States and the international community. According to one side, the prospect of human-induced global warming is a near certainty, and failure to address the problem will have catastrophic ecological consequences. According to the other side, global warming is a hypothesis lacking scientific validation, and reducing greenhouse gas emissions will have serious negative economic consequences.

In 1992, the United States, along with roughly 150 other nations, signed the United Nations Framework Convention on Climate Change (FCCC) at the Earth Summit in Rio de Janeiro. The FCCC was ratified by the US Senate in 1992 and has now been ratified by a total of 166 nations. The ultimate objective of this treaty is to "achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." In line with this objective, the most industrialized nations, including the U.S., agreed to the voluntarily aim of returning their greenhouse gas emissions back to 1990 levels by the year 2000. However, the U.S. and most other industrialized nations are not on course to meet this target. In fact, emissions in the U.S. are projected to be 13 percent higher in the year 2000 than they were in 1990.

Because these voluntary targets have proven inadequate in curbing emissions growth, there is now widespread agreement that legally-binding measures are necessary. The upcoming climate conference in Kyoto, Japan, is based on the premise that the
participating nations should agree, for the first time, upon a legally-binding limit on emissions.

Questions:
1. Should the U.S. agree to legally-binding limits on greenhouse gas emissions? Why or why not?

2. Should the U.S. impose special taxes on carbon dioxide emission to encourage energy conservation, even if this increased monthly electricity and heating bills by $25 per month? Why or why not?

3. Would you be willing to pay increased taxes in order to provide funding for research on alternative energy resources, such as solar power and fusion reactors? Why or why not?

4. Should the U.S. reduce automobile emissions by setting higher gas mileage standards, even if this increased the average cost of a new car by $500? Why or why not?
Scenario III

Researchers are just beginning to unravel the role of diet and nutrition in the development of cancer, or carcinogenesis. It is clear that carcinogenesis is a slow process, often taking 10 to 30 years. Diet may play an important role during the initiation of cancer whereby certain foods may serve to increase detoxifying enzymes that help stop the initial stimulation and growth of the cancer cells. At the same time, other nutrients and foods such as fat may serve as promoters for already initiated cancer cells.

Scientists have estimated that diet is responsible for 20 to 40 percent of all cancers, perhaps as high as 70 percent. Diets rich in fruits, vegetables, and fiber have consistently been shown to have a beneficial effect on cancer. On the other hand, heavy consumption of red meats, saturated fats, and salty foods have been linked to a variety of cancers. Other lifestyle factors related to nutrition also appear to be associated with cancer. Obesity has been linked to a variety of cancers, including endometrial, breast, colon, and ovarian. Alcohol consumption has been linked to cancers of the digestive tract and liver. Conversely, several studies have supported the beneficial aspects of physical activity, which may reduce the risk of several types of cancer, including colon, breast, and prostate.

Questions
1. How would you rate your overall awareness of the impact of diet and related factors on the development of cancer?
2. Has your awareness of the benefits of physical activity and a diet rich in fruits and vegetables impacted how you conduct your life? If not, why not? If so, in what way(s)?

3. Do you ever base decisions about what to eat on your understandings of current research into diet and cancer? If not, why not. If so, in what ways?

4. Do you regularly exercise? Why or why not?

5. Would you support increased legislation on foods associated with cancer, including removing high risk foods from the market?
Many researchers believe that smoking accounts for a large proportion of all cancers and as much as 30 percent of all cancer deaths. Cigarette smoking has specifically been implicated as the cause of cancer of the lung, oral cavity, larynx, esophagus, bladder, kidney, and pancreas. Additionally, the risk of developing cancer is greater for people who smoke more and who start smoking at a younger age. Furthermore, researchers believe that smoking may be the cause of 25 to 30 percent of all heart disease. Exposure to passive tobacco smoke is very likely a significant cause of cancer in nonsmokers. Some scientists believe that the increased risk could be as high as 50 percent. It has been estimated that thousands of people die each year due to exposure to passive cigarette smoke.

Recently, nicotine in cigarette tobacco has been identified as a drug whose addictiveness exceeds that of opium and heroine. In addition to this, documents have come to light that indicate that some tobacco companies have used a variety of methods to increase the amount and potency of nicotine in cigarette tobacco. Finally, it has been shown that many people begin smoking as teenagers, and once started, have a very difficult time quitting.

In contrast to these claims, tobacco companies have consistently asserted that while tobacco may be associated with increased risk for various cancers and heart disease, it has never been proven to cause these diseases. Furthermore, to smoke or not is a free choice that should be up to the consumer, not government agencies.
Questions

1. Given the reported dangers of cigarette smoke and its addictiveness, should legislation be passed that would make cigarette smoking illegal? Why or why not?

2. Would you support legislation that makes it more difficult for minors to obtain cigarettes and/or penalizes tobacco companies who target minors in their advertising? Why or why not?

3. Do the alleged dangers of passive cigarette smoke justify banning smoking in public places such as restaurants and bars? Why or why not?
APPENDIX D
NATURE OF SCIENCE QUESTIONNAIRE

Last six digits of your social security number: xxx - _____ - ______

Instructions

Answer the following questions, using the back of the page if you need more space. Please note that there are no "right" or "wrong" answers to these questions. I am simply interested in your views of a number of issues about science.

1. After scientists have developed a theory (e.g., atomic theory, kinetic molecular theory, cell theory), does the theory ever change? If you believe that scientific theories do not change, explain why and defend your answer with examples. If you believe that theories do change: (a) Explain why. (b) Explain why we bother to teach and learn scientific theories. Defend your answer with examples.

Note: Parentheticals are not part of the questionnaire.

(This question aims to assess understandings of the tentative nature of scientific claims and why these claims change. It is common for respondents to attribute such change solely to the accumulation of new facts and technologies, rather than the inferential nature of scientific theories and/or paradigm shifts. The question also aims to assess respondents' understandings of the role of theories in science as well as the theory-laden nature of scientific observations).
2. Science textbooks often represent the atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine the structure of the atom?

(This question aims to assess understandings of the role of human inference and creativity in science, the role of models in science, and the notion that scientific models are not copies of reality.)

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

(This question aims to get at a common misconception about the relationship between the products of science. Many respondents believe in a hierarchical relationship between the two whereby theories become laws if and when enough evidence has been accumulated in their favor. Additionally, respondents express many ideas related to their understandings of the nature of science and science process as they attempt to delineate the difference between theories and laws.)
4. How are science and art similar? How are they different?

(This question aims to assess understandings of the role of creativity and imagination in science, the necessity of empirical evidence in generating scientific knowledge, and the cultural and social embeddedness of science.)

5. Scientists perform experiments/investigations when trying to solve problems. Other than in the stage of planning and design, do scientists use their creativity and imagination in the process of performing these experiments/investigations? Please explain your answer and provide appropriate examples.

(This question aims to assess respondents' understandings of the role of human creativity and imagination in science. While respondents generally recognize that experimental design involves creativity, they rarely say that creativity is used in data analysis in the sense that scientists are, for instance, "creating" patterns rather than "discovering" them.)
6. In the recent past, astronomers differed greatly in their predictions of the ultimate fate of the universe. Some astronomers believed that the universe is expanding while others believed that it is shrinking; still others believed that the universe is in a static state without any expansion or shrinkage. How were these different conclusions possible if the astronomers were all looking at the same experiments and data?

(By posing a scientific controversy and stressing the fact that scientists are using the same data but coming up with differing explanations, this question invites respondents to think about factors that affect scientists' work. The factors range from scientists' personal preferences and biases to differing theoretical commitments to social and cultural factors.)
Following is a list of additional factors that the respondents indicated had influenced their decisions, along with representative quotes.

**Scenario 1**

1. Moral/ethical issues
   a. ethical issue:
   
   The desire to stay alive and the desire to assist a family member in staying alive is strong and in itself justified if that chance of a cure doesn't negatively impact anyone else in a significant fashion. (A2, DMQ)

   To intentionally abort is unethical if one respects the life of that child. However, if a miscarriage took place then I would see no problem using brain cells or fetal tissue in experiments. (B3, DMQ)

   The problem with this situation is an ethical one. How far should medicine go to artificially extend or improve the quality of life? (B5, DMQ)

2. Values
   a. personal choice:
   
   I believe they should be allowed to do whatever they want with the aborted fetus. (A1, DMQ)

   Abortion is a personal choice. (B4, DMQ)

3. Social/political issues
   a. legal issues:
   
   ...as long as abortion is a legal procedure, productive use of the tissue to save adult lives seems fine. (A8, DMQ)
Either it's legal or it's illegal. It is currently legal, so she should be allowed to have the abortion... (B6, DMQ)

b. societal benefit:

Yes [the research should continue], since brain tissue from aborted fetuses is available in the ordinary conduct of medical practice and the tissue can provide medical knowledge and benefits. (A4, DMQ)

Definitely [the research should continue]! These treatments have the potential to greatly reduce suffering in the human population. (B8, DMQ)

4. Support of science

Fetal transplant will remain "experimental" unless further research is done to determine it's safety and effect. (A1, DMQ)

Well, I believe in what's happening scientifically. There are advances that are always being made and as a people we are moving forward. So, I have a lot of confidence in the scientific approach. (B4, DMQ-interview)

5. Miscellaneous

a. status of the fetus:

Our society does not allow the murder of another human; it does not, however, view a fetus as a human being. (A5, DMQ)

Despite this distasteful situation (and an even worse situation if the couple becomes pregnant to donate the cells), I believe that this group of cells is part of the woman's body and should be treated accordingly. (B8, DMQ)

b. status of the father:

They would be justified in going beyond consideration if they determine that they do not want the additional child, if her father is not too elderly and infirm, etc... (A3, DMQ)

c. nature of the disease:

Another reason that makes such a consideration more viable in this case is that Alzheimer's and Parkinson's diseases are non-curable. Currently, once you get the disease there are no other options... (A7, DMQ)
Probably not. If it were a not an experimental procedure I would have answered the same way. Again, if somebody has a debilitating disease I’m very comfortable with trying an experimental treatment. The results of the experiment will not be any worse than the disease. (B8, DMQ-interview)

d. making the best of a bad situation:

If they decide to abort the fetus, one would hope for some good to come of this. The use of the tissue to ameliorate or correct the father's Parkinson's disease is one such good. (B1, DMQ)

Scenario 2

1. Social/political issues

My first reaction is that, yes, this sounds like a good idea. However, the population most impacted by this would likely be poor people in cold climates who can't pay for their heat as it is. If electricity and heating bills go up as a result, so should our support of social service programs. (A1, DMQ)

Yes [the US should agree to legally binding limits on greenhouse gas emissions]. The US has a reputation for doing what it wants and working treaties and international agreements to its sole advantage. (B5, DMQ)

2. Pragmatism

The US should not agree [to binding limits] for three reasons. The first is that effective monitoring of compliance (for a country) is almost impossible. Incentives have historically always (or almost always) worked better for such challenging issues than regulation. (A9, DMQ)

Yes [the US should agree to legally binding limits on greenhouse gas emissions], if these limits are technically feasible and the costs are not prohibitive. (B6, DMQ)

3. Personal issues/values

From my understanding emissions from cars cause the problem. In addition to car emissions being the problem of the green house effect, they are also just a problem in general, because they are ugly, and people who drive them are crazy. I can’t stand them. (A1, DMQ)
Yes [the US should set higher gas mileage standards]. I would especially like to see the gas-guzzling cars like the sport utility vehicles people in Oregon drive taxed to the point where people would think twice about buying them... What's the point of me driving a small car when my neighbor drives a tank? (B7, DMQ)

4. Personal philosophy

a. conservation

Yes, taxes should be imposed on electricity usage, as this would encourage conservation. Cheap electricity (from fossil fuel burning plants) and gasoline encourages its consumption. (A6, DMQ)

At some point we need to have alternative energy sources. It seems wise to me to simultaneously pursue conservation and alternative energy sources. (B5, DMQ)

b. reducing emissions is good, in general

[Reducing greenhouse gas emissions] is good to do independently of human influenced global warming—it reduces reliance on fossil fuels, it reduces pollution, etc. (A3, DMQ)

5. Economics

On economic grounds, the United States also has an obligation to lead the way in reducing the amount of energy used, as well as the amount and kinds of emissions produced. (A5, DMQ)

I believe that the economic consequences of curbing greenhouse gases may be greater than the effects of global warming. (B8, DMQ)

6. Miscellaneous

a. ethics

No [the US should not impose special taxes on carbon dioxide emission]. This is punishment on everyone when industry needs to be accountable for its own production standards. There should be other ways to fund energy conservation than individual taxes. (B3, DMQ)

b. long-term consequences

We have no idea what the extent of [climate] changes we are looking at in 50 to 100 years. Serious action is called for. (B2, DMQ)
Scenario 3

1. Values

a. convenience

The one area of my diet that I know is problematic and that I have not successfully resolved is the eating of fresh fruits and vegetables. Since college, my erratic schedule makes buying and remembering to bring fruits and vegetables a challenge. (A5, DMQ)

No, I exercise on a sporadic basis. I generally don’t make time in my schedule. (B9, DMQ)

b. personal choice

No, I support information, but not restriction. I think what we eat should not be the government’s business. (B8, DMQ)

No [I would not support increased legislation on foods associated with cancer]. Freedom of information, freedom of choice is too important. (A8, DMQ)

c. body image

I watch my weight because I am more concerned about avoiding the social stigma associated with obesity than with reducing my risks of various cancers. (A5, DMQ)

I like to go to the gym 2 or 3 times a week and do an exercise routine and jog around the gym for a mile to maintain some body tone. (B2, DMQ)

2. Moderation

I emphasize a balanced diet of foods in modest amounts. (A4, DMQ)

No, I would not [support increased legislation on foods associated with cancer]. I can’t believe all of these “bad” things are necessarily bad if taken in moderation. (B7, DMQ)
3. Miscellaneous

a. personal experience

[I regularly exercise] because my family history indicates I should—a cousin died of a heart attack at age 29 and an uncle had heart bypass surgery. (A3, DMQ)

Our parents (now in their 60’s) have had exemplary healthy diets for many years from which they have enjoyed numerous benefits. They have encouraged us to do the same. While our parents do have some health problems, cancer is not one of them at this point. (B5, DMQ)

b. personal benefit

I exercise two or three times a week because it improves my health and because I am much sharper mentally when I exercise. Exercise gives me an energy boost. (B1, DMQ)

Scenario 4

1. Values

a. personal choice

No [legislation making cigarette smoking should not be passed]. I believe in individual choice!!! (B8, DMQ)

I think it is evil for tobacco companies to lure young people to use their highly addictive, health jeopardizing products. (B5, DMQ)

2. Pragmatism

I do not believe such legislation should be passed. Even if smoking could be made illegal, smokers would find ways of getting tobacco. I imagine a situation similar to prohibition would arise. (A6, DMQ)

Soooo many people smoke that I can’t believe it would be politically useful to outlaw cigarette smoking entirely. A prohibition would only lead to contraband cigarettes and increased lawlessness. (B7, DMQ)

3. Miscellaneous

a. limit freedom of minors
Yes. Risk perception tends to be unrealistic in minors. Minors should be protected and tobacco companies penalized for targeting minors. (B9, DMQ)

b. societal rights

Yes [smoking should be banned in public places]. The public has a right to a safe environment. (B4, DMQ)

c. human nature

No [cigarette smoking should not be banned]. People need to be changed from the inside out, not outside in.

d. personal rights

I think if people are willing to risk their lives and smoke, that's their business. But when their smoking risks MY life, not to mention ruins my meal, then they're impinging on my civil rights. (A1, DMQ)

e. personal convenience

I know many people who support and would continue to support a ban of cigarettes in public places, regardless of the scientific evidence for or against its dangers: They find smoking a public nuisance; they think the smoke and smell more problematic than the possibility of cancer. (A5, DMQ)