Use of the History of Science in a Nonscience Majors Course: Does It Affect Students' Understanding of the Nature of Science?

Linda Easley Roach
Louisiana State University and Agricultural & Mechanical College

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Use of the history of science in a nonscience majors course: Does it affect students’ understanding of the nature of science?

Roach, Linda Easley, Ph.D.

The Louisiana State University and Agricultural and Mechanical Col., 1993
USE OF THE HISTORY OF SCIENCE IN A NONSCIENCE MAJORS COURSE: DOES IT AFFECT STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE?

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

Linda E. Roach
B.S., Northwestern State University, 1976
M.A., Louisiana State University, 1991
December 1993
DEDICATION

To my husband, Scott and my daughter, Katie for their enduring love, patience, and support.
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<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
<th>page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgement</td>
<td>iii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>viii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>ix</td>
</tr>
<tr>
<td>Abstract</td>
<td>x</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Research Questions</td>
<td>5</td>
</tr>
<tr>
<td>Review of Literature</td>
<td>8</td>
</tr>
<tr>
<td>Theoretical Basis for Research</td>
<td>8</td>
</tr>
<tr>
<td>Misconceptions Research</td>
<td>10</td>
</tr>
<tr>
<td>History and Nature of Science</td>
<td>12</td>
</tr>
<tr>
<td>Model of the Nature of Science</td>
<td>13</td>
</tr>
<tr>
<td>Use of the History of Science in Science Classrooms</td>
<td>17</td>
</tr>
<tr>
<td>Techniques</td>
<td>20</td>
</tr>
<tr>
<td>Stories</td>
<td>21</td>
</tr>
<tr>
<td>Interactive Historical Vignettes</td>
<td>24</td>
</tr>
<tr>
<td>Attitudes of Science Emphasized</td>
<td>28</td>
</tr>
<tr>
<td>in the Vignettes</td>
<td></td>
</tr>
<tr>
<td>Previous Studies</td>
<td>30</td>
</tr>
<tr>
<td>Textbook Presentations of the History of Science</td>
<td>31</td>
</tr>
<tr>
<td>Assessment Techniques</td>
<td>33</td>
</tr>
<tr>
<td>Intervention Techniques</td>
<td>36</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>43</td>
</tr>
<tr>
<td>Pilot Studies</td>
<td>43</td>
</tr>
<tr>
<td>Instrument Development</td>
<td>43</td>
</tr>
<tr>
<td>Subjects</td>
<td>48</td>
</tr>
<tr>
<td>Description of Students</td>
<td>50</td>
</tr>
<tr>
<td>Instructional Procedures</td>
<td>52</td>
</tr>
<tr>
<td>Experimental Technique</td>
<td>54</td>
</tr>
<tr>
<td>Quantitative Analysis</td>
<td>69</td>
</tr>
<tr>
<td>Qualitative Analysis</td>
<td>74</td>
</tr>
<tr>
<td>Journals</td>
<td>75</td>
</tr>
<tr>
<td>Interviews</td>
<td>78</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>82</td>
</tr>
<tr>
<td>Quantitative Analysis</td>
<td>82</td>
</tr>
<tr>
<td>Qualitative Analysis</td>
<td>83</td>
</tr>
<tr>
<td>Research Question 1</td>
<td>84</td>
</tr>
<tr>
<td>Research Question 2</td>
<td>87</td>
</tr>
<tr>
<td>Qualitative Analysis of NOSQ Responses</td>
<td>88</td>
</tr>
<tr>
<td>Analysis of Journals by Entry</td>
<td>93</td>
</tr>
<tr>
<td>Analysis of Individual Journals</td>
<td>101</td>
</tr>
<tr>
<td>Journal 1--Freshman</td>
<td>102</td>
</tr>
<tr>
<td>Journal 2--Sophomore</td>
<td>103</td>
</tr>
<tr>
<td>Journal 3--Junior</td>
<td>104</td>
</tr>
<tr>
<td>Journal 4--Elementary Education Major</td>
<td>106</td>
</tr>
<tr>
<td>Journal 5--Nontraditional Student</td>
<td>107</td>
</tr>
<tr>
<td>Analysis of Individual Journals and Interviews</td>
<td>108</td>
</tr>
<tr>
<td>Journal 6--Freshman</td>
<td>109</td>
</tr>
<tr>
<td>Journal 7--Sophomore</td>
<td>110</td>
</tr>
<tr>
<td>Journal 8--Junior</td>
<td>116</td>
</tr>
<tr>
<td>Journal 9--Elementary Education Major</td>
<td>120</td>
</tr>
<tr>
<td>Journal 10--Nontraditional Student</td>
<td>123</td>
</tr>
<tr>
<td>Research Questions 3 &amp; 4</td>
<td>128</td>
</tr>
<tr>
<td>Research Question 5</td>
<td>130</td>
</tr>
<tr>
<td>Research Question 6</td>
<td>131</td>
</tr>
<tr>
<td>Student Comments</td>
<td>132</td>
</tr>
<tr>
<td>Summary and Conclusions</td>
<td>134</td>
</tr>
<tr>
<td>Summary of Study</td>
<td>134</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>135</td>
</tr>
<tr>
<td>Limitations of the Study</td>
<td>137</td>
</tr>
<tr>
<td>Future Research</td>
<td>138</td>
</tr>
<tr>
<td>References</td>
<td>140</td>
</tr>
<tr>
<td>Appendix A: A Model of the Nature of Science</td>
<td>150</td>
</tr>
<tr>
<td>Appendix B: Sample Vignette: Genius Lost</td>
<td>151</td>
</tr>
<tr>
<td>Appendix C: Nature of Science Questionnaire</td>
<td>155</td>
</tr>
<tr>
<td>Appendix D: Schedule of Vignette Usage</td>
<td>157</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Means and Standard Deviations of Student Groups Pilot Tested</td>
<td>46</td>
</tr>
<tr>
<td>3.2</td>
<td>Description of Control Section</td>
<td>49</td>
</tr>
<tr>
<td>3.3</td>
<td>Description of Experimental Section</td>
<td>49</td>
</tr>
<tr>
<td>4.1</td>
<td>Summary of Results from NOSQ for Experimental and Control Groups</td>
<td>86</td>
</tr>
<tr>
<td>4.2</td>
<td>Summary of Results from NOSQ for Nontraditional Students, Elementary Education Majors and Other Nonscience Majors</td>
<td>129</td>
</tr>
</tbody>
</table>

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# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Concept Map of Interactive Historical Vignettes</td>
<td>27</td>
</tr>
<tr>
<td>3.1</td>
<td>Statistical Analysis--Experimental vs. Control Groups</td>
<td>71</td>
</tr>
<tr>
<td>3.2</td>
<td>Statistical Analysis--Traditional Students vs. Nontraditional Students</td>
<td>72</td>
</tr>
<tr>
<td>3.3</td>
<td>Statistical Analysis--Elementary Education Majors vs. Other Nonscience Majors</td>
<td>73</td>
</tr>
<tr>
<td>F.1</td>
<td>Vee Diagram of Proposed Research</td>
<td>161</td>
</tr>
<tr>
<td>H.1</td>
<td>Statistical Analysis--Experimental vs. Control Groups</td>
<td>163</td>
</tr>
<tr>
<td>H.2</td>
<td>Statistical Analysis--Traditional Students vs. Nontraditional Students</td>
<td>164</td>
</tr>
<tr>
<td>H.3</td>
<td>Statistical Analysis--Elementary Education Majors vs. Other Nonscience Majors</td>
<td>165</td>
</tr>
</tbody>
</table>
ABSTRACT

In response to a call for more research into using the history of science to teach the nature of science, a call for development of curriculum materials for inclusion of the nature of science in undergraduate nonscience majors courses, and in keeping with the nature of science described in the literature, interactive nature-of-science historical vignettes were utilized in a quantitative and qualitative investigation. Interactive nature-of-science historical vignettes employ the interrupted story form and binary opposites involving conflict to generate student participation and spark discussion about the nature of science. They were utilized as an experimental technique in a university level, introductory nonscience majors course to determine if inclusion of the history of science in such a course would induce conceptual change about the nature of science without sacrificing student understanding of the physical science content included in the course. An instrument, the Nature of Science Questionnaire (NOSQ), was developed based on a model of the nature of science drawn from science education research literature and was utilized to quantitatively determine if the experimental technique was useful. Qualitative research, in the form of content analysis of journals and transcripts of interviews, was performed to determine what conceptions and/or misconceptions students held before and after treatment. Qualitative research also investigated differences between elementary education majors and other nonscience majors, and between traditional and nontraditional
students in their understanding of the concepts associated with the nature of science both before and after treatment. Students who participated in the interactive nature-of-science vignettes demonstrated statistically significant gains in an understanding of the nature of science. These students showed no losses in understanding of physical science content topics. Students who did not participate in the interactive historical vignettes did not show similar gains in their understanding of the nature of science. Content analysis of journals and interview transcripts provide evidence that qualitative research should accompany questionnaires when investigating student understanding of the nature of science.
INTRODUCTION

Science for All Americans (SFAA), (1990) provides recommendations about what knowledge and ways of thinking are essential for all citizens who live in this world shaped by science and technology. The purpose of education is to prepare people to lead personally fulfilling lives, relying on themselves to accomplish their goals. In order for a person to do this, according to SFAA, s/he must be scientifically literate.

Scientific literacy seems to be the "Mom and apple pie" of science education these days. Lederman (1992) states that it is the most often stated goal and the most important purpose of science education. SFAA provides guidelines and recommendations for teachers to follow to produce scientifically literate students. Among them are: "basic knowledge about the world as currently seen from the perspective of science" and an "understanding of some of the great episodes in the history of the scientific endeavor...that can serve as (a) tool for thinking about how the world works" (pp. ix-x). A realistic conception of the nature of science is necessary for one to be scientifically literate (Klopfer, 1969; Lederman, 1986). If students are to become scientifically literate, then the teachers who teach them must also understand the nature of science so appropriate behaviors and attitudes can be modeled. Teachers' views on the nature of science can influence students' conceptions and can limit the view of the nature of science that is portrayed to students (Abell & Smith, 1992).
A body of evidence has accumulated which suggests students at all educational levels are scientifically illiterate. As late as 1986, Lederman states "After three decades of research concerned with the 'nature of science' we know little more than that we are unhappy with the conceptions currently held by our secondary school students" (p. 3). These people will be ill-equipped to make informed judgments about science-related decisions which will affect the quality of their lives. Students must understand the nature of science in order to evaluate and apply the effects of science and technology on society (Griffiths & Barry, 1993). Some of these citizens will become political leaders who will be no better prepared to deal with such important issues (Hendrick, 1992). All will be voters and an understanding of the nature of science will provide these potential voters with a better understanding of science related-issues they will face (Krajkovich & Smith, 1982).

Leon Lederman, 1988 Nobel Laureate in Physics, believes a basic problem is that nonscience majors are 'pretty uncomfortable with science' (Hendrick, 1992). Hendrick goes on to say it is very important to make nonscience majors comfortable with science and proposes introducing the history and philosophy of science into nonmajors' courses to achieve these ends.

In 1951, J. B. Conant advised science educators that giving a larger dose of scientific facts to nonscience majors was not the same thing as
providing them with an understanding of science. He recommended imparting knowledge of scientific strategies to those who were not (nor would ever be) scientists. He argued that use of the histories of the various sciences could accomplish this. (This was reiterated by Klopfer in 1969 and Shahn in 1988). As early as 1954, Wilson advised university professors that knowledge about the attitudes (my emphasis) of science is more important for the majority of college students than detailed knowledge of scientific laws.

Brown (1991) provides a rationale for incorporating a historical approach to science teaching in both college and precollege classrooms. He states this approach will stimulate students’ sense of wonder and curiosity about the natural world and promote scientific literacy. He calls it "a humanistically oriented qualitative alternative" (p. 357). Anderson (1978) suggests a holistic approach that includes historical and philosophical aspects. He professes that by rounding out the teaching of science and not relying on reductionist texts, each student can be placed in a learning situation that will match his or her interests, and consequently, the student will learn more science.

Helmstatdler (1970) reminds us that no matter how many people intuitively believe something is good, we must provide evidence to support these beliefs. No one seems to disagree that inclusion of the history and nature of science in science classes is the proper thing to do to revise the distorted view of science by the masses, and many studies have been done to
provide support for these ideas. By far the majority of studies on inclusion of history and nature of science in science courses have involved secondary science classrooms, with a few middle school classrooms included. Only rarely does a study use college nonscience majors and/or elementary education majors (Abell & Smith, 1992; Lavach, 1969; Wilson, 1954); however, other studies have shown that teachers themselves do not understand the nature of science (e.g., Gallagher, 1991; Hodson, 1991; Lavach, 1969; Lederman & Zeidler, 1987; Schmidt, 1969).

There is a growing interrelation between epistemological, historical, and educational research. This research has changed the views about how knowledge is acquired, both by scientists as a part of a scientific community and by students (Giannetto, Tarsitani, & Missoni, 1991). Wandersee (1985) reports that science education researchers from several areas note a parallel between the historical development of scientific ideas and cognitive development in students. He challenges science educators to "investigate and explore the application of the history of science to modern science education" (p. 594). Lederman (1986) bemoans the fact that while teachers are being urged to teach the nature of science in their classrooms, they have not been offered research-based advice on how to accomplish this. Both Gallagher (1991) and Ray (1991) advise there is little teaching of the history of science at the university level. Ray (1991) further states there are few history and philosophy curriculum materials for use in science classrooms, and Bybee,
Powell, Ellis, Giese, Parisi, & Singleton (1991) report there are few efforts to develop materials to teach the history of science.

My proposed research investigates the effects that the use of history in science teaching has on college nonscience majors' understanding of the nature of science. Of interest in this research are the ideas of preservice elementary education majors since they will be early influences on students' conceptions of the nature of science.

Teachers are expected, if not required, to address a certain number of topics in a given teaching period (school year or college semester). To develop scientific literacy, students must master a reasonable amount of subject matter in order to understand the historical and philosophical generalizations presented (Arons, 1991). Furthermore, Arons (1991) states "specific examples of historical and philosophical perspectives...can be infused into introductory courses without seriously affecting the amount of physics being covered, and that do not...do violence to the history or the philosophy involved" (p. 170). Wandersee (1990) also recommends the limited infusion of history and philosophy into existing courses. The British National Curriculum Council recommends about 5% of program time be spent on history and philosophy (Matthews, 1992).

Research Questions

The literature has established a need for the inclusion of the histories of the natural sciences in existing courses for nonscience majors and further
calls for development of curriculum materials to achieve these ends. In their summary of science education research in 1990, Finley, Lawrenz, and Heller, (1992) call for future research to learn "what features of the nature of science our students should learn, what their initial conceptions of science include, and to develop curriculum and instruction which is consistent with the most recent developments in our understanding of the nature of science" (p. 270). Garrison and Bentley (1990) describe this area of research as a frontier area, and call for more research and reflection. Consistent with this call for research, and consistent with curricular materials that I have written, the purpose of which is to infuse the histories of science into an existing course, the following questions were investigated:

1. Will including interactive nature-of-science vignettes, drawn from the histories of science, in a college introductory physical science course for nonmajors induce conceptual change about the nature of science?

2. What conceptions of the nature of science do university students hold (before and after the treatment)?

3. Are there differences between traditional students (ages 18-21) and nontraditional students (age 23 and older) in the initial and final understanding of the nature of science?

4. Are there differences between elementary education majors and other nonscience majors in the initial and final understanding of the nature of science?
5. Can interactive nature-of-science vignettes, drawn from the histories of science, be used as an instructional strategy to induce conceptual change about the nature of science without sacrificing student understanding of the physical science course content?

6. Will students demonstrate an increased interest in scientific topics and/or scientists as a result of instruction employing interactive nature-of-science vignettes?
REVIEW OF LITERATURE
Theoretical Basis for Research

All of the research questions in this study have foundations in conceptual change theory, although the first, second, and fifth have the most direct relationship. Conceptual change theory asserts that learning is not merely an accumulation of information by a passive learner, but a process in which the learner must be actively engaged, reshaping his or her ideas (Cleminson, 1990; Posner, Strike, Hewson, & Gertzog, 1982). Learning may be viewed as a process by which repeated encounters with information have a cumulative effect on a students' conceptual ecology (Cleminson, 1990). Children do not have isolated concepts, but rather their ideas are part of a conceptual network that allows them to understand and explain the world around them. Humans construct mental models of their environments based on past experiences. New experiences are interpreted, explained, and understood based on their relationships to these existing mental frameworks (Driver, 1991). When meaningful learning takes place, these existing mental frameworks are restructured and actively reorganized by the learner. For learning to take place, the learner must first become dissatisfied with his or her current conceptions (Posner, Strike, Hewson, & Gertzog, 1982), then separate and recombine what s/he knows with what s/he needs to know and establish new patterns (Gowin, 1981).
Students’ explanations, including the words used to describe them, develop long before they are taught any formal science. They arise from interaction with and observation of the natural world and help pupils make sense of their surroundings. Both science education and cognitive psychology have realized that knowledge consists of a complex mesh of information and new knowledge is strongly influenced by this prior knowledge (Shuell, 1987). We interpret and understand new information and experiences based on what we already know. If our new experiences and encounters cannot be meshed with our old ideas, the new information becomes somewhat meaningless (Watt, 1988). My third and fourth research questions investigate the possibility of different prior experiences among students having an impact on their cognitive structures.

Meaningful learning is aided by cognitive bridges. These allow the student to incorporate new knowledge into a relevant existing model. Interactive vignettes based on the histories of science could be described as cognitive bridges, allowing students to make connections between what they know and what they need to know. Question six explores whether or not students show an increased interest in science by seeking other cognitive bridges (more information on the scientist and/or topic) to assist them in the process of conceptual change about the nature of science.

Since conceptual change does not result from a one-shot treatment of the concepts to be changed, but takes several exposures to the concept(s)
before integration into students' conceptual frameworks is accomplished, the experimental treatment in my study lasted the full length of the introductory physical science course into which it was integrated.

**Misconceptions Research**

There is a body of research which is commonly referred to as **misconceptions research**. While there is no standardized term to describe the students' ideas which deviate from scientists' views, science education researchers agree on the importance of these ideas and their effects on science learning. Misconceptions research shows that the alternative concepts students construct to explain the real world are tenacious and very resistant to change. These conceptual frameworks are stubbornly rooted, and universal in nature across age, race, and nationality.

While most misconceptions research has dealt with students' understanding of the concepts associated with a particular content topic (e.g., forces and motion, light, electricity, etc.), less attention has been paid to students' intuitive theories about the nature of science (Griffiths & Barry, 1993). My study attempts to address not only the misconceptions students have about the nature of science and those concepts underpinning it, but is also an effort to effect conceptual change about the nature of science.

Two concomitant topics of interest in science education research for the 1990s are students' models and epistemologies, and use of history of science in science teaching. Each was the topic of a special issue of the
Closely related to the misconceptions research into students' intuitive beliefs about the nature of science is an interest in students' epistemologies and models. This body of research investigates students' understanding of how scientific knowledge is acquired and validated.

Growth of thinking is a process of forming, elaborating on, and arranging concepts into systematic structures. These systematic structures or frameworks of concepts are used to order knowledge (Wartofsky, 1968). Science has constructed a conceptual framework which goes beyond that found to explain common, everyday language. Special language is used by scientists and scientific concepts are often more specialized, often to the point where they are so different from the everyday concepts that they could be described as incompatible (Wartofsky, 1968). Nersessian (1991) advises that when the same word is used both in everyday language (the students' current conceptual structures) and in scientific language, its meaning often changes significantly. Calling attention to these differences in meaning is quite helpful in the instructional process of attempting to effect conceptual change and restructure these frameworks. In order for students to understand the nature of science, their current conceptions (and the differences among them and scientific conceptions) must be identified.

The role of observation and experiment in science, the nature of hypotheses, laws, theories, and models are epistemological concerns.
However, before students can begin to evaluate conditions for generating and testing scientific knowledge claims, the misconceptions they have about experiments, hypotheses, laws, theories, and models must be addressed. When students describe the demonstrations I do in class as hands-on experiments, characterize theories as guesses, laws as proven beyond any doubt, and indicate that the statement, "Elephants like hay.", is a hypothesis, we see that students do have misconceptions about the concepts underlying the nature of science. Science educators should be concerned when these misunderstandings of the inherent substructure of commonly used terms surface. These misconceptions tend to translate into misunderstandings about how science is conducted (Griffiths & Barry, 1993).

In order to effect changes in students' conceptions about the nature of science, the nature of science itself must first be defined.

**History and Nature of Science**

Contemporary views of the nature of science have evolved since the ancients. Within this evolution, one can see the birth, development, and demise of ideas. However, it is important to note that this evolution is not an orderly, linear progression of ideas, but includes controversies found in modern science. Science education has not seen a conversion of the curriculum to embrace this evolved view of the nature of science (Duschl, 1990).
The following model of the nature of science was developed from a review of the literature. It is only one of several possibilities and represents the researcher's selection of those aspects of the nature of science considered relevant to the parameters of the study, yet which are pervasive across the reviewed literature. The definitions for the nature of science found in the literature are multifaceted (Meichtry, 1993). When one considers the different viewpoints expressed by the various philosophers of science, it becomes evident that there is no one preferred model of the nature of science (Lederman, 1992). See Appendix A for a cross reference of the declarations of my model to the literature and to the attitudes emphasized in the experimental technique.

Model of the Nature of Science

1. Scientific knowledge is tentative.

2. Science is a process utilizing many scientific methods.

3. Science is a search for knowledge; technology is the application of science to alter the environment or human condition.

4. Science is a human endeavor involving curiosity, creativity and imagination.

5. Science is grounded in nature.

6. Science searches for the simplest explanation of events, often using mathematics in this search for parsimony.
Textbooks, instructional materials, and teachers all tend to present a positivistic account of scientific knowledge. The curriculum emphasizes incorrect and/or misleading views of scientific knowledge implying that it is either absolute truth and not subject to change; or an accumulation of knowledge (Bybee et al., 1991; Garrison & Bentley, 1990; Meichtry, 1993). Teaching about the scientific method usually involves memorizing a set of steps. Teachers inappropriately represent the nature of science by designing projects which allow students to confirm the ideas presented in lecture class (Bybee et al., 1991). Students (including preservice teachers) see science as a product rather than a process (Linn, Songer & Lewis, 1991). They leave the university with their ideas about the nature of science intact. The problem is that these teachers are taught to accept what Lemke (1990) calls the "mystique" of science, including the myths of science rather than the nature of science. For generations, the published results of scientific research have had an impersonal quality that has left the general public blind to the complex nature of science and its vital human component (Shropshire, 1981), further perpetuating the myths of science. Students see only one of the faces of science—the products (or final form science), and are not shown the other face of science—the processes. If the nature of science is thought to be an integral part of the subject matter, then neither face of science should be neglected (Rutherford, 1964). To do so leaves science curriculum "epistemologically flat" (Duschl 1990). Garrison and Bentley (1990) advise
that teachers will need help in examining their instructional practices for areas where this positivistic tone is communicated, and help in developing new practices to accurately communicate the nature of science.

If used as a framework for teaching the nature of science, contextual realism can help reduce this positivistic portrayal of science. It can demonstrate the many scientific methods and nature of science united by general similarities (Good & Schlagel, 1992). Course content and instructional methods of science classes should reflect the nature of science. For this to occur, research and reflection must continue and an effort must be made to introduce the modern perspective into preservice teacher education programs (Garrison & Bentley, 1990). An understanding of the contributions of science, both the past and present, is critical for those who will teach science (Duschl, 1990). Furthermore, Lederman and Druger (1985) suggest that enhancing teachers’ conceptions of the nature of science must be accompanied by training in relevant teaching behaviors and methods so teachers can effectively convey their conceptions to students.

The portrayal of science as impersonal, smoothly operating, linearly progressing, and unproblematic must be discarded. The image of the scientist as a hoary bearded, bespectacled, eccentric, white male has led to disenchantment with science by many students. If we are to recruit more students into science, we must dispel this image and show students that science is an endeavor carried out by humans, not robots.
Current teaching practices and curriculum materials misrepresent science as positivistic. Lemke (1990) describes stylistic norms of language that are found in science classrooms which mislead both students and teachers to imagine that science operates outside the world of humans. Included in his list are: avoidance of personification, personalities of scientists, history, narrative, fiction, or fantasy. He further states that good science teachers break out of these norms to humanize science. Guided studies of the history of science can also aid in correcting this positivistic, inhuman representation (Garrison & Bentley, 1990). Stinner (1989) states that in addition to teaching the inductivist scientific method, we must also acquaint students with the intuitive, imaginative processes that Galileo and Einstein used in developing their physics. Rather than simply teaching the historical account of the discovery or development of the concepts, students must be given some insights into how scientists like Galileo and Einstein came up with their ideas. Additionally, students must have some idea of the cultural setting in which these people worked and the presuppositions guiding their thoughts. History can show how science fits in with the rest of society.

Currently there is little emphasis on the inclusion of the history and nature of science in science courses (Bybee et al., 1991). Lemke (1990) describes the history of science as a footnote to the curriculum. While science education researchers are advocating the inclusion of this important aspect of science in curricula, it must not be reduced to a list of names,
dates, and discoveries, but must be more rounded to provide students with
the cultural, philosophical, and sociological settings within which the
scientists worked. The former would be simply using history in a positivistic
manner and not helping students develop an understanding of the modern
view of the nature of science. Schwab (1978) states that while the young
should not be molded into expert historians, some mastery of history is
needed to enable them to understand the past, thus allowing them to think
about the future.

Use of the History of Science in Science Classrooms

Within the last five years, the history and philosophy of science have
begun to influence both the theory and practice of science education
(Matthews, 1992). This attention, however, is not a novel idea.
Researchers for decades have been advocating use of the history of science in
science classrooms to help students gain a greater understanding of the nature
of science. As early as 1951, Conant recommended imparting knowledge of
scientific strategies to those who were not (nor would ever be) scientists and
argued for use of the histories of the various sciences to accomplish this.

There is a well documented crisis in American science education,
evidenced by low ratings of American students on international standardized
tests, few preservice teachers in science education, and students taking fewer
and fewer optional science courses in both high schools and universities.
Improving prospective teachers' competence in mathematics and science is a
national concern. The National Science Foundation warns that undergraduate programs in science no longer meet national needs because of a decline in their quality and scope (Heilbron, 1987).

Science has become somewhat meaningless to a large body of students who can quote definitions, equations, and formulae, but have no idea how to apply them (Matthews, 1992; Tobias, 1990). An understanding of the nature of science can humanize science, and provide connections to the students between science and their own personal, ethical, and political concerns. It can also improve teacher training by providing insight into the structure of science and show teachers its importance in the overall intellectual structure of education. Advocates of history and philosophy of science in science education argue for a contextualist approach, which includes teaching about science (Matthews, 1992). The contextual realist tradition asserts that the history of science makes the following contributions to science teaching:

1. It engages and motivates students.
2. It provides a human aspect to content.
3. It promotes greater understanding of concepts by tracing their developments.
4. It provides for understanding of pivotal episodes in history.
5. It demonstrates patterns of scientific change, therefore
6. it provides a viewpoint other than scientistic ideology.
7. It provides a deeper understanding of scientific methods.
Practicing teachers' epistemologies are formed from textbooks and their own teachers, neither of which have provided much historical information nor emphasized the nature of science (Matthews, 1992). There is conflicting information about how a teacher's conception of the nature of science affects how s/he teaches the subject. Herron, (1969) shows a positive correlation between a teachers' understanding of the nature of science and classroom behaviors, while Lederman and Zeidler (1987) and Duschl and Wright (1989) show no correlation between understanding of the nature of science and classroom practice, with some evidence of negative correlation. A later study by Zeidler and Lederman (1989) does show correlation between teachers' language and student conceptions of the nature of science.

Herron (1969) considers an adequate account of the nature of science critically necessary to the science curriculum and teacher training, yet reminds us that we are teaching science courses, not philosophy courses. Ideally, science education should include an entire course on the history and philosophy of science; however, this is not current practice. In fact, both Gallagher (1991) and Ray (1991) advise there is little teaching of the history of science at the university level and few history and philosophy curriculum materials for use in science classrooms.

In 1964, Rutherford advised that the study of the processes of science could not be divorced from content and is best accomplished by focusing on
a specific scientist or several scientists in the context of a specific problem
rather than trying to describe abstractly the processes of science. Arons
(1991) says the inclusion of the history of science into existing science
courses through short, humanizing, detail-specific stories, can give meaning
to the scientific concepts being presented without seriously affecting the
amount of physics taught, or doing violence to the historical aspect of
science.

While there are those who claim that the history which is included in
classrooms is quasi-history, pseudohistory, or simplified history, Matthews
(1992) advises "the pedagogical task is to produce a simplified history that
illuminates the subject matter, yet is not a caricature of the historical
process" (p.21). The distortions that occur in classrooms are best dealt with
by better presentations of historical material in preservice and inservice
training (Matthews, 1992).

Techniques

In order to convert the plans set forth in Science For All Americans
(SFAA) into classroom realities, curricular materials must be produced.
These materials must be appropriate for use in classrooms and teachers must
become acquainted with them in their teacher education programs.
Otherwise, the materials will not be used, or will be used inappropriately.
Teachers who lack an understanding of the nature of science cannot just be
given curricular materials. Teachers must be instructed in the nature of science so they can properly use these curricular materials (Matthews, 1992).

In the special issue of the Journal of Research in Science Teaching on science curriculum reform, Anderson (1992) describes curricular materials that teach the nature of science. They should reflect the beauty of science, its influence on culture, and how science progresses. Curricular materials should be adaptable to several class sizes and reach all students, especially those who have been neglected in the past (minorities and females).

Stories

Stories represent one way of knowing and thinking. Stories arose to help folks explain the things they did not understand (Lipke & Lipke, 1992). People organize experiences into plot structures which help sort out the details of their lives and solve problems. These stories recapture the richness of human experiences. Narrative structures are natural and common modes of thinking, reflecting the structure of the mind, and built from information provided by experience and from the mind's inventory of stories provided by culture (Carter, 1993). Smith (1990) describes a major function of cultures as that of providing and perpetuating stories. These stories are needed to help people make sense of the world in which they find themselves. They are extensions of people's curiosity about the world around them.

The story form invites the listener into the text, engages his or her imagination and allows the listener to vicariously experience the events...
experienced by the people in the story (Barone, 1992). People of all ages are readily engaged by stories, therefore the story form can be used to teach any content more meaningfully (Egan, 1986).

Storytelling is one way of establishing meaning. Gowin (1981) calls educating a social event of shared meanings. The purpose of using story form to shape lessons is to use its engaging power to ensure that those important meanings contained within it will be communicated to the class (Egan 1986). The richness and nuances of human affairs cannot be expressed in definitions or formulae, but can be expressed in stories (Carter, 1993). Good stories deal with only the problem set up at its beginning. Everything in the story takes it forward toward resolution of conflicts (Egan, 1986). They are very directed, indeed.

There are a number of articles which advocate using stories (Rutherford & Ahlgren, 1990; Arons, 1991; Kauffman, 1991; Klopfer, 1969; Klopfer & Watson, 1957; Shahn, 1988; Wandersee, 1990) to infuse the history of science into science classes. Stories are fun. Everyone enjoys them, yet these puissant tools for engaging students in meaningful learning are often overlooked by busy teachers (Roach & Wandersee, 1993).

Neurobiological theory asserts that the brain is not a passive receiver of information, but an active processor of experience (Anderson, 1992). The constructivist theory of learning emphasizes the active construction of meanings influenced by what the learner already knows. Students learn by
picking up bits and pieces of information, then organizing and reorganizing them until connections are made and the "aha" stage is reached (Solomon, 1991).

Stories provide continuity of subject matter, recounting a string of events. In order for a person to understand a story, s/he must connect the events contained therein (Carter, 1993). Gil-Perez and Carrascosa-Alis (1992) describe understanding as knowing relationships and further remind us that isolated bits of information are soon forgotten. Stories provide many connections among old and new concepts making the new ideas more meaningful to the learner. Instruction must be both relevant and understandable to the student (Matthews, 1991). Stories make topics both understandable and relevant to students' existing conceptual structures. The historicality (the condition of being based on events reconstructed from the past without professing objective truth) of the story form makes it an effective tool for connecting new concepts to existing concepts in a learner's conceptual ecology (Wandersee, 1992).

Stories can be a powerful tool for motivating students and piquing their interest in a given subject (Roach, 1992). Stories from the past personalize science for students and can shed light on not only the white men of science, but the minorities and the women who also helped shape its development (Solomon, 1991).
Interactive Historical Vignettes

Wandersee (1992) suggests that the smallest practical instructional unit for including the history of science in existing courses is the historical vignette. Historical vignettes (Wandersee, 1990) are interactive and do more than deliver information in story form. Interactive vignettes drawn from the histories of science are brief stories that tell an attention-grabbing piece of a bigger story. They are developed to provide specific limited information to students both about the nature of science and a content topic or a specific scientist. See Appendix B for a sample vignette. Klopfer (1969), professes that scientists should be viewed as distinctive individuals, experiencing frustration and joy, and who lead rich lives within and outside of their chosen scientific fields. Historical vignettes provide this information to the student as well as information about how science works and how it has changed over time (Wandersee, 1990).

In order for meaningful learning and therefore conceptual change to take place, the learner must be involved. Historical vignettes serve as a tool to get the students involved in a story called science. They can be used as Lemke’s (1990) recommended story or anecdotal introduction to a lesson to elicit student interest in the topic. These fictional stories are based on historical accounts of science and function to make science interesting while providing important information to the students about the history of scientific
developments. Just as the history of politics enriches students' understanding of current events, the histories of science can help enhance students' understanding of science (Klopfer, 1969). The basis of each vignette is historically correct, the details are fiction. The vignettes are short and entertaining, designed to take no more than 10 minutes of class time, yet these 10 minutes stimulate questioning by students, inspire discussion of relevant ideas, pique curiosity, and allow students to make predictions about the outcomes of the vignettes.

Each story has three parts:

1. An introduction establishes some sort of conflict, causing the students to become involved in the story and makes them think. This might be compared to Piaget's disequilibrium or the cognitive conflict described by Gil-Perez and Carrascosa-Alis (1992).

2. An interruption is strategically placed so students may ask questions and the teacher may question the students. Since the point of the vignettes is to get students to think, the questions posed are open-ended with more than one correct response. All evidence-based answers which demonstrate involvement and thought on the students' parts are accepted, furthering the students' interest in the story. Students are encouraged to answer other student's questions, so all will participate and begin to think about the situations portrayed.
3. The conflict is resolved and all questions answered (in the historical sense) in the final section of the vignette. Additionally, each of the vignettes portrays attitudes of science. These, and the relationship of historical science to modern science, are revealed through class discussion. This application phase (Gil-Perez & Carrascosa-Alis, 1992) provides opportunities for students to use the new conceptions and consolidate them.

An episode from the scientific past is selected and binary opposites are identified. The episode is chosen for its potential to generate interest and spur discussion. Discussion techniques, while widespread in other subject areas, are rarely used in science. However, discussion can be used creatively and constructively (Watt, 1988) to involve students in the construction of knowledge.

The introduction establishes some sort of conflict and students are invited into the story through questioning about the conflict. Gil-Perez and Carrascosa-Alis (1992) call this the elicitation phase. Comments about students' questions and answers are reserved for later to keep students interested in the outcome. Students maintain a high interest as the story continues. Once students are "hooked" they are predisposed to learn more about the topic.

Figure 2.1 (follows) is a concept map describing conceptual organization underlying the construction and use of interactive historical vignettes.
carefully crafted interactive historical vignettes

constructed using

binary opposites

interrupted story form

drawn from histories of the sciences

in order to elicit conflict

involving

student generated questions and explanations soluted by

resolution of the conflicts presented

followed by

designed to encourage scientific attitudes centered on
discussion of the nature of science

followed by

in order to elicit conflict

Figure 2.1. Concept Map of Interactive Historical Vignettes. Note: Adapted from Roach and Wandersee (1993).

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These historical vignettes emphasize the following 20 attitudes of science. Of course, not all 20 attributes can be considered in every vignette. Those considered are provided to the reader (teacher/researcher) in notes at the end of each vignette (Roach, 1992).

**Attitudes of Science Emphasized in the Vignettes**

1. Curiosity—What is happening here and why?
2. Empiricism—Check out phenomena; verify with your senses.
3. Determinism—Look to see what is causing the phenomena.
4. Scientific manipulation—Beware of all causes of phenomena, control variables.
5. Precision—Be uncomfortable with vagueness.
6. Respect for theory—Theories tie data sets together and explain why things happen.
7. A thirst for knowledge—Knowledge is its own reward.
8. An open mind—Be willing to change your mind in response to evidence.
9. Suspend judgment—Don’t form your opinion until you gather and analyze all the evidence.
10. Skepticism—Question currently held beliefs when they don’t make sense.
11. Respect for quantification—Attaching numbers to your data may help you see patterns you might have missed.
12. Thrill of discovery— It's fun to find the answers to scientific problems.

13. Loyalty to reality— Nature is the "reality" for science, its testing ground.

14. Aversion to superstition— Prefer scientific explanations over supernatural explanations or folklore.

15. Communication— Share your findings with others. Science is a social activity.

16. Empathy— Have empathy for all organisms and ecosystems.

17. Accuracy— Take care when making observations and measurements.

18. Parsimony— Choose the least complicated solution over the most complex one.

19. Perseverance— Don’t give up if your first attempts to solve a problem fail.

20. Common sense— Look at the big picture. Do your data make sense?

These attributes (Roach & Wandersee, 1993) were adapted from lists prepared by Beveridge (1957) and Schrock (1991).

Students become involved in the story through questioning and making predictions about the outcome. Since the topics are related to current science at the same time as they are revealed in the vignette, the possible problem of
a student missing the modern version because s/he was absent when the old was related to the new (thereby reinforcing misconceptions) is avoided.

Lederman and Zeidler (1987) suggest a more balanced treatment of the history and philosophy of science for preservice teachers. They also advocate specifically targeting teaching behaviors that teachers should learn in order to successfully transmit their increased understanding of the nature of science to elementary and secondary students. This technique will assist in this endeavor; it is powerful, yet simple enough for teachers to construct their own curriculum materials (which was urged by Cohen in 1950) by consulting Roach and Wandersee (1993) or Roach (1992).

Interactive vignettes also respond to the contextual realist school of thought by teaching the nature of science in the context of a particular topic or scientist. Content is not divorced from the nature of science.

Previous Studies

Watts (1988) reminds us that it is important to periodically reflect on practice and evaluate the state of the art. Norman Lederman's 1992 article in the Journal of Research in Science Teaching reflects on the state of the art by providing a review of studies which have been conducted during the past three decades.

The research related to the nature of science can be categorized in the following manner: a) evaluation of textbook presentation of the history of science; b) assessment of student and teacher conceptions; and c) intervention
programs to improve conceptions about the nature of science. The reviewed studies primarily involved high school students or practicing and preservice science teachers. These studies will be discussed only with respect to method, since the subjects in my study are elementary education majors and other nonscience majors in a university setting. There is a paucity of research addressing the understanding of the nature of science by this population of students, yet these are the types of students we need to reach to make all Americans scientifically literate.

**Textbook Presentations of the History of Science**

Honey (1992) reports that very little history is found in school science texts and these limited examples often provide an unbalanced impression of science of the past. Often these examples are presented positivistically (i.e., Priestly discovered that oxygen is given off as a result of the activities of plants.) and draw the students' attention away from the continuous change and gradual progress that science makes. These examples modify history and do not present science as a dynamic, human activity. Contributions by women and minorities are not a priority. Honey first examined the examples in current school science texts used in the United Kingdom. He reports that the examples in the British texts could be called ahistorical and could have taken place at almost any time in history. His second point is that the examples of history in the texts do not relate the history of science to the social context within which they occurred; cultural settings are ignored.
Honey also found that the term "experimental" was very narrowly defined and notes that not all science is governed by experiment. These findings could contribute to a student's misunderstanding of the history of science and therefore a misunderstanding of the nature of science. The interactive historical vignettes address the points which Honey describes as critical. Both the historical and sociological settings are portrayed in the vignettes. They present science as an ever-changing human activity practiced by men, women, and minorities, using many methods. Additionally, since they are interactive, these key points, emphasized in the vignettes, are discussed with the students.

Carson (1992) suggests teaching science as a culture, representing the forms of thought that are characteristic of science— including historical, philosophical, and social contexts. He questions why current texts are "so deplorably artless" (p. 149) and suggests that they be written as historical narratives. He has fictionalized an account of a meeting between Dalton and Thomsom and designed it to illustrate the important aspects of the growth of science. He states that his chapters are followed by discussions which clarify the conversation between the two scientists and build upon it. He is convinced "While scientists may protest, students may rejoice" (p. 154). Unfortunately, few teachers have the background ability to rewrite the chapters in their texts, nor do they have much say in the selection of texts for use in their classrooms. The interactive historical vignettes address the
positive points addressed by Carson: they are lively and illustrate important aspects of the nature of science, yet they are short enough that they do not impose upon the curriculum prescribed to teachers by governing bodies.

Assessment Techniques

Wilson’s 1954 study does not attempt to answer the question of what should be the purposes of science in general education, but reports the opinions held by both high school and college students. This inventory consisted of 29 questions to which respondents agreed or disagreed. While this instrument did address some of the declarations presented in my model of the nature of science, it is rather old and there is no information available on its reliability or validity.

In 1957, Mead and Metraux found that inventories did not always give students a chance to express themselves completely. They found that the "official" image of a scientist held by students is positive, but when asked open-ended questions and promised anonymity, students described scientists quite differently. These results provide evidence that check-marked questionnaires are too sparse to provide a detailed expression of a student’s understanding. Lederman and O’Malley (1990) make the same contention. For this reason, my study includes evaluation of journal entries which allow students to express themselves more fully.

Kimball’s 1967 research which resulted in the Nature of Science Scale (NOSS) involved both science teachers, scientists, and philosophy majors.
This instrument was considered for my dissertation because it had been validated at the university level, has high reliability, brevity, and simplicity of language (Ogunniyi, 1982); and because it was based on a model of the nature of science which was consistent with the new philosophy of science. Upon closer examination of the instrument and comparison of it to the experimental technique, it was rejected because of its emphasis on the differences between pure and applied science (science and technology) and because most of its responses (23 out of 29) required a negative response on the part of a student possessing a valid conception of the nature of science. This instrument failed to target all the areas of the nature of science emphasized in the historical vignettes.

The Test On Understanding Science (TOUS) developed by Klopfer and Cooley (1963) as a research tool, is the most widely used assessment instrument (Lavach, 1969; Lederman, 1992; Schmidt, 1969). This instrument was developed to assess high school students' understanding of the nature of science and a form appropriate for junior high has since evolved. The items also embrace a negative viewpoint of science and reflect current stereotypes of science and scientists (Aikenhead, 1973). This instrument was inappropriate for my study because it was written for high school students and it contained many negative elements. My instrument balances positive and negative responses to statements so that students who have a valid...
conception about the nature of science respond positively about half the time and negatively about half the time.

The Conceptions of Scientific Theories Test (COST) (Cotham & Smith, 1981) was considered for use in this study because it was written for elementary and secondary teachers of science, was developed to be sensitive to alternative conceptions of the nature of science, and had high estimates of reliability and validity. Closer examination revealed that this instrument targets only the tentative and revisionary aspect of the nature of science, concentrating on theories, their generation and development. Thus, the scope of this instrument made it inappropriate for my study.

In an exploratory study, Abell and Smith (1992) analyzed preservice elementary teachers' written responses to questions about the nature of science to derive categories and themes. These themes were then evaluated with respect to philosophy of science. The students responded to only one question: "What do you mean by the term science? Define the discipline in your own words." or "What do you think science is about?" (p. 12) Analysis of the writings revealed that these particular preservice teachers held realist and positivist views of the nature of science. The researchers call for a richer presentation of science to preservice teachers in content area courses. My study involves this richer presentation of the nature of science and scientists in the context of a content course. It also is based on a model of
the nature of science which is neither relativistic nor positivistic, but reflects the contextual realistic philosophy of science.

Griffiths and Barry (1993) used no instrument for their research into the views which high school students hold about the nature of science. They simply asked open-ended questions similar to those that I have used as journal entries for my study (see Appendix E). Central to their study were the basic questions: What is science? What is a law? What are theories? What is a fact? Students provided classic responses to these questions, with no novel information provided to the body of literature.

Pomeroy (1993) compared the beliefs about the nature of science among scientists, secondary science teachers, and elementary educators. No reliability or validity was established for the survey instrument used in the study. Pomeroy did find that elementary teachers had a better understanding of the nature of science than secondary teachers and considered these results to have been influenced by the teachers own construction of knowledge and their understanding of how children learn.

**Intervention Techniques**

In 1956, Klopfer and Watson reported a diversity in the classroom use of historical materials; ranging from stories to historical descriptions in texts, to use of biographies, to duplication of classical experiments and projects, to use of case studies.
One of the earliest techniques used to improve students' understanding of the nature of science was the Physical Science Study Committee's (PSSC) physics course. This course was designed to provide a better understanding of the development and structure of science. Both Trent (1965) and Crumb (1965) determined that students who took this course showed statistically significant gains (on the TOUS) in understanding the nature of science. Students who took a traditional course did not show similar gains.

A 1968 study by Carey and Stauss investigated whether a secondary science methods course emphasizing the nature of science could improve prospective secondary science teachers' conceptions about the nature of science. While their results were positive, with students showing improved conceptions of the nature of science, the method is very fuzzy. Students were introduced to the nature of science by "lecture, discussion, and outside reading" (p. 359). Thereafter, the objectives of the course, (planning, presentation of lessons, and test construction) were linked to the nature of science. The experimental treatment in this study is ambiguous and would tend to vary with the instructor's conception of the nature of science. It is also unclear as to what the outside reading consisted of...both from the standpoints of what and how much. It does support the contention that the experimental treatment should last the full length of the course in which it is incorporated. The instrument used in this study was the Wisconsin Inventory
of Science Processes (WISP). The WISP was rejected for my study because it contains 93 items.

Another intervention technique permeating a course is presented by Aikenhead (1979). In this case, the entire course is directed toward improvement of students' conceptions of the nature of science. Entitled Science: A Way of Knowing, this course for 10th graders was developed to improve scientific literacy. This full academic year course concentrates on how knowledge is gained (6 weeks), followed by units showing science as one way of knowing (27 weeks), succeeded by a culminating 3 week unit on science and society. This particular course has had positive results for students. However, I am not looking for a new course, but an intervention method which can be used in existing courses. Furthermore, teachers are reluctant to give up any of their classroom time to information not directly related to the course content. Even when they can be convinced of the salience of the use of these materials, they often do not know enough history to properly implement this approach (Hendrick, 1992).

Lavach (1969) organized an inservice program around the history of science. This 11 week-course involved lecture-demonstration and laboratory work. The science teachers involved reported improved attitudes toward the history of science and demonstrated an improved understanding of the nature of science. Both qualitative and quantitative analysis indicated the program effectively improved teacher conceptions about the nature of science. A
summer institute for physics teachers was designed and implemented by Lawrenz and Kipnis (1990). This course (including lectures, seminars, laboratory work, and project work) also reported improved attitudes toward the history of science and increased understanding of the nature of science. Students of the participants were polled during the following school year. These students were more likely to have been involved in hands-on activities, enjoyed their physics classes, and received a historical perspective (Lawrenz & Kipnis, 1990). While inservice programs are a superb means of reaching practicing teachers, they also limit the number of individuals who can be affected. Infusing the history and nature of science into courses which all preservice teachers are required to take will reach more prospective teachers.

Ray (1991) suggests the use of case studies and long-term project work to help students develop a more holistic conception of science. This technique would seem to work better with smaller classes, but is inappropriate for large enrollment classes. Based on the experiences I had during the pilot study, with limited outside group work in classes of 135, the idea of project work generates visions of insurmountable problems.

Another intervention technique, perhaps the most commonly used so far, is the use of units of study. Materials drawn from the history of science are used to develop units for use in existing courses. In 1957, Klopfer and Watson developed the case history method of teaching the history of science. They developed cases, or units of study, in which the development of a
major scientific concept was critically analyzed. These cases involved not only the final results of the inquiry, but stressed the scientists involved, the social and intellectual climate in which they worked, and the development (my emphasis) of the ideas. The best known of this type of treatment is the History of Science Cases (HOSC) developed by Klopfer and Cooley (1963). Each unit is presented as a separate booklet containing historical narrative, quotes from original scientific papers, experiments, notes, and questions for students to answer. Sufficient teaching aids (manuals, kits, supplementary books and articles) are provided to the teacher to facilitate use of this technique. When high school students were tested using the TOUS, it was found that students made statistically significant gains in understanding the nature of science without sacrificing understanding of physics content.

A curriculum similar to the HOSC was used by Jones (1965) in college physical science courses. The course emphasized historical development, the interaction of science with society, and philosophical aspects of science. These college students, when tested using TOUS, showed greater understanding of the nature of science than students taught by the traditional method.

Duschl (1900) advocates the use of units in existing course to provide information to students about theory development and to teach students the nature of science and the nature of scientific progress. His units involve detailed background information to show how theories have developed over
time. Hodson (1991) also suggests using historical case studies to present science as a social activity, showing what happens on a day-to-day basis.

The use of units or case studies on the history and nature of science has a couple of drawbacks. Teachers are required by many state and local curriculum guidelines to "cover" a certain amount of material in a school term, usually more than is humanly possible. Students are presented mountains of material which seem to have little connection to the past, present, or future (Roach & Wandersee, 1993). A unit on the nature of science may appear to both students and teachers as just another mountain to be scaled, (information memorized for the test and forgotten soon afterwards). Convincing a teacher to add another unit or several case studies to his or her already bulging curriculum may be an unattainable goal. Another drawback to the use of units has a direct relationship with conceptual change theory. Conceptual change requires repeated exposure to the information being learned so it can be incorporated into the conceptual frameworks of the learner. A one-shot unit is less likely to induce conceptual change about the nature of science than a technique that allows for repeated exposure to the ideas to be learned. Minor changes gradually introduced are important when characterizing real conceptual change (Villani, 1992).

The studies previously discussed generally failed to evaluate the effects of teacher characteristics or different teaching strategies. In other
words, the teacher as a variable was disregarded (Aikenhead, 1973; Lederman, 1992). Since I taught both the control and experimental classes, varying only the experimental technique, this variable is controlled in my study.

The review of the literature and the experiences of the pilot studies provide support for development of a teaching method to facilitate conceptual change. The literature review also supports the development of a curriculum which consists of capsulized examples of the history of science which illustrate the nature of science. There is a need for a technique for including the nature of science in existing science courses. The technique must be stimulating, to engage the students; complete and easy to implement, so teachers will utilize it; and subjected to analysis, to provide research-based evidence of its effectiveness (Meichtry, 1993). My technique has the desired characteristics and was subjected to analysis.
METHODS AND MATERIALS

Pilot Studies

Two pilot studies were conducted as a part of this dissertation research and will be referred to in this chapter. During the first pilot study research questions were refined and narrowed, and deficiencies in the planned dissertation research were identified and corrected. Results of the first pilot study indicated a need for development of an instrument to measure changes in students' understanding of the nature of science. Instrument development was the focus of the second pilot study.

Instrument Development

Cooley and Klopfer (1963) caution that while instrument development is encouraged, they do not imply that every study in science education must involve a project including elaborate (my emphasis) test development. They call it "unrealistic and unnecessary" (p. 75), yet advise that some (my emphasis) test development must take place when an appropriate instrument is not available.

The purpose of this part of the study was to develop a valid and reliable instrument which has the following characteristics:

1. sensitivity to alternative conceptions about the nature of science
2. capability of inferring understanding of the nature of science and scientists (Cotham & Smith, 1981).
In the construction of a new instrument, one must specify student outcomes to be measured (Cooley & Klopfer, 1963). This was done by reviewing the literature and creating a model of the nature of science containing six subscales. This model has previously been described and can be found cross-referenced with the literature and the attitudes of science emphasized in the historical vignettes in Appendix A. The original statements were used as the basis for writing test items (Cooley & Klopfer, 1963). The items are Likert-scaled with four choices: 1 = strongly agree, 2 = agree, 3 = disagree, and 4 = strongly disagree. The omission of a neutral choice forces students to decide if they agree or disagree with the statement, yet provides more information about the sample than agree/disagree response choices (Krajkovich, 1982). The general guiding principle in the writing of the Likert type test items was that if the student understood the nature of science, s/he would choose one alternative and if s/he held misconceptions about the nature of science, s/he would choose the opposite alternative. Questions were written such that a student exhibiting an understanding of the nature of science would have to agree with some statements and disagree with others. Thirty questions were written, with the design scheme of a final instrument consisting of 24 items.

Validity was established by examination of the instrument by a panel of 10 experts (Cooley & Klopfer, 1963; Kimball, 1967); by administering the instrument to three groups of students (Cotham & Smith, 1981); and by
interviewing 10 students to verify that they understood the questions and had answered the questions as intended.

The first part, examination of the instrument by a panel of experts, involved distribution of the scale items to consultants at Northwestern State University and to experts in the field of science education research. These consultants included four scientists, two science teachers, a philosopher, an instructor not in the field of science, and two science education researchers whose specialty area is the nature of science. These consultants criticized the items as to content validity, appropriateness to model, and understandability.

Comments from all advisors were compiled and reviewed. Five items receiving the most comments from advisors were eliminated. Two items were reworded based on suggestions from the reviewers. One item was eliminated because upon further inspection of the instrument, it was noted that this item was very similar to a previously accepted statement. The 24 items selected were arranged into the document found in Appendix C.

The Nature Of Science Questionnaire (NOSQ) was administered to a group of Science 1010 (n=91) and Science 2010 (n=41) students who were not taught the nature of science (NONOS), (n=132); to a group of Science 1010 students who were taught the nature of science (NOS), (n=166); and to a group of university sophomore, junior, and senior physics and chemistry majors (n=12) who are in active contact with practicing scientists through the Joint Venture (JOVE) Program which Northwestern conducts in
association with NASA. The results were statistically analyzed using the t test to determine whether or not differences existed among the three groups. The means and standard deviations can be found in Table 3.1. Statistically significant differences were found between the JOVE students and the NONOS group at p = .012 and between the JOVE students and the NOS group at p = .021. Differences between NOS and NONOS were not statistically significant, but there is an indication of movement toward an understanding of the nature of science. Since the experimental treatment is more rigorous during the dissertation research, statistically significant differences between NOS and NONOS are expected.

Table 3.1

Means and Standard Deviations of Student Groups Pilot Tested

<table>
<thead>
<tr>
<th>Group</th>
<th>sample size</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>JOVE</td>
<td>12</td>
<td>2.09</td>
<td>.208</td>
</tr>
<tr>
<td>NOS</td>
<td>166</td>
<td>2.26</td>
<td>.318</td>
</tr>
<tr>
<td>NONOS</td>
<td>132</td>
<td>2.28</td>
<td>.286</td>
</tr>
</tbody>
</table>

Since researchers tend to presume that students hold the same meanings for words in the test items as do the researchers (Griffiths & Barry, 1993), ten students were interviewed to determine if the questions were
worded such that the students understood the question the way the researcher intended, and whether the students' marked responses did indeed reflect what they intended to mark. These interviews provide supportive evidence that the students did indeed understand the questions and there was consistency among the written responses and the oral responses. The interviews were audiotaped so I could recheck any ambiguous comments. Finally, the responses on the NOSQ were triangulated with student journal responses during the data collection phase of the research and commented on in Chapter 4.

Reliability was calculated at .74 using Cronbach's alpha coefficient. The published reliability of the TOUS, the most widely used instrument to measure precollege students' understanding of the nature of science is .76. The published reliability of the NOSS, another widely used instrument is .72 (Meichtry, 1993).

Originally, I planned to use the Kuder-Richardson Formula 21 to calculate reliability because it has been used by other researchers (Carey & Stauss, 1968). Kuder-Richardson Formulas generally provide a lower reliability coefficient than other methods, therefore the calculated reliability can be thought of as a minimum estimate of the instrument's reliability (Borg, 1987). However, upon further examination of the statistical tool, it was found inappropriate because it is based on the assumption that there will be one correct answer for instrument questions. My scale involves several
choices, therefore the Cronbach's alpha coefficient is the proper tool to use. When the reliability statistics were run on only those students whom I had taught, the reliability coefficient was .76, providing some evidence that the teacher does influence the students' understandings of the questions, whether or not they were taught the nature of science (Lederman, 1986; Rothman, 1969).

After having established construct validity and acceptable reliability on the instrument, I utilized the NOSQ in the following research project.

Subjects

This study is designed to promote scientific literacy as described by Science for All Americans (1990), and the nonscience majors are appropriate for that aspect of the research. This study also includes evaluation of an understanding of the history and nature of science by prospective elementary educators, and the course selected is one required of all elementary education majors. The sample, chosen by virtue of the registration process at Northwestern State University, includes nonscience majors at all levels (see Tables 3.2 and 3.3). Two of my sections, each with 30 students, constituted the sample. This allowed me to regulate the experimental and control treatments, materials, and evaluation, as well control the "teacher variable."
Table 3.2

Description of Control Section

<table>
<thead>
<tr>
<th></th>
<th>Fr</th>
<th>So</th>
<th>Jr</th>
<th>Sr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary education</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Other nonscience majors</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>Nontraditional students</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: These groups are not mutually exclusive.

Table 3.3

Description of Experimental Section

<table>
<thead>
<tr>
<th></th>
<th>Fr</th>
<th>So</th>
<th>Jr</th>
<th>Sr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary education</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Other nonscience majors</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Nontraditional students</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>13</td>
</tr>
</tbody>
</table>

Note: These groups are not mutually exclusive.

ACT scores were secured on class members and a t test performed to determine academic equivalence. Equivalence in an understanding of the nature of science was established by performing a t test on the pretest scores on the NOSQ (see Appendix C) and comparing groups.
Description of Students

During the pilot study, there appeared to be two definable groups along the continuum of students enrolled in this required course: (a) those who are concerned about their learning and/or their grades, and (b) those who care little about either. Those who do not care simply come to class (or don't), sit the required time, and leave. They do not enter into class discussions, and apparently write their journal entries in class on the date they are due. During one classroom examination, one student even marked answer "C" to all items on a test and turned it in. During regular semester sessions, I experienced a high percentage of absenteeism (30%). An informal survey of instructors across campus revealed that they also experienced a similar level of absenteeism during the Spring, 1993 semester. I believe these students are affecting the statistical analysis of the data by masking statistical significant changes in students' understanding of the nature of science. By including their results in the analysis, the data are skewed. Journal entries read during the pilot study have convinced me that the students who care about their learning do have a deeper understanding of the nature of science at the end of the treatment.

For analysis of the dissertation data, these people who seemed to not care were isolated and their data analyzed independently of the rest of the group, providing a clearer picture of the conceptual change taking place as a
result of the experimental treatment. These students were identified in the following ways:

1. Three independent journal readers determined whether or not students put thought into their journal entries based on their responses to the first two entries, and

2. If a student missed two or more classes during the duration of the study, his or her data were analyzed separately.

During the dissertation research, all of the students enrolled in the experimental section of the course fell into the group who did care about their learning. While two of the journal writers appeared not to have put much thought into their first entries, their second entries demonstrated thought, and no attending students fell into the category of two or more absences during the session. Therefore data from all students enrolled in the experimental section were included in the quantitative analysis.

Three of the thirty students in the control section fell into the category of students who seemed to not care about their learning. None of these students were in class the first day to take the pretest and one missed class the day the posttests were administered. Therefore, the data from these three students were not included in the analysis.

Another difference between regular semesters and the summer sessions is the percentage of seniors enrolled in the class. If one examines the numbers, approximately the same number of seniors attend the regular
semester sessions and the summer sessions. However, the percentage of seniors in summer sessions is high due to the low number of underclassmen attending the summer sessions. On the first test, I asked the seniors to tell me why they were taking this freshman level course so late in their college career. Most of them stated they have been afraid of science, or dislike science, and have put it off until the last possible semester. The two music majors advised that they have so many courses in their majors which are "permanently" scheduled (e.g., Theory courses are taught every day from 10:00 a.m. to 11:00 a.m. for four semesters, which precludes them from taking any 9:30 a.m. to 10:45 Tuesday/Thursday classes for two years.) For this reason, they have to enroll in summer school to take their core requirements. Two students had transferred from Louisiana Scholars College to NSU, and were required to complete this core requirement before graduation. Another had failed the course and was repeating it. The low number of freshmen can be attributed to incoming freshmen traditionally entering college in the fall after they graduate from high school.

Instructional Procedures

The course used in my research was a physical science course, in which the first half of the semester was spent on physics topics and the second half was spent on chemistry topics. The experimental treatment lasted the entire semester.
Both sections were taught by lecture, discussion, and demonstration methods. Approximately 50% of class time involved lecture. About 20% of the time was spent on demonstrations. Fifteen percent of the time was spent discussing the topics (i.e., I asked students questions about the concepts being lectured on and encouraged questions from the students).

The remaining 15% of the time in the control section was devoted to review of physics concepts through questioning of students and answering the questions at the end of the chapter in the textbook. While inclusion of the history of science was expressly avoided, it could not be eliminated. In addition to the standard presentation of physics and chemistry concepts, each chapter introduction in the adopted text, *An Introduction to Physical Science* (Shipman, Wilson & Todd, 1993), has an historical introduction to the topic. The text also includes "Chapter Highlights" to each chapter which emphasize either a scientist or new technology. These readings were available to the students, but were not discussed in either the control or the experimental class. During the pilot study, a journal entry asked students how much attention they paid to the chapter highlights. Only 30% of the students had even read any of them and only 10% read them consistently. Student utilization of these readings during the dissertation research will be discussed in Chapter 4.

The remaining 15% of the time in the experimental section involved answering questions at the end of each chapter (5%) and infusion of the
histories of science into the course (10%) via interactive historical vignettes emphasizing the nature of science (developed at Louisiana State University).

Experimental Technique

The attitudes emphasized in the vignettes are closely related to the model of the nature of science which was used to construct the NOSQ. Neither the attitudes nor the aspects of the model are explicit in the vignettes; both are implicit. The attitudes addressed in each vignette are listed at the end of each vignette found in I Have a Story About That: Historical Vignettes to Enhance The Teaching of The Nature of Science (Roach, 1992).

The aspects of the model of the nature of science are related to each vignette during the discussion phase at the close of each vignette. They will also be listed at the end of each vignette and in an appendix in a future edition of the book. Below is a listing of each of the vignettes employed in this study, a brief description of the situation portrayed, attitudes of science emphasized and features of the model of the nature of science that are demonstrated.

"Myko’s Medicines"--In this vignette about ancient tribal women, Myko is taught how to test plants for their effects on the human body. It emphasizes controlling variables, respect for theory, observation, communication, suspension of judgment, and empathy for organisms. It demonstrates that science is a human endeavor, a search for knowledge, and that it is grounded in nature.
"Red For Stop, Green For Go"--Garrett Morgan is highlighted. It describes the situation that prompted his invention of the traffic signal. This vignette emphasizes that a person with very little education and scientific background can make remarkable contributions to technological advances. It emphasizes empathy, the thrill of discovery, and the need for common sense in scientific investigation. It demonstrates the difference between science and technology.

"Aristotle's Eggsperiments"--This vignette contrasts ancient and modern methods of inquiry and tells how Aristotle disproved the hypothesis that the female is merely an incubator for offspring. It describes how Aristotle dissected, observed, and drew pictures of the developing chicken embryo. It emphasizes skepticism, determinism, observation, communication, and accuracy. It demonstrates that science is a search for knowledge, that scientific knowledge is tentative, grounded in nature, and is a human endeavor involving creativity and imagination.

"You Call That Genius"--This vignette describes Einstein during his youth. It emphasizes skepticism, loyalty to reality, curiosity, determinism, observation, respect for theory. It demonstrates how mathematics is involved in the scientific endeavor, that this endeavor is a human one involving creativity and imagination, that it is a process utilizing many scientific methods, and it is a search for parsimony. It also shows students that someone who may not seem very smart, may indeed become a scientist.
"Space Teacher"—This vignette describes the steps involved in the selection of Christa McAuliffe to be the first citizen in space. It emphasizes perseverance, communication (her project was to keep a diary of her time in space), and the thirst for knowledge. Since McAuliffe was a history teacher, this vignette about her demonstrates that science is a human endeavor, that it is a process utilizing many methods, is grounded in nature, and is a search for knowledge.

"Genius Lost"—This vignette involves a museum tour of a Leonardo DaVinci display. This account of his accomplishments emphasizes curiosity, respect for theory, communication, skepticism, loyalty to reality, aversion to superstition, and common sense. It explains why DaVinci's ideas were not communicated with others and therefore lost for centuries. It demonstrates that science is grounded in nature, that it is a human endeavor involving curiosity, creativity and imagination, that the knowledge is tentative, and that it involves a search for the simplest explanation.

"Standing on the Shoulders of Giants"—Sir Isaac Newton describes how science progresses. He denies that he "invented" gravity while sitting under an apple tree, but describes the development of the ideas which lead to his laws of motion. Mentioned in this vignette are Aristotle, Galileo, Brahe, and Kepler. This vignette emphasizes curiosity, empiricism, scientific manipulation, that a scientist must be willing to change his mind in response to evidence (Brahe did not.), skepticism, communication, and common sense.
It demonstrates that scientific knowledge is tentative, that it is a human endeavor, that it is a search for knowledge, grounded in nature, and a search for parsimony.

"Black Holes"--This vignette about Stephen Hawking clearly shows that science does not have to be done in a laboratory utilizing The Scientific Method, but that a person severely handicapped can have great thoughts. It emphasizes curiosity, imagination, respect for theory, respect for quantification, and loyalty to reality. It demonstrates the differences between science and technology, that science is a process, that the knowledge is tentative, is grounded in nature, that it is a human endeavor involving imagination and creativity, and that it is a search for parsimony.

"Hot or Cold"--This vignette describes the development of the thermometer and describes both Celsius and Fahrenheit's inventions and the basis for each of their temperature scales. It emphasizes scientific manipulation, respect for theory, quantification, and accuracy. It demonstrates that science is a search for parsimony, that the knowledge is tentative, grounded in nature, and involves human creativity and imagination.

"The Real McCoy"--This vignette is about Elijah McCoy and his lubricating devices. It shows how society considered this black man ignorant, regardless of his engineering degree. It emphasizes accuracy, perseverance and common sense. It contrasts science and technology,
demonstrates that science is a human endeavor involving creativity and imagination, that it utilizes many methods and is grounded in nature.

"Moonwalkers"--The Apollo crew discusses the first lunar landing and their experiences with the gravitational pull on the moon. It emphasizes curiosity, empiricism, respect for theory, suspension of judgment and a thirst for knowledge. It demonstrates that science is a human endeavor, is grounded in nature, that scientific knowledge is tentative, and that science is a process utilizing many methods.

"Stargazers"--This is a story about Tycho Brahe and his sister, Sophie. It describes a night of observation and collection of data. Emphasizing curiosity, empiricism, precision, skepticism, respect for theory, loyalty to reality, and communication; it also shows that society did not value the input of a woman during this time in history. It describes Brahe's measurements, made without the use of a telescope. It describes scientists working as a team, discussing ideas and observations. Brahe noted anomalies in his data, but was unable to explain them based on the geocentric model of the universe. This vignette demonstrates that science is a human endeavor, utilizes many methods, searches for parsimony (which these two did not find), is grounded in nature, and is tentative. It also contrasts science and technology.

"Twinkling Stars"--Annie Jump Cannon and her classification of stars is highlighted in this vignette. Students are invited to observe a typical work
day with her including her description of how stars can be classified based on their spectra. This story emphasizes respect for theory, determinism, quantification, a thirst for knowledge, and a loyalty to reality. It demonstrates the differences between science and technology, shows how science is grounded in nature, that knowledge is tentative, and utilizes many methods. It also describes another woman scientist in an attempt to dispel the stereotype of the white male in a labcoat. Since her work is published in The Henry Draper Catalogue, a discussion is held about why her accomplishments are described in a book not bearing her name.

"Listerine Kills Germs"—A typical surgical procedure, performed during 1865, is described in the opening section of this vignette. Joseph Lister's hypotheses about germs and experimentation with sterile surgery procedures and post-operative cleanliness are described. This vignette emphasizes empathy for organisms, determinism, respect for theory, accuracy, and parsimony. It demonstrates the tentativeness of scientific knowledge, contrasts science and technology, shows that science involves human imagination and creativity, and is grounded in nature.

"Fields and Dreams"—This is the story of Michael Faraday and describes how someone with practically no mathematical background can provide qualitative insight into scientific phenomena. It describes his

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1 This vignette is not found in I Have a Story About That: Historical Vignettes to Enhance The Teaching of The Nature of Science.
background as an apprentice to a bookbinder, his employment by Davy, and his description of the electrical field. It emphasizes determinism, scientific manipulation, skepticism, thrill of discovery, perseverance, and communication. It also describes how society accused him of stealing the work of others and how he overcame this. This vignette contrasts science and technology, shows that it is a human endeavor involving creativity and imagination, is grounded in nature and is a search for parsimony.

"Daring Dutchwoman"—This vignette is a conversation between Aletta Jacobs and a co-worker and describes how society snubbed a female physician in the 1890s. It describes how research done by women was often credited to their husbands, and this woman's determination to both help women (by inventing birth control) and maintain the credit for her work. It emphasizes empathy, respect for theory, aversion to superstition, and a thrill of discovery. It demonstrates that science is a human activity, that it is grounded in nature and is a search for parsimony.

"Development of the Atomic Model"—This vignette describes several atomic models and their developments: the Thomson model, the Rutherford model, the Bohr model and the quantum model. This vignette clearly demonstrates the tentativeness of science, that it involves human imagination and creativity, that it is a search for knowledge, grounded in nature, and

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2 This vignette is not found in I Have a Story About That: Historical Vignettes to Enhance The Teaching of The Nature of Science.
searches for parsimony. It emphasizes determinism, scientific manipulation, respect for theory, a search for knowledge, suspension of judgment and communication.

"A Model Brain"—This vignette describes how Florence Sabin, one of the first women to study at Johns Hopkins Medical School, saw a need for and produced a model of the brain. It describes how models are used to study structures and systems which are not readily available to the scientist. Emphasizing precision, respect for theory, loyalty to reality, communication, and empathy for organisms; this vignette demonstrates that scientific knowledge is grounded in nature, is a human endeavor involving creativity, and contrasts science and technology.

"An Idea Worth Repeating"—This vignette describes Lise Meitner's replication study of Enrico Fermi's splitting of the uranium atom. It also highlights international communication among scientists, and how society utilizes scientific knowledge. It emphasizes curiosity, determinism, perseverance, respect for theory, suspension of judgment, skepticism, and common sense. It demonstrates the tentativeness of scientific knowledge, the process of discovery, the human side of science, its search for parsimony, and that it is grounded in nature. It clearly contrasts science and technology.

"The Curies' Cure"—This vignette describes an evening at the Royal Institute. Pierre Curie is delivering a lecture about radium, describing its effects. His objective is to present the medicinal values of radium. Although
joint research, only Pierre was allowed to present the findings. This shows
the societal values at the time. This vignette emphasizes empathy,
determinism, and communication. It also demonstrates that Pierre did not
use common sense in his work with radium. It contrasts science and
technology, shows that science is grounded in nature, is a human endeavor
involving curiosity, creativity and imagination, and that the knowledge is
tentative.

"The Discovery of Radioactivity"--Henri Becquerel's impatience with
the weather, and subsequent discovery of radioactivity is the topic addressed
in this vignette. It describes the process that Becquerel used and his
accidental discovery. It emphasizes curiosity, determinism, empiricism,
scientific manipulation, respect for theory, a willingness to change his mind
in response to evidence, and communication. It also demonstrates the
tentativeness of science, that it is a process involving many methods,
grounded in nature. It shows that science is a human search for knowledge
and parsimonious explanations.

"Reading the Cards"--Dmitri Mendeleev is visited in his laboratory in
this vignette. Mendeleev describes how he assembled the periodic table of
the elements and concluded that the properties of elements are in periodic
dependence to their atomic weights. It emphasizes respect for theory,
suspension of judgment, skepticism, respect for quantification, perseverance,
communication, and a search for parsimony. It also demonstrates the human,
creative side of science, that it is a search for knowledge, grounded in nature, and tentative.

"Heavy Ashes"--This vignette describes Antoine and Marie Lavoisier's experiment with mercuric oxide, and subsequent conclusion that matter is not gained or lost in a chemical reaction. It shows that Marie was a very important part of his work as a scientist, yet her contributions are usually omitted when his work is described. This vignette emphasizes manipulation, suspension of judgment, respect for quantification, communication, and perseverance. It demonstrates the tentativeness of scientific knowledge, describes one process of searching for parsimonious knowledge, and shows the human creativity necessary in the endeavor.

"Darwin's Devil Waters"--Darwin's experiences with phosphorescent algae while on board the Beagle are described in this vignette. It is the story of his collecting glowing seawater and observing it under both wet and dry conditions. This vignette emphasizes aversion to superstition, curiosity, empiricism, determinism, communication, and empathy for organisms. It demonstrates another of the methods of science, shows that it is grounded in nature, is a human endeavor involving curiosity, and a search for parsimonious explanation of events.

"Its Only Peanuts"--George Washington Carver's experiments with peanuts are highlighted in this vignette. It describes how the farmers became angry with Carver after he suggested that they rotate their crops, and his
subsequent discoveries of uses for peanuts and their products. This vignette emphasizes that Carver had a thirst for knowledge, respect for quantification, perseverance, and common sense. It demonstrates the creative, human side of science, the differences between science and technology, and its basis in nature.

"Take Your Vitamins"--This story describes Linus Paulings’ interest in the relationship between vitamins and physiology. It depicts his investigation of the effect of large doses of Vitamin C on schizophrenic patients. It emphasizes curiosity, empiricism, scientific manipulation, suspension of judgment, respect for superstition, respect for quantification, and communication. It characterizes the tentativeness of science, the creative human factor, its foundation in nature, and its search for parsimonious knowledge.

"The City Dump"--This story about the archeological team of William Rathje and Wilson Hughes and describes one of their digs. This excavation, however, is of a landfill. Students hear descriptions of intact contents of the landfill. This vignette emphasizes curiosity, empiricism, a thirst for knowledge, precision, quantification, accuracy, and communication. It demonstrates that scientific knowledge is tentative, carried out by humans, using another of many methods, and that it is grounded in nature.

"An AIDS Vaccine?"--This vignette describes a scientist that most students think is dead. It describes the controversy between Salk and other
AIDS researchers over the use of killed whole virus (Salk) and genetically engineered antigens (the others). It clearly demonstrates that scientific knowledge is a human endeavor and that scientific knowledge is tentative. It describes science as a search for knowledge, grounded in nature. This vignette emphasizes scientific manipulation, respect for theory, communication, and common sense.

"The Family Tree of Genetics"--This vignette shows how scientific knowledge is tentative by describing the developments over the past 200 years in the area of genetics. It highlights Barbara McClintock's receipt of the Nobel Prize and includes a brief description of the works of Mendel, Thomas Hunt Morgan (and his wife, Lillian), Herman Muller, and McClintock. It emphasizes curiosity, determinism, respect for theory, suspension of judgment, skepticism, loyalty to reality, aversion to superstition, empathy, and communication. It shows that science is a human endeavor, describes one of the many methods of scientific investigation, clearly shows the tentativeness of scientific knowledge, and the search for parsimonious knowledge.

"Science"--The final vignette sums up the process of scientific investigation. It reviews and reiterates the attitudes and characteristics of science that have been emphasized and demonstrated by the vignettes over the past period of use. It demonstrates all the precepts of the model of the nature of science and most of the attitudes.
Since I am attempting to teach the students the nature of science (not necessarily the nature of physics), vignettes from all areas of science (including biology, chemistry, physics, and technology) were employed. While these vignettes concentrate on a particular topic or scientist, the majority of them cross the line between the sciences. For example, during a discussion of the differences between science and technology, the vignette about Garrett Morgan (inventor of the traffic signal) was utilized. This vignette emphasizes that a person with very little education and scientific background can make remarkable contributions to technological advances of society. When discussing heat and temperature, the vignette about Elijah McCoy and his lubricating devices was used. While not directly related to heat and temperature, the previously taught topic of friction is integrated into the lesson, showing its relationship to heat and to technology which aids in the prevention of damage to engines from friction. During the lesson on the atom and the development of atomic models, the vignette about Florence Sabin and her model of the human brain demonstrates that models are used to study structures and systems which are not readily available to the scientist. During lessons on chemical reactions, George Washington Carver’s experiments on peanuts demonstrate how these chemical reactions which are being discussed can be used to develop widely used, everyday materials. While each of the sciences has its own history and specific areas of investigation, they are integrated into a whole that provides new knowledge
and technologies, knowledge and technologies that often overlap. A schedule for use of materials can be found in Appendix D.

Since the summer sessions consist of three week sessions, with classes three hours per day, five days per week, two interactive vignettes were utilized per class period. At the beginning of the class period and at convenient breaks in the topical discussions, a vignette was introduced. The first section of the vignette was told (read) to the students. The first section of the interactive vignette establishes some sort of conflict which will be resolved during the story process. At the strategically placed break in the story, students are asked to analyze the conflict and are invited to ask questions of their own. The questions posed to the students are open-ended. All students are encouraged to participate and several answers to the questions are entertained. All evidence-based, thoughtful answers and questions are accepted and students are encouraged to question each other and answer each other's questions.

The second section of the vignette involves resolution of the conflict. Often, questions are asked of the students at critical points in the conflict resolution section, and students are encouraged to stop the storyteller to interject their own questions at any point in the story. In this section of the vignette students see whether or not the predictions they made in the first part of the story were correct.
Finally, students are asked to identify characteristics of science exemplified in the story and describe how the story helped them understand more about the nature of science. They are encouraged to make connections between science of the past and science of the present. A sample vignette can be found in Appendix B. The example shows where and how to interject the questions to stimulate student thinking, and how to relate the story to the nature of science and scientific attitudes.

Since the interactive vignettes take approximately 7-10 minutes to read and discuss, the experimental treatment constituted about 10% of instructional time. (Recall that the British National Curriculum recommends 5%).

Both classes wrote the NOSQ pretest and posttest and responded to identical journal entries (see Appendix E) throughout the semester. These journal entries were used to generate qualitative data, and were not discussed in class. As previously described, an amount of time equivalent to that devoted to historical vignettes with the experimental group was spent reviewing topics addressed in the course with the control group.

As an evaluative tool (not further treatment of the experimental group), historical materials were placed on reserve at Watson Memorial Library. The materials included information about the scientists and/or the topics addressed in the vignettes. Students were advised of the availability of these materials, but not encouraged in any way to utilize them. Since
students must have the call numbers of any materials placed on reserve at this library, the students were given a copy of those call numbers. They were also told that if they didn’t find anything on reserve that they wanted to pursue further, they could find more information in the section Q60-Q181 on the third floor of the library. Several times a week, after a vignette was discussed, students were reminded, "If you are interested in finding out more about this scientist or topic, materials are available on reserve at the library." Student usage of these materials, evidence of increased interest in science and/or scientists, will be discussed in Chapter 4.

Quantitative Analysis

The NOSQ (see Appendix C) was administered to both classes during the first class meeting of the semester to assess their understanding of the nature of science. The NOSQ is a cognitive scale assessing a populations’ understanding of the nature of science. It is an inventory consisting of 24 modified Likert scaled items. It includes six subscales, each of which is organized around a characteristic of science gleaned from a review of the literature. Each characteristic is represented by two alternative conceptions of that characteristic, thereby discriminating between alternative conceptions and a realistic conception of the nature of science. The NOSQ was also administered as a posttest on the last class meeting before final exams.

The results were analyzed using both independent and dependent t tests. Differences were examined between the control group and the
experimental group on the pretests and posttests as well as differences within
the two groups from pretest to posttest. An independent t test was performed
on the pretest scores to establish equivalence between groups. An
independent t test was performed on the posttest scores to determine if there
were differences between the groups on the posttest scores. Additionally, a
dependent t test was performed on both groups to determine if there were
differences between the pretest and posttest scores.

Independent t tests were performed on the pretest because there were
two samples, each of which was evaluated using the NOSQ. At this point,
there was no dependence between the samples, since the decision to subject
one sample to the experimental treatment was random. Dependent t tests
were performed on the pre- posttest scores because the same instrument was
utilized as a pretest and a posttest, constituting a repeated measure (Kirk,
1990). Any decrease in the total score on the NOSQ must be viewed in light
of the subject's original score on the NOSQ.

Examination of the data for differences between traditional and
nontraditional students and between elementary education majors and other
nonscience majors was accomplished using the t tests as described above.
This aspect of the research is exploratory in nature.

A graphic representation of the statistical analysis is found in Figures
3.1, 3.2, and 3.3. A graphic representation showing the results can be found
in Figures H.1, H.2, and H.3, in Appendix H.
Figure 3.1. Statistical Analysis--Experimental vs. Control Groups
Figure 3.2. Statistical Analysis--Traditional Students vs. Nontraditional Students
Figure 3.3. Statistical Analysis—Elementary Education Majors vs. Other Nonscience Majors
Additionally, qualitative data were generated from student responses to the NOSQ (Aikenhead, 1973). By analyzing the pretest and posttest data, the following questions were addressed: What have the students learned? What misconceptions about the nature of science are still evident? This information was then compared to the journal writings for a fuller picture of the conceptual change experienced by the students.

Qualitative Analysis

Qualitative approaches contend that the object of study must be described in its own ecology or setting. Qualitative research is both simple, yet incredibly complex (Rist, 1982). Paper and pencil questionnaires provide questionable results for several reasons. Students may not interpret the items in the manner hoped for by the researcher (Griffiths & Barry, 1993). Paper and pencil tests limit the amount of information that can be retrieved (Lederman & O’Malley, 1990; Mead & Metraux, 1957). They are carried out by a researcher who controls the situation to which the subjects are asked to react (Krippendorff, 1980). The wording of the questions may affect how the student responds to the item (Mead & Meatraux, 1957). For these reasons, as well as for exploratory reasons, the data from the NOSQ were triangulated with data from journal writings and interviews.

Triangulation compares at least two research techniques or solutions to the same problem or question. It is used to provide greater validity and reliability for results obtained by all methods. Triangulation allows...
researchers to monitor findings and increases confidence that conclusions are sound. This technique allows researchers to bring forth more than one form of evidence to support the interpretation of results. The responses to the NOSQ were both quantitatively and qualitatively analyzed and triangulated with content analysis of journal writings and interviews.

Journals

Since the results of any study are affected by variables beyond our control, due to the complexity of interactions among individuals (House, 1991), qualitative research was also done. Students from both classes were required to keep journals throughout the semester. Each week, students responded to four questions posed by the researcher about the nature of science (see Appendix E for a list of journal entries). Students were required to write at least four sentences in response to the questions and demonstrate that they had pondered the question posed. This allowed them to express their ideas more completely than the NOSQ allowed. Listening to their own stories through journal writings also allows students to reflect on their learning, and often illuminates abstract ideas, making them more concrete and accessible (Rice, 1993). The questions were worded neutrally so the tone of the question would not affect the answers (Mead & Meatraux, 1957). Journal records are a recognized method of data collection and can provide insight into students’ epistemologies. Therefore, a selected set of journals from the experimental section was content analyzed.
It was found during the pilot study that some students put a great deal of thought into their journal entries, while others just wrote the four required sentences with little thought about the question posed. Journals were selected for analysis based on the depth of thought the students exhibited in their first entry: Why aren't you a science major? Student journals showing some depth of thought about this entry were separated and 10 journals from these students were chosen for analysis. A stratified sample was used to recognize and evaluate the following subpopulations: elementary education majors, freshmen, sophomores, juniors, and nontraditional students. Two journals from each of these groups were analyzed. Independent judges evaluated the first entry as described above.

These selected journals were content analyzed using methods outlined by Kassarjian (1977), Krippendorff (1980), and Wandersee, Mintzes, and Arnaudin (1989) to evaluate the effects of the history and nature of science on students understanding of the nature of science. Content analysis seeks to understand data by unobtrusive analysis and is potentially one of the most important research methods utilized by social scientists (Krippendorff, 1980). Fundamentally empirical in nature, it is both exploratory and predictive. It was used as a supplementary technique to cross-validate findings obtained by the NOSQ.

Content analysis is the evaluation of a body of communicated material (journals) to make valid and replicable inferences (Krippendorff, 1980) in
order to determine meaning. One of seven types of qualitative analysis described by Rist (1982) is thematic analysis of material. In this type of analysis, information gleaned from the material is clustered and presented by key themes found in the study.

An accepted technique of content analysis is the thematic analysis described by Rist (1982), in which the researcher applies a classification scheme to the material analyzed with respect to the content of interest. This is necessary to produce empirically meaningful data (Krippendorff, 1980). Since raters often interpret the information differently, affecting the reliability of the measurement (Eltinge & Roberts, 1993), three journal readers were used. Journals were read in search of common patterns. Key words and/or phrases were identified and grouped into categories. Each reader identified key themes in the writings, which were classified, evaluated, and tabulated.

Krippendorff (1980) describes types of units for analysis that should be a part of each content analysis. The sampling unit in this study was the class, the physical units of analysis were the journals. The recording units were the words and the units of enumeration were the ideas described by these words. The categories (which were generated from the raw data) must be viewed in the context of the study. The referential unit (context) was the model of the nature of science.

I read the journals five times. The first reading was simply to grade the journal. The second reading involved a search for patterns and themes.
During the third reading, I generated interview questions and noted them in the margins. The fourth time involved reading each entry from all ten students to acquire an overall class viewpoint of the specific question. At this time, comments from the other readers were utilized to make sure I had not missed something and that my interpretation of students’ writings were consistent with those of the other readers. Finally I read each student’s journal from beginning to end to track changes in the individual’s understanding of the nature of science. Again, comments from the other readers were utilized to verify my interpretation of students’ writings.

Generalizations gleaned from this evaluation of the journals were compared to the model of the nature of science. Since journals help students reflect on their learning, these journals provide a record of the process of conceptual change. The journals are somewhat interactive, as I comment on each student’s entry, asking questions about points s/he has made and requesting responses to these questions.

**Interviews**

Additionally, one student from each of the above-described groups of journal-keepers was interviewed at the end of the semester using techniques described in Posner and Gertzog (1982) and Krippendorff (1980) in order to triangulate with the journals and the written test results. Since paper and pencil tests and questionnaires can be misleading, the journals provide more insight into what the students are thinking. Interviewing students provides an
even deeper understanding of their thoughts. Previous research on students’ understanding of the nature of science did not include interviews, thus provides an incomplete picture of their ideas (Lederman & O’Malley, 1990). Whether or not a student understands a concept is determined by the words s/he uses relating to that concept (Stenhouse, 1986). Interviewing is one of the best avenues to student thoughts (Cummins, 1992), allows us to better judge a student’s understanding of the nature of science, and provides more reliable evidence. The clinical interview allows us to generate a potentially unlimited set of data on students’ cognitive structures (Posner & Gertzog, 1982).

The audiotaped interviews were transcribed by the researcher and the transcripts triangulated with journal entries and scores on the NOSQ to provide more information about the student’s understanding of the nature of science. The type of interview used is described by Posner and Gertzog (1982) as a "controlled but flexible conversational interview" (p. 198).

Specific questions arose as a result of reading the journals. Each interview was guided by these questions, but not bound by them, allowing the researcher greater understanding of the situation (Cummins, 1992). For example, when describing the nature of science, one nontraditional student stated "inventions may occur." The student was asked to elaborate on that phrase. The same student stated that scientists prove their findings and was asked to define the word prove. Several students stated that science was the
"study of" something. They were asked what exactly "study" means to determine if study is a process of gleaning new knowledge involving observation, experimentation, and reaching conclusions or if study is something you do to learn about existing knowledge. An elementary education major wrote that science "sets laws." The interview was utilized to clarify what that meant. The same student indicated the purpose of science was to invent things that will better mankind. She was asked to elaborate on that statement. A sophomore indicated that she did not want to be a science major because she would not like "experiment(ing) on something again and again until it works". In another entry she described a scientist as continuing to experiment until it worked. She was asked how one knows when one's experiment has worked. During the interview, students were encouraged to speak freely about his or her writing and understanding of the nature of science and how it had changed over the length of the course.

A set of materials was placed on reserve at the university library. These materials provided additional information about the scientists and/or the topics discussed in class. At the end of the summer, I attempted to review the usage record of these materials to see if students sought more information about people or topics discussed interactively through the historical vignettes. Upon requesting this information from the librarian, I was told that library use records are confidential. She checked the usage record and reported to me that none of the books had been checked out. In
an attempt to verify this information, I contacted as many students as possible
(by telephone or seeing them on campus) and asked them if they had checked
out any of the books on reserve.
RESULTS AND DISCUSSION

Quantitative Analysis

The instrument used to quantitatively determine differences among groups was the NOSQ (see Appendix C). The NOSQ is a cognitive scale assessing a populations' understanding of the nature of science. It is an inventory consisting of 24 modified Likert scaled items. It includes six subscales, each of which is organized around a characteristic of science gleaned from a review of the literature. Each characteristic is represented by two alternative conceptions of that characteristic, thereby discriminating between alternative conceptions and a realistic conception of the nature of science.

The NOSQ was administered to both classes during the first class meeting of the semester to assess their understanding of the nature of science. It was administered as a posttest on the last class meeting before final exams. Statistical data were generated using the Statistical Package for the Social Sciences (SPSS). Dependent t tests were calculated by hand.

All data were entered into the program from the student answer sheets. Demographic data were entered using the permission slips signed by the students. Students were classified as nontraditional, elementary education majors, and/or other. Answers to the NOSQ were reverse coded for those questions requiring a negative response (i.e., 4 became 1, 3 became 2).
Therefore, a lower score on the NOSQ indicated a better understanding of
the nature of science.

The results were analyzed using both independent and dependent t
tests. Differences were examined between the control group and the
experimental group on the pretests and posttests as well as differences within
the two groups from pretest to posttest. An independent t test was performed
on the pretest scores to establish equivalence between groups. An
independent t test was performed on the posttest scores to determine if there
were differences between the groups on the posttest scores. Additionally, a
dependent t test was performed on both groups to determine if there were
differences between the pretest and posttest scores.

Examination of the data for differences between traditional and
nontraditional students and between elementary education majors and other
nonscience majors was accomplished using the t tests as described above.
See Appendix H for a graphic representation of the data.

Qualitative Analysis

Qualitative analysis of the data was done by content analyzing journals
and audiotaped interviews. Journals from 10 students in the experimental
group were content analyzed. Five of these students were interviewed and
transcripts of the audiotaped interviews were content analyzed. This type of
analysis yields more information about the student's understanding of the
nature of science than questionnaires can provide. Paper and pencil tests can
be misleading and the journals afford insight into students’ thoughts. Interviewing students provides an even deeper understanding of their ideas. Since earlier research on students’ understanding of the nature of science did not include interviews, findings were weak (Lederman & O’Malley, 1990). A students’ understanding of a concept is inferred by the researcher based on the words s/he uses relating to that concept (Stenhouse, 1986).

Often there is a rush by researchers to measure outcomes in new programs which are not fully understood. When this happens, the results have limited value (Rist, 1982). In order to provide a deeper understanding of the quantitative results produced by this innovative technique, qualitative research was also done. The purpose of the qualitative analysis was exploratory in nature. In other words, there was no hypothesis tested during the qualitative phase of the research. The data were approached with no hypothesis in order to find out what the students thought. This type of research provides further evidence of the students’ understanding of the nature of science.

Research Question 1

Will the inclusion of interactive nature-of-science vignettes drawn from the histories of science in a college introductory physical science course for nonmajors induce conceptual change about the nature of science?

In order to control for scholastic ability (Trent, 1965), academic equivalence between the control and experimental classes was established by
comparing composite ACT scores. The mean for the control class (n=32) was 16.77 and the mean for the experimental class (n=31) was 16.26. The difference between these means were not statistically significant.

Means from the pretest were compared between the groups using an independent t test. No statistically significant differences between the groups on the NOSQ pretest were revealed by analysis. The pretest mean for the control group was 2.22 and the pretest mean for the experimental group was 2.29. Note that the mean score of 2.22 indicated that on the pretest, the control group had a better understanding of the nature of science than the experimental group, but the differences were not statistically significant.

Pretest-posttest means were compared within groups. Since any posttest score cannot be evaluated fully without taking the pretest score from that individual into consideration, a dependent t test was done on the pretest-posttest scores. This is similar to a situation in which two groups of animals have been fed different diets and their weights compared. Without knowing the original weight of the animals, the final weights become somewhat meaningless (Blackwell & Solomon, 1964). A baseline is needed in order to determine if changes occurred.

The pretest score was subtracted from the posttest score for each subject and a t test performed on the gains score. The control group did not show statistically significant gains, t(26), p = .05. The experimental group did show statistically significant gains, t(28), p = .05 from pretest to posttest.
The control group showed no statistically significant gains from pretest to posttest. As a matter of fact, the mean score deteriorated somewhat. The experimental group did show statistically significant gains from pretest to posttest. See Appendix H for a summary of these statistics.

Posttest scores were compared between groups. Utilizing the independent t test, statistically significant differences were found between the control group and the experimental group on posttest scores at \( t(26), p = .04 \). The control group score was higher than the experimental group score. See Table 4.1 for a summary of the statistics.

Table 4.1

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretest mean</th>
<th>Pretest s.d.</th>
<th>Pretest n</th>
<th>Posttest mean</th>
<th>Posttest s.d.</th>
<th>Posttest n</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.22</td>
<td>.276</td>
<td>30</td>
<td>2.25</td>
<td>.280</td>
<td>27</td>
<td>.71</td>
</tr>
<tr>
<td>Experimental</td>
<td>2.29</td>
<td>.200</td>
<td>30</td>
<td>2.11</td>
<td>.247</td>
<td>29</td>
<td>.004</td>
</tr>
</tbody>
</table>

These statistics provided evidence that the experimental treatment induced statistically significant conceptual change about the nature of science in the experimental group. These differences between the experimental group and the control group were also statistically significant. Therefore, the
answer to Research Question 1 is yes, the inclusion of interactive nature-of-science vignettes in a college introductory physical science course for nonmajors does induce conceptual change about the nature of science, however, the differences are small. A raw score percent change was calculated from pretest to posttest for the experimental group. The mean on the posttest was subtracted from the mean on the pretest and divided by four (the number of choices on the scale). The raw score difference was .18, representing a 4.5% change toward a better understanding of the nature of science. Without the qualitative data which follows, the study may be viewed as weak by some researchers.

Research Question 2

What conceptions of the nature of science do university students hold (before and after treatment)?

Because there is often a rush by researchers to measure outcomes in new programs, (Rist, 1982) qualitative research was done on this innovative technique to flesh out the study. In this descriptive approach, there was no hypothesis tested. The data were approached with no hypothesis in order to "paint a picture" (Helmstatler, 1970, p. 64) of the students' understanding of the nature of science and to supplement information learned from the statistical analysis of the first research question.
To circumvent introduction of biases and prejudices that may have been carried into the study, I provide detailed descriptions which will afford the reader a holistic view of the data (Rist, 1982).

**Qualitative Analysis of NOSQ Responses**

Raw scores from the pretest and posttest were examined to determine what conceptions the control class and the experimental class held about the nature of science before and after treatment. These were classified according to the model of the nature of science found in Appendix A.

The control group agreed that science is uncertain, but did not understand that it is revisionary. They did not indicate an appreciation of the many methods that scientists use to answer questions. While the control group did not understand the differences between science and technology, and indicated that the purpose of science is to improve the human condition, they did acknowledge that scientists are people. The control group had a weak understanding of the search for simplicity in science.

The experimental group saw science as tentative and revisionary. They understood that there are many ways to solve problems. The experimental group differentiated science and technology and they appeared to have a deeper understanding of the human side of science. The experimental group had a strong understanding of the search for parsimony. The following paragraphs provide descriptions of the class consensus to items on the NOSQ.
The responses to the NOSQ pretest by the control group indicated a general understanding of the tentative nature of science. Posttest responses indicated that they were more sure of the tentativeness of science. Although the journals from the control group were not content analyzed, I read them to grade them. During that reading I noticed that in response to the question, "Is science certain or uncertain? Explain.", only about half the students stated that science is uncertain. Most of those students indicated that it was uncertain because scientists do not know the answers to all questions, such as a cure for AIDS. Only a few students described the tentative and revisionary nature of science. These students saw science as certain, but not for the reasons stated in the NOSQ.

The control group identified "THE SCIENTIFIC METHOD" as the method of choice. This response concurred with findings by Griffiths and Barry (1993). However, they acknowledged that the method chosen by a scientist is based on the questions being asked. On the pretest, they tended to agree more with the statement "There are many scientific methods.", than they did on the posttest.

Answers on the pretest and posttest indicated that the control group understood the purpose of science as searching for knowledge and technology as application of that knowledge. However, their journal entries (which were read, but not content analyzed) provided evidence that they did not understand the difference between science and technology.
The control group realized that human creativity is a necessary part of science, they did not see classification schemes as human inventions, but inherent in the material being classified. Although the NOSQ scores indicated that they agreed that scientists have lives outside the laboratory, their journal entries did not reflect this. The overwhelming response to "Draw a typical scientist. What does one do?", was that of the stereotypical scientist in the laboratory. This disparity between responses to a questionnaire and free responses mirrored the findings of Mead and Metraux (1957). The students in that study also indicated that they held a positive view of scientists when asked specific questions on a questionnaire, but when allowed to respond freely, described scientists quite differently. The student drawings were similar to those described by Rosenthal (1993).

On the pretest, the control group agreed that scientific knowledge must be consistent with nature, but disagreed on the posttest. They generally disagreed that models are man-made and not designed to represent reality and these responses did not change from pretest to posttest.

The control group had a weak understanding of the search for simplicity in scientific endeavor. Their understanding of this characteristic of science did not change from pretest to posttest.

The responses to the NOSQ pretest by the experimental group indicated a general understanding of the tentative nature of science. Posttest responses indicated that they were more sure of the tentativeness of science.
Noticeable movement toward a greater understanding of the nature of science was seen in their responses to the statements addressing science as a body of knowledge and the tentativeness of laws. Content analysis of 10 journals from the experimental group, described in detail in the following section, support these findings.

The experimental group acknowledged that there are many approaches to solving scientific problems. This agreement is stronger on the posttest than on the pretest, with the exception of the question about "the scientific method." Students disagreed (on the pretest) that the scientific method consists of the often recited five steps, but agreed with this item on the posttest.

Answers on both the pretest and posttest indicated that the experimental group understood the purpose of science as improving the human condition. However, when asked to describe the differences between science and technology in a journal entry ("Is the discovery of a new drug to treat AIDS science or technology? Explain."), they correctly differentiated the two. This indicated that while they do understand the differences between science and technology, they still have misconceptions about the purpose of science.

The experimental group realized that human creativity is a necessary part of science, but they did not see classification schemes as human inventions. They strongly agreed that creativity is an integral part of science.
and disagreed that scientists study something to make money. Yet, most
drew a picture of the stereotypical scientist, with laboratory equipment
around him. These students’ responses also mirrored those reported by
Mead and Metraux (1957) and their drawings were similar to those depicted
by the students in Rosenthal’s (1993) survey.

On both the pretest and posttest, the experimental group agreed that
scientific knowledge must be consistent with nature. They generally
disagreed that models are man-made and not designed to represent reality and
these responses did not change from pretest to posttest.

The experimental group had an understanding of the search for
simplicity in scientific endeavor. Their understanding of this characteristic of
science strengthened from pretest to posttest.

In summary, while the responses to the NOSQ pretest were similar
for the control and experimental groups, differences were noted on the
posttest. Analysis of posttest responses indicate that the control group has
not grown in its understanding of the nature of science. These students
agreed that science is uncertain, but are not sure how or why. They
maintained that the scientific method is the method of choice. The
experimental group saw science as tentative and revisionary and understood
that there are many ways to solve problems. The control group did not
understand the differences between science and technology. The
experimental group differentiated the two. Both understood the human side
of science, and the experimental group appeared to have a deeper understanding of scientists as people first. The control group had a weak understanding of the search for simplicity and the experimental group had a strong understanding of this characteristic of scientific endeavor.

Analysis of Journals by Entry

Ten journals from the experimental group were content analyzed as described in Chapter 3. Each entry was examined to provide information about the class as a whole. Next, each student’s complete journal was studied, to track the changes in an individual student’s understanding of the nature of science. As described above, this descriptive analysis provides additional evidence about the students’ understanding of the nature of science to the reader.

The first description is that of the class as a whole by analysis of the journals by entry. This analysis was done simply to describe the group’s understanding of the nature of science and to determine what misconceptions remained after treatment (Aikenhead, 1973). It also answers Research Question 2: What conceptions of the nature of science do university students hold (before and after the treatment)?

The first entry was "I am not a science major because...." Five of the ten students stated that poor prior experiences with science had turned them off to science. Four liked something better. One stated that she had no
curiosity, however, in informal conversation with this student, I learned that her conception of science was entirely at odds with her religious beliefs.

Entry number two, "What is your understanding of the nature of science. What is science and what does it do?", provided a wealth of information to triangulate with the NOSQ.

Only one student saw science as tentative at this point in the course, two described is as a process, and two saw it as a body of knowledge. The most popular answer was that science is the study of something, either nature, the universe, or things we do not understand. Students described science as a means to explain the unexplained (4), answer questions (2), solve problems (2), and better mankind (3). They saw science as grounded in nature (4) and ubiquitous (2).

The answers these students marked on the NOSQ showed a split between certainty and uncertainty. Six responses were consistent with an uncertain science, four with a certain science. Seventy percent agreed that science emphasizes the practical aspect of its discoveries, disagreed that inventions are not the goals of science, and agreed that its purpose is to improve the human condition. Only half responded positively that inventions are the goals of science. Seven of the ten agreed that scientific knowledge must be consistent with nature. These responses correlated positively with journal writings.
When asked to draw a typical scientist, students drew the expected (Rosenthal, 1993), stereotypical scientist, an unattractive male with glasses and unkempt (or no) hair, in a laboratory or lab coat, with a pocket protector. One student drew a black male scientist and one drew a white female scientist. These two scientists were still somewhat stereotypical with lab coats or in a lab. Only one student drew a naked, genderless person. She said "He can have a head full of hair or a shiny bald one. He may wear glasses. I'll bet he's nearsighted. He probably has a pocket protector and a calculator. He has very poor fashion sense and a dirty lab coat." She justified this description with, "What is a typical scientist? I don't have enough information. Is 'he' male or female? Is 'he' black, white, hispanic, oriental? Does 'he' have blond, red, or brown, or white hair? Is 'he' tall or short? Fat or skinny? Does he have dreams, aspirations? Is 'he' disabled? There are too many '?s'".

All students saw this scientist as experimenting, with three indicating that these experiments were carried out to better mankind, which was consistent with NOSQ responses.

"Is science certain or uncertain? Explain.", was the fourth entry. Students seemed to have gained a better understanding of the nature of science at this point in the course. Six of the ten described it as tentative and
One student stated that "I believe that science is certain because it has been proved to be true...Once Science has been proved it is incapable of failing". A freshman said we are certain about some technologies, but other things change.

Entry number five, "Why is a basic understanding of science important?", reflected the students views of the nature of science. This class saw science as ubiquitous, explaining life and nature, answering questions, and providing technology.

The sixth entry was, "Do you understand science better than when you first walked into this room? What techniques have you encountered that have helped you understand better? What has been useless? This question was to probe students to see if they felt the vignettes were useful. All students felt that they had a better understanding of science. Helpful techniques (in order of most often cited to least often cited) were demonstrations (9), practical examples and applications (5), diagrams (3),

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Although journals from the control group (n=30) were not content analyzed, it is interesting to note that nearly half of these students described science as certain. Of those who described it as both certain and uncertain, or uncertain, only two indicated that science is tentative and revisionary. One noted that science is uncertain because all measurements have some degree of uncertainty. The others stated that science is uncertain because we do not know the answers to all the questions (e.g., a cure for AIDS, or how to travel at the speed of light).
vignettes (2), reviews (1), repeating (1), individual attention (1), and "its ok [sic] to ask questions" (1). No techniques were described as useless.4

The seventh entry was, "In physics lessons, there are often assumptions or thought experiments which cannot be realized in actual experiments (like ignoring air resistance or friction, or traveling at the speed of light). Do you think this method is useful? Explain." All students believed that these were useful to stimulate the imagination, and encourage problem solving, creativity, and critical thinking by the student. This indicated that these students had a conception of the method of idealization in science. These findings contrasted those reported in Matthews (1992). One freshman could not imagine doing an actual experiment without doing it in his head first.

The eighth entry asked, "Is there a place for history in the science class or should it be left to the history class? Why?" All students saw a place for history in the science class.5 Three students mentioned that it is nice to know about the discoveries, one of those stating that what was discovered was more important than who discovered it. One student described it as the beginning that continues on as long as there is science. Four students saw the inclusion of the history of science as an important link

4 These remarks are consistent with those made by the control group.

5 It is interesting to note that the majority of the students in the control group also saw a need for history of science in science classes, even though they had had limited exposure to the history of science in this class.
to help us understand the present and future. One student said it helped show how things fit together in the jigsaw puzzle of science and commented that both the successes and failures of science should be taught. Two students thought it was interesting and provided a perspective about what the scientists were thinking as they studied the phenomena in question. Three students said they would rather science teachers teach the history of science, one because she did not see it fitting into Louisiana history or American history and the other two because they felt that science teachers could do a better job of it. They stated that history teachers would have to do a lot more research to properly present the material and would probably not be as interested in it or know it as well as the science teacher.

The ninth question was, "What is the role of mathematics in science? Why do you think that I have deemphasized math in this course?" Four students saw mathematics as important when making measurements and "proving theories". Two saw it as the language of science, but did not elaborate further. One student said that math was more uncertain than science because we can do things with math that we cannot do in real life. One student stated that mathematics describes unknowns and another stated that it helps make connections among concepts.

Three students felt that I deemphasized mathematics because of the limited time we had for the course. Two felt that I did it to reduce the stress, one elaborating that I had removed an excuse that students had for not
being successful at science. One stated that I had deemphasized mathematics to change the misconception of "big headed men doing long problems and pouring dangerous chemicals into one another." The rest of the students stated that the reason was because nonscience majors need a basic understanding of the concepts of science, and not necessarily the mathematical emphasis which is placed on many courses.

When asked whether the discovery of a new drug to treat AIDS was science or technology, all journal writers whose writings were content analyzed said that the process of development and testing of the drug was science and the finished product was technology. Two noted that technology was utilized during the process of development.

Finally, students were asked how much attention they paid to the Chapter Highlights sections of the text. Recall that these pages emphasize either a scientist or new technology related to the content of the chapter. They are often historical in nature, highlighting such scientists as Marie Curie, Antoine Lavoisier, or Mendeleev. Only two of the ten authors of content analyzed journals had read them. One said that they were helpful because they rounded out the information being presented by providing historical information about the topic. He found it interesting to learn how society treated the scientists during and after their discoveries. One said that they piqued her interest in the regular pages and made her want to find out more about the content topic. She further stated that the vignettes were
interesting and helpful too. About 30% of the entire class had read or skinned them, 15% had read them consistently. This was consistent with the findings in the pilot study.

In summary, the class as a whole has moved toward a greater understanding of the tentative and revisionary nature of science. The students appreciated the human factor and saw the place of curiosity, creativeness, and the imagination in the scientific endeavor. They indicated an understanding that many methods can be utilized to gain a greater understanding of nature. They understood the differences between science and technology, and communicated those differences clearly in their responses to the posed question.

It appears that the "hidden curriculum" has carried important messages about what science is and has affected the students' conceptions about the nature of science (Gil-Perez & Carrascosa-Alis, 1992). Students did not comprehend the role of mathematics in science as evidenced by the perfunctory responses to the question. Perhaps this was because I deemphasized mathematics in this course and emphasized conceptual understanding of the content. While, as one student sagely wrote, I have removed any excuse that students have for not being successful in the course, it seems as though I have sacrificed some understanding of the nature of science in the process.
Another aspect of science that the class had not grasped is the purpose of science. My students, as did those of Wilson (1954), still saw the goals and purposes of science as those associated with inventions and improving the human condition. Upon reflecting upon the course content, I find that I may have contributed to this misconception by stressing the practical applications of science to their everyday lives. The purpose of these practical applications and everyday examples was to provide connections between the material these nonmajors were learning and their own conceptual frameworks by showing how science affects their everyday lives.

Analysis of Individual Journals

Next, each student’s journal was examined, intact, to track the changes in an individual student’s understanding of the nature of science. In this phase, the journals of individuals were compared with their responses to the NOSQ, both pretest and posttest to generate qualitative data (Aikenhead, 1973). By analyzing the pretest and posttest data, and triangulating them with the journal writings, the Research Questions were addressed. These analyses contributed to an understanding of the quantitative data generated. None of these students were interviewed.

This section serves to answer Research Question 2: What conceptions of the nature of science do university students hold (before and after treatment)?
Journal 1 -- Freshman.

The first journal was written by a 19 year old white male freshman (FM19) who listed his major as general studies. He has never thought of a major in science and did poorly in science in high school. He stated that his "ACT scores and all other test scores push me toward science." Overall, his score on the NOSQ moved toward a better understanding of the nature of science. He saw science as uncertain rather than certain, stating that "nothing can be proved for certain...nobody actually knows the truth." He appreciated the role of mathematics in science, especially in measurement and was more sure of its capacity to identify patterns and demonstrate relationships. His third journal entry showed the stereotypical scientist and on his NOSQ pretest, he answered that he strongly agreed that the work of a scientist requires such a dedication that s/he is unable to have the same type of lifestyle as people who choose other fields of work. He disagreed with this statement on the posttest. FM19 saw science as answering questions, explaining the mysteries of the unknown, explaining phenomena, and "helping the livelihood of all living things."

However, two misconceptions were still evident. His NOSQ scores (pretest = 2.42 and posttest = 2.04) and his journal writings indicated that a major goal of science is to improve the human condition and he indicated that the laws of nature were not subject to change.
Journal 2—Sophomore.

SF23 wrote the second journal which was content analyzed. She is a 23 year old sophomore, white female who has done poorly in science in the past. She inferred that teachers did not want to teach students who did not "have a clue as to what was going on 'underneath the big rock' of science."

She told me that she had never passed a science test in her life "on her own."

She is a nontraditional married student. In general, she has moved toward a greater understanding of the nature of science (NOSQ pretest = 2.46, posttest = 2.17), but still held several misconceptions. She viewed science as certain at the beginning of this course, but quickly changed her views, indicating in her second and fourth entries that it is tentative and always changing.

Her third journal entry showed the stereotypical scientist and on the NOSQ pretest, she answered that she strongly agreed that the work of a scientist requires such a dedication that s/he is unable to have the same type of lifestyle as people who choose other fields of work. She qualified her drawing by remarking, "there are many types of scientists" and disagreed with this statement on the posttest. She originally agreed that science must be consistent with nature, but disagreed on the posttest. This could have arisen from our class discussions about relativity or my instructions to ignore air resistance. She did not answer the question addressing thought experiments in her journal, rather answered that experiments are useful to help her understand the topic being discussed. Her concepts of hypotheses,
laws, theories, and models were more consistent with the scientific concepts. Her answer to the journal entry about mathematics was ambiguous, but she agreed that attaching numbers to data help us see patterns that we might have missed. She realized that conversion of observations to mathematical relationships is not the goal of all science.

SF23 held onto the misconception that the purpose of science is to better human life, emphasizing the practical and technology. She knew the difference between science and technology, and described science as a process of discovering a new drug, often using technology in this process. She characterized the final product of this process as technology. However, on the posttest, she agreed with the statement that the most fitting definition of science is a body of knowledge. This was also inconsistent with her description of science as tentative and changing.

Journal 3—Junior.

The junior's journal belonged to a 21 year old black female, advertising design major who has always done poorly in science and therefore strongly dislikes it. Her interests lie in the arts. JF21 agreed with statements of certainty on the pretest and disagreed with the statement that science is uncertain. On her posttest, she disagreed with statements of certainty, but also disagreed that science is uncertain. A look at her journal reveals that she saw the tentativeness of science. She stated that one scientist may come up with a logical conclusion that sticks for a while, then another
scientist may have a good argument against the first theory and he may be successful and the theory may change. "And then the cycle may repeat."

However, on the posttest, she indicated that science is a body of knowledge.

JF21 maintained many misconceptions about the nature of science. When asked to draw the scientist, she drew a black male in a lab coat with glasses. While this indicated that she understood that scientists do not have to be white, she saw them as male and did not change her views that they have a different lifestyle from ordinary people, due to their dedication to their work. She also did not change her views that the purpose of science is to improve human welfare. She stated that it explains the everyday things we take for granted and deals with what it takes for us to live and what allows us to live. She was more sure on the posttest that science emphasizes the practical application of its discoveries, and that penicillin, plastic, and television were the goals of scientific research. However, she was more sure that scientists study something because they are curious about it. This student changed most of her answers from pretest to posttest and showed an improved score (NOSQ pretest = 2.58, posttest = 2.13).

When one examines the journal writings of JF21, one sees evidence of an understanding of the nature of science as tentative, and grounded in nature. She understood the difference between science and technology by describing the processes of experimentation, observation, and research to get the drug as science and the product that affects the human condition as
technology. She saw science as a human endeavor involving curiosity, but missed the point of the thought experiments. She admitted that she did not understand the role of mathematics in science.

**Journal 4—Elementary Education Major.**

The elementary education major was a 21 year old white female (EEF21) who stated that she never really thought about a major in science. She is fascinated by helping and watching children learn. She loves horses and participates in the equine science camp for children each summer.

EEF21 had a good conception of the nature of science from the beginning, and after having this course, she was more sure of her answers, by marking the strongly agree or disagree answers on the posttest more often than on the pretest (NOSQ pretest = 2.13, posttest = 1.71). She saw science as explaining how things work, as both tentative and revisionary and referred to "discoveries and breakthroughs on ideas and questions that we thought were solved." She saw scientists as curious and using their imaginations to do thought experiments, acknowledged that what actually happens might be different from what was imagined. Her answer to the question about mathematics was vague, but she saw that attaching numbers to data helps us find patterns we might have missed. She described the process of developing a drug as science and the drug itself as technology or the product of that process. EEF21 still saw the purpose of science as improving the human condition and the goals of science to better the human race.
Journal 5—Nontraditional Student.

The nontraditional student was a 43 year old white male (NTM43) who served in the armed forces prior to returning to school. He is a computer software technician and could be classified by some as a science major. He said he is not a science major because he is more interested in the how to than the why.

His NOSQ scores indicated that he did not change his understanding of the nature of science (NOSQ pretest = 1.83. posttest = 1.83). He saw science as more certain and less uncertain. His journal reflected this as he indicated that the nature of science is to "provide the correct answers to the question, why." He described science as both certain and uncertain. He asserted that we move toward the future with the certainty of what we discover and name as natural laws, basing our "forward steps on things such as Newton's Laws of Motion and Gravity, Einstein's Relativity, and Planck's Constant." He further acknowledged that if these laws have a flaw, it will be discovered and something new becomes fundamental. He subsequently spoke of the ups and downs, successes and failures of science to support his contention that history of science does belong in the science class.

He understood the differences between science and technology and comprehended that the purpose of science is to produce knowledge, rather than to better the human condition. He saw math as a tool for scientists to use to prove their abstract ideas. NTM43 saw science as a human endeavor.
and appreciated the role of the imagination in thought experiments to help scientists look at things from a different reference point, thus forcing them to give up what they are accustomed to. He originally thought of scientists as stereotypical and drew a stereotypical scientist, but realized that they are much like the rest of us with a great curiosity.

Four of the five student journals analyzed in this part of the study indicated that their authors understood science as tentative and scientists as humans employing creativity and curiosity to answer questions. All saw science as grounded in nature and acknowledged that there are many methods for scientists to use in their study of nature. While they correctly classified science and technology, they described science as a means to improve the human condition. An understanding of the role of mathematics in science was not evident.

Analysis of Individual Journals and Interviews

In this section, the responses to the NOSQ, both pretest and posttest are triangulated with five individual journal writers and their interviews to generate additional qualitative data (Aikenhead, 1973). By analyzing the pretest and posttest data and triangulating them with the journal writings and interviews, Research Question 2: What conceptions of the nature of science do university students hold (before and after the treatment)? was addressed. These analyses contribute to an understanding of the quantitative data.
generated and provide evidence that responses to questionnaires can be misleading (Lederman & O’Malley, 1990).

Journal 6—Freshman

FF18 was an elementary education major who has had poor experiences in science and finds it useless. She described her previous experiences in science as boring. She recalled that they studied out of the book and usually talked to each other or stared out the window. She was shy, neither asking, nor answering questions in class and during the interview, was reluctant to elaborate on her ideas beyond the specific questions asked. Her scores on the NOSQ did not improve much from 2.29 on the pretest to 2.25 on the posttest.

She described science as the study of everything. In her interview, she clarified that description.

L: You talked about science being the study of something. What do you mean by study of? What does it mean to study something?

LT: Um, the process of looking and curious.

L: OK, you’re not saying study...go look it up in a book?

LT: No.

L: You’re saying study...go out and find whatever it is?

LT: Yes.

She was the only student who drew a female scientist and qualified that by stating that the reason she did so was because she had seen only
female scientists on television or in the movies. She contended that scientists spend long hours in the laboratory, experimenting on things about which they are curious. She maintained this image of the scientist, so dedicated to her work that she had no social life, from pretest to posttest. She maintained throughout the session that science is a body of knowledge, yet described the process of developing a drug to cure AIDS as science and the drug itself as technology because it affects humans. When specifically asked whether the purpose of science was to create knowledge or to better mankind's life, she replied, "Both.", and would not elaborate.

She was not sure whether science is certain or uncertain. Her answers on the NOSQ contradicted each other. Her journal read, "I think science is certain because many of our theories prove to be true and uncertain because we find out things we believe aren't true and things we never even thought of can happen. If science was certain many of the devices we used to destroy our environment would have been rethought...scientists are certain about certain technology but uncertain of the long term effect."

During the interview, she used the example of the atomic bomb as the technology that had uncertain long term effects. She also cited industrial wastes as another example.

Journal 7--Sophomore

SF24, a sophomore physical education major, showed marked improvement in her understanding of the nature of science during the session.
Her NOSQ pretest was 2.50 and her posttest score was 2.13. When the NOSQ was examined, it was noted that she had changed her answers on one half the items. These changes indicated movement toward greater understanding of the nature of science. This student originally saw science as certain, saying "once science has been proved it is incapable of failing", and was the only student to describe it as a body of knowledge. Scientists were the stereotypical white males, using the scientific method to make money and better the human condition. Her understanding of theories, laws, principles, and hypotheses was the classic one. In her first journal entry she stated that scientists experiment on something again and again until it works. In her second journal entry, she described science as a body of knowledge.

During the interview, I attempted to find out more about these two statements.

**L:** In your first entry you said that you did not want to be a science major because a scientist will "experiment on something again and again and again until it works." How do you know it works? How does he or she know it works?

**M:** How do they know it works?

**L:** Uh huh.

**M:** That's a good question. (Long pause).

**L:** Is that something that you might not say today? I mean this has been a good while ago, this has been a semester ago that you said that. Is
this something that you might not say today or you might not say exactly like that? They do experiment again and again and again, that's true. But until it works...do you think you might use different words?

M: Most likely. What words I would use, is another story.

L: (laughs) Do you know what words you'd use?

M: No.

L: OK. Well that's all right. All through here you describe science as a body of knowledge. Can you tell me a little bit about where that idea comes from?

M: Uh, Just from nature itself, I guess.

L: OK. Have you been taught at any point in your life that science is a body of knowledge?

M: No.

L: OK. What is your science background? How many sciences did you have in high school?

M: Not very many.

L: OK. Did you have...

M: I took that basic physical science. I guess that's what its called. I never did take chemistry or physics.

L: OK. Did you take biology?

M: No.
L: OK. All right. Um, OK. You say that science is certain because it is dependable and reliable. "Once science has been proved, it is incapable of failing." What about the flat earth?

M: What about the flat earth? What do you want to know about that?

L: Would you have called that science? Would you think of that as science and something that had changed?

M: No.

L: Would you expound on that a little bit?

M: I think it was always that way. I don't uh (Long pause).

L: Do you think that the flat earth was a scientific principle or what do you think it was?

M: Was it a scientific principle?

L: Was it a law?

M: No I wouldn't necessarily say that because at one time they said it was round, and then one time they said it was flat.

This particular subject was rather quiet, reserved, and reluctant to offer much information beyond answering the questions asked; until we got to the question on uncertainty or doubtfulness.

L: Do you think science is ever doubtful?

M: Um, yes I think it can be doubtful, and the only thing I can think of to come back at that is evolution.
L: OK.

M: To me its doubtful that we came from monkeys or as they say slime from the ocean and uh (pause).

L: Is that doubtful because of the scientific evidence that has been available to you or is that doubtful to you because of something else, or both?

M: Both.

L: OK.

M: Its doubtful, uh, for one I've always been taught that evolution was not, I've been taught against evolution and two its because I go back to what it says in the Bible. When it says He created man and woman, I believe that there was man.

Several times during this session, in informal conversation, this student brought up evolution and her prior religious teachings. Although she did not recall having been taught that science is a body of knowledge, she must have been. While we, as scientists, want students to understand the scientific evidence supporting evolution and its place as a theory guiding the biological sciences, in this case discussion of the theory of evolution accomplished a quite different goal. In SF24's reflection of her beliefs about science and about the flat earth and the theory of evolution, she realized (in her mind) that science is not a body of knowledge, incapable of failing, but is subject to revision based on new knowledge.
The last question I asked her showed that her understanding of science is changing.

L: OK. How would you describe science, a body of knowledge or a process? Is it something that we already know, a body of knowledge, or is science a process of discovering new knowledge, learning?

M: I think science is a process of discovering learning because everyday somebody learns something else.

This development of understanding was evident in the journal entry which asked, "Is the discovery of a new drug to treat AIDS science or technology?" She described the process of drug development and testing as science and the application of that drug to treat AIDS, thereby improving the human condition, as technology. Although she still defined the scientific method as a set of steps used to solve a problem, she acknowledged that there are many scientific methods.

In her journal she commented that math must be important to science because we have formulas. In the interview, she expressed a need for more math in the course.

L: Do you think this course could be improved by not just putting more math in for the sake of math, but by including more math to show how math and science are interrelated.

M: I have had my algebra, and I’ve passed it. I think that a lot more time could be spent on the math so you could understand it better.
L: Do you think it would make, add to the course. Would it add to your understanding of the scientific principles that we talked about?

M: I think so.

SF24’s responses to the NOSQ posttest indicated that science is uncertain and that scientists study something because they are curious about it, not necessarily just because it will lead to a money making invention. There was also evidence that her understanding of the concepts of theories, laws, and hypotheses had improved. However, as has been seen with other students, she believed that the purpose of science is to improve the human condition.

Journal 8–Junior

JF26 is a junior elementary education major who loves science, but changed her major from secondary science education when she made an F in chemistry. She remarked that she can still be a science teacher, and a good one. She plans to teach science throughout the curriculum to motivate children and instill a desire for them to want to know what makes things behave in certain ways. Her pretest score on the NOSQ was 2.04, indicating a pretty good understanding of the nature of science. Her understanding improved and deepened over the course, as indicated by her posttest score of 1.79.

JF26 elaborated on her understanding of the nature of science in her journal and in the interview. She saw science as ubiquitous. She described
it as the study of everything that we do not know or understand. During the interview she elaborated on this.

L: You describe science as the study of everything that we do not know or have a complete understanding about. What do you mean by "study?"

A: Um, study

L: What does it mean to study something?

A: I think it means to really look closely at something, to examine it, to delve, try to find a particular meaning.

L: OK, how would we go about doing this, would we look in a book, or how would we do this?

A: Um, through books or through observation or through examining it in a book, looking at it, playing with it, you know.

L: Experimentation, maybe?

A: Yeah, experimentation.

This is the student who drew a genderless naked scientist and asked me questions about it. An excerpt from her interview provided more information about her choice.

L: I also noticed that on your typical scientist...I'm fascinated by that. Is the stereotypical scientist the first thing that comes to mind? You gave me two answers, how did you come about that?
A: Well I just. In my own experience I don’t know a typical scientist. I don’t know any scientist at all. I really, but the scientist that comes to mind might be an actor, on television or a movie, you know, a nutty professor. Something like that and classes I have taken like with Dr. Magri. I don’t think he is a typical scientist. You know.

L: The thing that fascinated me was that you acknowledged that there is a stereotypical scientist but

A: I would need to know more about it. You know like if I went to the library and wanted to look something up in the computer, it would want specific information, I couldn’t just say I want to know about um, computer applications of reading. I’d really have to define it otherwise I’d get 3000 listings for it.

Her NOSQ responses, her journal writings and her interview reflected the tentative nature of science. In her journal, she mentioned that we tend to think of science as certain, but the more we know and learn, the more questions we ask. In the interview, she explained why she thought that people tend to see science as certain.

L: You said that science is uncertain but we have a tendency to think of science as certain. Why do you think people tend to think of science as certain?

A: I would think that we take so much for granted like the earth is flat, the earth is round and we used to think it was flat. Um, we just take so
much for granted. In this age of information, we think we know so much and we’re just learning that there is so much that we don’t know. I think its just man’s ego or something like that.

JF26 was the other student who realized that the purpose of science was to create and test knowledge, not to improve the human condition. She was more sure of the multitude of scientific methods at the end of the session.

L: One more question and that has to do with science and technology. Do you think that scientists emphasize the practical applications of their work?

A: No I really don’t. I think that society emphasizes the practical applications because they are the ones that benefit.

She further described how science guides our behaviors.

L: Super. You say that an understanding of science is important because it establishes rules and patterns that guide our behavior. Can you give me some specific examples?

A: Well, you know I’ve heard of kids getting up on roofs and think that they can fly. Science tells us that we cannot fly. It tells us how to fly, how to make something and fly it, you know, but it tells that we cannot fly. We are not aerodynamically able to fly. It also establishes patterns and you know, so called norms.
Thought experiments were useful to stimulate creative and critical thinking and develop problem solving skills. She further applied these types of experiments to the space program and their usefulness in anticipating problems that the astronauts might have with weightlessness. However, her understanding of how math and science are interrelated was weak. She focused on measurement as its primary usefulness, but stated that we can assign meaning to concepts through numbers.

**Journal 9—Elementary Education Major**

EEF21 is an elementary education major who has had a poor background in science. Originally she saw science as a means to improve the human condition, mentioning inventions and technology in her first several journal entries. Later, she distinguished science as the lengthy process (which sometimes utilizes technology) of developing a drug to treat AIDS. She acknowledged that it might have happened by accident during the process of developing another drug. She described technology as data collection and finding other uses for the drug. When asked to elaborate on this she once again mentioned the accidents that occur.

L: Is the purpose of science to invent something?

C: Yes, and no. I don’t think that a scientist sets out to invent something because he wants to. He does it maybe because he has a curiosity, he wants to know more about it and it may be that he accidentally invents something and he didn’t set out to invent it. And then there are those
scientists that do set out to invent something. But as they are inventing that new problems arise and something else might be the outcome of it.

Like many other students, she saw science as the study of nature, but also included in her description of science the processes of experimentation, theory development, and problem solving. She said that science "sets laws." Her interview disclosed more about her ideas.

L: You describe the nature of science as the study of the environment, the study of nonliving things and the environment. What does it mean to study? What do you mean by studying?

C: To dig deeper into it to find out what makes it work. You have to break it down basically.

L: How do you do that? What do you do specifically, physically to study something?

C: First off you have to take it in somewhere like maybe into a laboratory and then do a bunch of experiments on it to see what makes it function.

L: OK, so you are not saying that we go look it up in a book.

C: No.

L: OK, then in another place you said that science "sets laws". What does that mean?
C: What I meant was that like we have the law of gravitation, gravity, Newton's laws, the inertial law, all of that. It just defines it, it gives it a set basis for what makes it work.

L: So you are not saying that Newton said "Hm, I think I'll set the law of gravity."

C: No, he had a reason for it.

Her understanding of hypotheses, laws and theories was acceptable on her pretest, but her posttest scores indicated that she was more sure of their meanings.

EEF21 maintained misconceptions about the nature of science. She drew the stereotypical scientist and portrayed him as experimenting, doing research, inventing, and learning. Her posttest responses indicated that she still saw scientists as curious, yet totally dedicated to their work. They may be in it for the money. When responding to items about the scientific method, her answers contradicted each other. She weakly agreed that the scientific method is a set of steps and she agreed that there are many scientific methods, on both the pretest and posttest. On the pretest she agreed that the method a scientist chooses depends upon the question being asked, but disagreed on the posttest.

Her total NOSQ score improved from 2.29 on the pretest to 2.13 on the posttest. She felt that she had learned a tremendous amount of science
this session. EEF21 commented that she could now hold a conversation about science with her science major boyfriend and not feel intimidated.

**Journal 10—Nontraditional Student**

NT41 is a nontraditional, female sociology major who saw social work as one type of science. She was petrified of scientific terminology and math. Over the course of the three week session, I learned a lot about this lady. She has learning disabilities and test taking anxiety. She once told me that by the time she began reading the second line of a test question, she had forgotten what the first line said. This student was a prime example of how paper and pencil questionnaires can be misleading. According to the NOSQ, her understanding of the nature of science degenerated during the course. Her pretest score was 2.17 and her posttest score was 2.38.

Analysis of the questions showed that she moved from an understanding of science as tentative to one of a certain science. However, throughout her journal she described science as a tentative process for answering questions. She described a newborn as a scientist, stating "he learns that if he cries, mom or dad will come to see what his needs are..." and further asks, "Is this an experiment the child performs? He gathers his data and cries again." When describing the nature of science she said "inventions may occur." During the interview she was asked about this phrase.
L: OK. You said somewhere in here that "inventions might occur", "inventions may occur" when you were describing the nature of science. Tell me a little bit more about that.

B: OK, for instance when someone's starting with one idea in mind and something else they find that is different that can be used in other aspects.

L: OK. Do inventions have to occur for it to be science?

B: No.

NTF41 described a typical scientist as always seeking to prove his findings and never trusting his senses. When asked what prove means, she conveyed her idea of proof.

B: Well, if you keep on doing something and say you do something three times. And it comes out twice the same and once not. OK, well the twice its been proven, its going to work the same way two out of three times.

L: OK. "And never trusting his senses, but always trying to identify the unidentifiable" Why not always trusting his senses?

B: Because you can't trust your senses in the world. Your senses ok, what you see, what I may see or envision in one thing you may see totally different. If I see a glass of coke, you may see why does the ice float or why did it bubble when I poured it? Your hearing, we all hear differently.
She described science as certain in her journal, using the definition of always or destined. When asked to elaborate on that, she said,

B: OK. I looked up, I keep a dictionary beside me 24 hours a day and I looked it up in there and see what their definition of each word was. OK determined, a scientist to me is more determined...they will do something over and over again. Destined, sooner or later you are going to find out something. It may not be what you are looking for, but you are going to find out an answer.

L: Let's take a look at the opposite. Let's look at uncertain, doubtful. Is science ever doubtful?

B: I think scientists are doubtful toward each other, toward each other's findings.

This student saw thought experiments as useful for stretching our minds and using our imaginations to solve problems. In her response to the question about a new drug to treat AIDS, she distinguished science (characterized by close observation, experimentation, classification of data, and the establishment of verifiable principals--the process of discovery) from technology (the end result).

She described the math as the language of science and said that "you can also describe an unknown through math equations." More information was gleaned about her understanding of the relationship between math and science during her interview.
L: OK, you said that math is used to help you be precise, to help you be exact, uh and to help you describe things.

B: Now I've learned that since I've been in class. You know the first scientists or even now, when they are trying to define something of the unknown, they do it in a mathematical equation. I may not understand that. I may not understand the equation what so ever, but to you, he could try to explain how he tried to do something or the process by which it would take place and you could understand him. I think that's great, I think that's wonderful. I can't do that (laughs).

L: Do you think that this course could be improved by not just putting more math in for the sake of math, but by including more math to show how math and science are interrelated.

B: I think I can answer that in two parts. Either this should not be a 100 class and it should be after you've taken your math so you can comprehend it a lot better. I mean after you have passed your algebra, after you have, you know, I wouldn't even say just algebra cause I've had the algebra, or part of it. And I'd say I don't know what some of the other maths are but I think you need more math before you get into this course.

NTF41 demonstrated an understanding of the nature of science throughout her journal writings and her interview, yet her test scores did not reflect this perception. She was one of only two students who realized
(without further questioning) that the purpose of science is not to invent new things to help humans live better, but to gain knowledge.

With the exception of one student, the students who were interviewed expressed a deeper understanding of the nature of science at the end of the session than was noted by the NOSQ at the beginning. These students were more sure of the definitions of hypotheses, laws, and theories. They recognized the tentative and revisionary nature of science. They indicated an understanding of many methods that can be utilized in the scientific process. They distinguished between science and technology, communicating those differences in their responses to the journal question about a new drug to treat AIDS.

Again, as with the previous analysis, it appears that the "hidden curriculum" has communicated information about the purposes of science (Gil-Perez & Carrascosa-Alis, 1992). Students still saw the goal of science as inventing technology and improving the human condition. Reflecting upon the course content, I found that I may have strengthened this misconception by stressing how science is used in the students' everyday lives. The purpose of these practical applications and everyday examples was to provide connections between the material these nonmajors were learning and their own conceptual frameworks by showing how science affects them.
Research Questions 3 & 4

3. Are there differences between traditional students (ages 18-22) and nontraditional students (ages 23 and older) in the initial and final understanding of the nature of science?

4. Are there differences between elementary education majors and other nonscience majors in the initial and final understanding of the nature of science?

Because of the possibility that a student's mental age, chronological age, or prior experiences (Crumb, 1965) may influence his or her understanding of the nature of science, differences among traditional students, nontraditional students, elementary education majors, and other nonscience majors were examined. To answer Research Questions 3 & 4, quantitative analysis of the NOSQ scores from nontraditional students and from elementary education majors in the experimental class was conducted. Since there were no statistically significant differences between pretest and posttest scores for the control group, one would not expect statistically significant differences among these subsets of students in the control group. Therefore, these statistics were not performed. A independent t test, done on the pretest, established equivalence among groups. The independent t test, done on the posttest scores indicated no statistically significant differences among these groups due to treatment. (See Table 4.2).
Table 4.2

Summary of Results from NOSQ for Nontraditional Students, Elementary Education Majors and Other Nonscience Majors

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretest mean</th>
<th>s.d.</th>
<th>n</th>
<th>Posttest mean</th>
<th>s.d.</th>
<th>n</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nontraditional</td>
<td>2.28</td>
<td>.201</td>
<td>13</td>
<td>2.09</td>
<td>.234</td>
<td>13</td>
<td>.06</td>
</tr>
<tr>
<td>Traditional</td>
<td>2.29</td>
<td>.211</td>
<td>16</td>
<td>2.11</td>
<td>.259</td>
<td>16</td>
<td>.03</td>
</tr>
<tr>
<td>Elementary</td>
<td>2.31</td>
<td>.185</td>
<td>7</td>
<td>2.16</td>
<td>.303</td>
<td>7</td>
<td>.293</td>
</tr>
<tr>
<td>All Other Nonscience Majors</td>
<td>2.80</td>
<td>.213</td>
<td>22</td>
<td>2.08</td>
<td>.234</td>
<td>22</td>
<td>.006</td>
</tr>
</tbody>
</table>

The differences between the traditional and nontraditional students on the pretest were not statistically significant, nor were the differences statistically significant on the posttest. However, both groups showed statistically significant gains in an understanding of the nature of science from pretest to posttest. When analyzed using the independent $t$ test, traditional students showed statistically significant differences $t(16), p = .03$ and nontraditional students showed statistically significant differences $t(12), p = .06$. A dependent $t$ test on the gains scores showed statistically significant gains for both sets of students $t(16,12), p = .05$.

The differences between the elementary education majors and other nonscience majors on the pretest were not statistically significant, nor were the differences statistically significant on the posttest. All other nonscience majors showed statistically significant differences in an understanding of the
nature of science from pretest to posttest. However, elementary education majors did not show statistically significant differences from pretest to posttest. A dependent t test done on the gains scores (as previously described) showed that both elementary education majors and other nonscience majors demonstrated statistically significant gains in their scores from pretest to posttest.

Statistically significant differences were found between the pretest and the posttest for nontraditional students and for all other nonscience majors, but not for elementary education majors. Statistically significant gains were seen for all students tested. While all students tested showed improved understanding of the nature of science, no one subgroup showed greater understanding than other subgroups.

**Research Question 5**

Can interactive nature-of-science vignettes drawn from the histories of science be used as an instructional strategy to induce conceptual change about the nature of science without sacrificing student understanding of the physical science course content?

In order to answer this question, the class averages of the two groups was examined. The average score for the course for the control group was 69.0 and the average score for the experimental group was 70.7. The experimental group performed as well as the control group on content examinations. Therefore, yes, interactive nature-of-science vignettes can be
used as an instructional strategy without sacrificing student understanding of physical science course content. These findings reflected those of Klopfer and Cooley (1963) who reported that students who studied the nature of science showed the same achievement in both chemistry and physics courses as students who did not study the nature of science.

**Research Question 6**

Will students demonstrate an increased interest in scientific topics and/or scientists as a result of instruction employing interactive nature-of-science vignettes (as evidenced by checking out materials placed on reserve by the instructor in a university library)?

The reserve librarian reported that none of the books placed on reserve at the university library were checked out by the students. After I had turned in grades for the session, I polled the students by telephone or in person in an attempt to validate this information. Twenty-four of the thirty-two students were reached (some had moved out of the dorms, several numbers had been disconnected, some could not be reached). Only one student had checked out books that had been placed on reserve. Of the remaining students polled, only three students offered reasons for why they had not checked out books. All students said the summer sessions were very intense and they just did not have the time to do any extra reading. Two of these students said they had kept the list of call numbers and intended to check some books out in the fall.
Fifteen professors were informally surveyed to find out what their experiences had been with "recommended but not required" readings. Two told me, "If it's not required, they won't do it." One reflected that the readings she talked most about in class were sometimes read, but those she did not mention were not. Another related that 60-70% of her students read the "recommended but not required" items. The remainder of those polled reported that less than five percent of their students read anything that was not required. One added that not all her students read the required material.

Student comments

The last day of class, after the final examination, students were asked to write a short paragraph describing what they thought about the vignettes. Students were told to submit these paragraphs anonymously. This technique fostered honest expression of their views (Mead & Metraux, 1957). All students liked the vignettes describing them as interesting and informative.

Several students elaborated on their feelings:

1. "The stories were great at first but sometimes I felt like I was in the first grade. It might have been because we heard them everyday instead of just like once a week or so in a regular class. Don't get me wrong, quite a few are really helpful in making the point get across, and striking up discussion in the classroom. It's just not everyday what you want to hear stuff."
2. They "made me believe, whether it's true or not, that you really enjoy what you do—you're genuinely interested in it, and you want us to be."

3. "They shed light on some ideas which could be left to question. I liked the way you presented, especially because you always started reading and asked us some questions about who or what we thought you were reading about."

4. "I really looked forward to your stories. I thought they were very creative and provided a great deal of information that helped the class understand the material better."

5. "I found the stories very informative. I think this is an excellent idea. More teachers need to use them. They give lots of information."

6. "I hope you continue to read your science classes vignettes because they really are helpful in learning."

7. "I feel they were helpful to me most because they steered me straight to who was being talked about and made it easier to study that person or phenomenon."

8. "They tried to put you in the mind frame of the person being discussed."

9. "It changed my attitude about scientists—I now think of them as being more human."
SUMMARY AND CONCLUSIONS

Summary of Study

Learning science is not easy. Learning about science is not easy. Abandoning cherished notions is difficult, even when exposed to new ideas periodically, over the duration of a science course. The NOSQ scores indicate that students in the experimental section changed their conceptions about the nature of science and student writings in their journals support and describe these changes in more detail.

The findings in this study indicate that the interactive nature-of-science vignettes are useful for helping students gain a better understanding of the nature of science. Students who were taught using the interactive historical vignettes showed greater understanding of the nature of science than students who did not. Klopfer and Cooley reported similar results in their 1963 study. Students who studied under HOSC instruction also showed significantly greater understanding of the nature of science than students who did not study under this method. Participants in a study by Lavach (1969) also showed statistically significant gains when taught with an historically oriented program designed to emphasize the nature of science. Teachers in a program designed by Billeh & Hasan (1975) also showed significant gains in understanding the nature of science. Other researchers (e.g., Carey & Stauss, 1968; Crumb, 1965; Jones, 1965; Lawrenz & Kipnis, 1990; and
Trent, 1965) also report that students who are taught the nature of science using a variety of techniques show growth in their understanding of the nature of science.

The findings of this research provide support for Grandy and Hamilton's (1992) contention that students show higher levels of concept acquisition when presented with examples of and elaborations on the concepts than when presented with concrete definitions and critical attributes of the concepts. Both classes were provided definitions of the concepts related to the nature of science. The experimental group, which was also provided with elaborations on these concepts, demonstrated a greater understanding of these concepts.

This research provides evidence that university students hold misconceptions about the nature of science. It further indicates that students do not necessarily glean a proper understanding of the nature of science from ordinary introductory science courses. Both the quantitative and qualitative results of this study indicate that through the use of instructional materials, specifically designed to teach the nature of science, statistically significant gains in student understanding about science can be achieved.

Significance of the Study

The findings of this dissertation study demonstrate that the technique (use of interactive nature-of-science vignettes) is effective in increasing student understanding of the nature of science when used in a nonscience
majors' introductory physical science course at the university level. These gains in understanding of the nature of science are realized with no concomitant loss of achievement in the content of the described course.

Statistically significant changes within the experimental group and between the groups (with small numbers of students) indicate a positive relationship between the treatment and the gains. Therefore, I can recommend the use of historical vignettes in science classes where the teacher is interested in developing a greater understanding of the nature of science in his or her students.

The technique utilized in this study is one that can easily be taught to teachers, allowing them to create their own curriculum materials. The paucity of curriculum materials described by Ray (1991) can be alleviated by the teachers themselves. As a matter of fact, I had the opportunity to instruct teachers on the construction and use of interactive historical vignettes in a workshop for the Center for Cooperative Learning at Northwestern State University on June 24, 1993. Mathematics and science teachers from Grades 4-10 were involved in this five-hour workshop. All teachers commented positively about the vignettes and many remarked that they planned to use them in their classrooms. They described the vignettes as motivational, interesting, and a wonderful way to get students involved in the lesson.

This study not only adds to the small body of literature addressing conceptual change with respect to the nature of science by university
nonscience majors, it provides a new technique for introducing the nature of science to students.

**Limitations of the Study**

This is the first study utilizing interactive historical vignettes as a technique for introducing the nature of science into an existing science course. It was conducted using small numbers of students in both the experimental and control groups. The features of the nature of science and the scientific attributes illustrated in the vignettes are implicit. Only a few of the vignettes state that a given scientist demonstrated a given scientific attitude or feature of the model of the nature of science by displaying certain behaviors. As described earlier, these aspects are related to the vignette in the discussion portion of their use. A researcher’s views of the nature of science and interpretation of the vignettes could affect the treatment.

The scientific history presented in the vignettes is accurate, however the details are fiction. The fictionalized details in the vignette do not alter the history presented, rather enhance it by illuminating the human and sociological attitudes characteristic of the era. However, it should be made clear to the students participating in vignette usage that the conversations among characters cannot be historically documented.

Although the statistical analysis of this study indicates statistically and practically significant differences, these are small. The raw score difference between pretest and posttest for control group was .18 on a four point scale.
This difference represents only a 4.5% change. Without the qualitative data included, some researchers may view the small differences as irresolute evidence of effectiveness of the experimental treatment. Although some educational research indicates that small sample sizes do not affect the strength of statistical analysis, the small number of students in the elementary education majors and nontraditional students subgroups weakens the statistical inferences that can be made with respect to these two subgroups.

**Future Research**

Several questions were raised during the study that should be addressed in future research. Will conceptual change about the nature of science occur if the vignettes are not used interactively, but simply read to the students, with no discussion time provided? Will students learn more about the nature of science if they construct their own vignettes in addition to participating in their use? Will secondary school students experience conceptual change about the nature of science by participating in interactive vignettes? Do elementary education majors who participated in interactive historical nature-of-science vignettes teach science differently from their peers who were not taught using historical vignettes?

Science and technology pervade today’s world and the scientific knowledge that we have is changing on a day to day basis. The citizen who understands the nature of science will maintain his or her confidence in scientific reports, even though these reports may contradict the science that
s/he learned in school (Connelly, 1969). This citizen will have an understanding of how science works, and therefore, can better judge the validity of the information s/he hears. With background in the histories of science, one understands the changes that have occurred in the past, and accepts the inevitable changes of the present and future.

In a time when science curriculum leans more than ever before on the influences of science and technology on our society, it is impossible for students to properly evaluate and apply the consequences of these interactions without an understanding of the nature of science (Griffiths & Barry, 1993). Science education researchers are not the only ones realizing this need. Killheffer (1993) describes numerous books that show children the people behind the abstract ideas they learn in science class. He reminds us that science is not going to go away, no matter how much we ignore it. He recommends learning about the scientists, and as a result, learning about the exciting work of science. Interactive nature-of-science historical vignettes provide a research-based technique for teaching the nature of the scientific endeavor and the exciting men and women who make it possible.
REFERENCES


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APPENDIX A

A MODEL OF THE NATURE OF SCIENCE*

A. Scientific knowledge is tentative. (C, K, R, C&S, Sh, L, D) (8, 9, 10)

B. Science is a process utilizing many scientific methods. (R, C&St, K, Sh) (2, 3, 4, 5, 16, 17, 20)

C. Science is a search for knowledge; technology is the application of that knowledge. (C&St, K, R&M, Sh) (7, 12)

D. Science is a human endeavor involving curiosity, creativity and imagination. (K&W, C, R, R&M, Sh) (1, 15, 16, 19, 20)

E. Science is grounded in nature. (C, R, K, Sh) (2, 3, 13, 16)

F. Science searches for the simplest explanation of events, often using mathematics in this search for parsimony. (K, R, R&M, Sh) (6, 11, 14, 17, 18)

* Use the following key for initials:

C&St= Carey & Strauss (1968) R= Robinson (1965)

The numbers refer to the attitudes emphasized in the vignettes which can be found on page 30.
"Wow! I knew he was a great artist, but I never heard of all this science stuff. He was really smart."

"Yes," answered Kodi, the museum curator, "DaVinci was a genius, but he is best remembered for his art. He did not publish his observations or his theoretical accomplishments. As a matter of fact, all the notes written on his drawings were done in mirror image."

"Now that you mention his drawings, I seem to remember something in my biology book about him making drawings of the human body."

"That’s right Katie, he and a colleague dissected cadavers (dead bodies) and Leonardo made intricate drawings of the muscles and organs. Not only that, but he had ideas in both physics and geology that had to be rediscovered hundreds of years later."

"Then why haven’t we heard of him? Why didn’t the other scientists build on his work? I thought that was one of the things that scientists do."

*At this point, STOP the story. Ask your students to analyze the story. Possible questions are: What do you know about Leonardo DaVinci? Why do you think he wrote his notes backwards? Why didn’t he share his knowledge with others? Why do we know more about his art than his science?*
"Let's talk about DaVinci and his accomplishments and perhaps you can figure that one out for yourself."

"OK. What's this? It looks like a drawing of a parachute."

"Yes, it is, Katie. DaVinci was fascinated by birds and flight from an early age. His mother was a peasant girl and his father was a lawyer. His father raised him on a grand estate where he was free to roam and explore. He loved to study nature. While roaming the estate, he would watch the birds and carefully study how they soared, flapping their wings only occasionally. He never lost this obsession with flying.

Later in life, he integrated these observations with other observations and theorized the concept of inertia. He didn't call it inertia, but he had the concept right. He noticed that when an object was at rest, it would not move without some violent action applied to it. He also noticed that when the birds flew, they remained in motion when soaring, although no violent force was being applied to them at the time. Over a hundred years later, Newton was credited with this idea. It was during DaVinci's studies of flight that he devised this parachute. This too, had to be rediscovered nearly one hundred years later."

Questions are interjected here to maintain the involvement of the audience. Did you know that DaVinci made drawings for parachutes, helicopters, and other flying machines? Why didn't DaVinci get credit for his work? Do you have any clues as to why he didn't share his knowledge?
"Miss Kodi, you said earlier that he theorized about geology too. Can you tell me about that?"

"Certainly, Katie. DaVinci found fossils and studied them. He knew that the land where he lived was once covered with water because the fossils were of seashells. Of course the Bible taught that the Great Flood had covered the Earth and that seemed to satisfy everyone else during the Renaissance, but to him, the parts didn't add up. Leonardo wondered about this. If the Earth is spherical, and if the flood covered the entire Earth, then where would the water go when the flood was over? There would be no downhill slopes for it to run down. (He had already established in his mind a theory of gravity, although he did not call it that). The only way that the water could have receded was by evaporation, and it seemed unlikely to him that such a great amount of water could be evaporated in the short length of time described in the Bible. He had observed earthquakes and volcanoes and after much pondering and observation, theorized that the ground must have been made of a sticky matter and that seashells and leaves got caught up in this goo. When the hot substance cooled and hardened, the imprints of the shells and leaves remained. More than three hundred years passed before this idea was brought up again."

Again, STOP the story for discussion. Possible questions include, but are not limited to: What clues do you have now about why his ideas were not published? NOW, for conflict resolution...
"Why don't science books tell us about all these great ideas that DaVinci had?"

"I can't answer that, Katie, but I can give you some insight into why his genius was lost. I told you before that he was born of a peasant woman. Does that give you a clue? What I didn't tell you is that his father was not married to his mother, nor did he ever marry her. The child was raised in solitude on an estate, kept out of the public eye. He was not given any education and had to teach himself to read and do simple arithmetic. He did not know Latin, the language of the learned. Scholars who have translated his notes tell us that throughout them, there are instructions about how to perform the experiments and how to make the gadgets described. It seems that Leonardo DaVinci planned to someday translate his notes into Latin and have them published. He just got too caught up in the excitement of study and never got around to it. After his death, his notebooks were passed into the hands of a colleague who for unknown reasons, chose not to share them. For that reason, mountains of knowledge about the world were lost to mankind, only to be rediscovered and credited to others hundreds of years later."

What scientific attitudes does DaVinci exhibit?

APPENDIX C

NATURE OF SCIENCE QUESTIONNAIRE

Circle the number on your answer sheet that corresponds to your understanding of how a scientist would respond to the following statements. 1=strongly agree, 2=agree, 3=disagree, 4=strongly disagree.

1. Attaching numbers to data helps us see patterns we may have missed.

2. Classification schemes are human inventions and are not naturally found in the materials being classified.

3. Science is certain because experiments are repeated until the scientist gets the right answer.

4. Inventions such as penicillin, plastic, and television were not the goals of scientific research.

5. Scientific knowledge is certain, because scientists prove their hypotheses with experiments.

6. Science does not emphasize the practical application of its discoveries.

7. Science is guided by nature.

8. The work of a scientist requires such a dedication that s/he is unable to have the same type of lifestyle as people who choose other fields of work.

9. Scientific knowledge is uncertain.

10. Scientific models are man-made and are not created to represent reality.

11. Scientists have to be creative and use their imaginations.

12. Scientists study something because they hope it will lead to a money making invention.

13. Scientists attempt to explain complex events with theories.

14. Scientists study something because they are curious about it.

15. The aim of all science is to convert observations and phenomena to mathematical relationships.

155
16. The scientific method consists of the following steps: define the problem, gather data, formulate hypotheses, experiment, and draw conclusions.

17. The method a scientist selects to complete his research is based on the questions being asked; there is not one set of approved procedures.

18. The most fitting definition of science is "a body of knowledge."

19. The goal of science is to invent machines and processes to improve human welfare.

20. The main function of a scientist is to improve the human condition.

21. There are many scientific methods.

22. There are plenty of animals around so it is an acceptable practice to capture and kill animals in order to study them.

23. While an hypothesis can be revised based on new information, laws of science do not change.

24. Tests of a scientific theory include its ability to explain and predict.
APPENDIX D

SCHEDULE OF VIGNETTE USAGE

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Vignettes</th>
</tr>
</thead>
</table>
| 1       | "Myko’s Medicines"
|         | "Red For Stop, Green For Go"
| 2       | "Aristotle’s Eggsperiments"
|         | "You Call That Genius"
| 3       | "Space Teacher"
|         | "Genius Lost"
| 4       | "Standing on the Shoulders of Giants"
|         | "Black Holes"
| 5       | "Hot or Cold"
|         | "The Real McCoy"
| 6       | "Moonwalkers"
|         | "Stargazers"
| 7       | "Twinkling Stars"
|         | "Listerine Kills Germs"
| 8       | "Fields and Dreams"
|         | "Daring Dutchwoman"
| 9       | "Development of the Atomic Model"
|         | "A Model Brain"
| 10      | "An Idea Worth Repeating"
"The Curies' Cure"

"The Discovery of Radioactivity"

11 "Reading the Cards"

"Heavy Ashes"

"Darwin's Devil Waters"

12 "Its Only Peanuts"

"Take Your Vitamins"

13 "The City Dump"

14 "An AIDS Vaccine?"

15 "The Family Tree of Genetics"

"Science"
APPENDIX E

JOURNAL ENTRIES

1. I am not a science major because...

2. What is your understanding of the nature of science—what is science and what does it do?

3. Draw a typical scientist. What does one do?

4. Is science certain or uncertain? Explain.

5. Why is a basic understanding of science important?

6. Do you feel like you understand science any better than before you began this course? What specific techniques have you encountered in this class that have helped you understand better? What has been useless?

7. In physics lessons, there are often assumptions or thought experiments which cannot be realized in actual experiments (like ignoring air resistance or friction, or traveling at the speed of light). Do you think this method is useful? Explain.

8. Is there a place for history in the science class or should it be left in history classes?

9. What is the role of mathematics in science? Why do you think that I have de-emphasized math in this course?

10. Is the discovery of a drug to treat AIDS science or technology? Explain.
11. How much attention have you paid to the peach colored "Chapter Highlights" pages? Be honest! If you have paid attention to them, were they helpful? How so?

This will provide one entry per week with the exception of the first week of class, the last week of class, and finals week.
APPENDIX F

VEE DIAGRAM OF PROPOSED RESEARCH

1. Will the inclusion of interactive nature-of-science vignettes drawn from the history of science in a college introductory physical science course for nonmajors induce conceptual change about the nature of science?

2. What conceptions of the nature of science do students hold before and after the treatment?

3. Are there differences between traditional students and nontraditional students in their initial and final understanding of the nature of science?

4. Are there differences between elementary education and other science majors in the initial and final understanding of the nature of science?

5. Can interactive nature-of-science vignettes be used as a technique to induce conceptual change about the nature of science without sacrificing understanding of the physical science course content?

6. Will students demonstrate an increased interest in science topics and in science as a result of the inclusion of nature-of-science vignettes in science learning?
APPENDIX G
PERMISSION SLIP

I, ________________________________, hereby give Linda E. Roach permission to use entries to my Science 1010 Journal and other course requirements as a part of a research project, designed for use in preparation and completion of her dissertation. I understand that my participation in her research is entirely voluntary, but that completion of the journal and other course requirements are mandatory for Science 1010. By signing this document, I release said information for her use. I understand that all information will be kept confidential and at no time will my name ever be used or connected with any information.

_________________________     ____________
signature                     date

Please provide the following demographic information:

birth year_______

student classification_______

major______________________
APPENDIX H

GRAPHIC REPRESENTATION OF QUANTITATIVE RESULTS

Figure H.1. Statistical Analysis--Experimental vs. Control Groups
dependent $t$ test $p < .05$

**Figure H.2. Statistical Analysis—Traditional Students vs. Nontraditional Students**
Figure H.3. Statistical Analysis—Elementary Education Majors vs. Other Nonscience Majors
VITA

Linda E. Roach was born in Cottage Grove, Oregon, on St. Patrick’s Day, 1955. When she was two, her family moved to northwest Louisiana, where she has lived since. She entered Northwestern State University under the Early Admissions Plan and completed a Bachelor of Science Degree in Medical Technology in 1977. While working at Louisiana State University Medical Center as a medical technologist, assisting with the training of medical technologist interns, she realized that she wanted to teach. She subsequently developed the curriculum for and taught the Medical Assistant’s course at Commercial College in Shreveport. In 1986, she returned to Northwestern State University, fulfilled the requirements for Louisiana State Certification in Biology and Chemistry, and taught all the science courses at Negreet High School. In 1989, she accompanied her husband to Louisiana State University, attended graduate school part-time, and taught all high school science courses at East Iberville High School. She received a Master of Arts Degree in Education in 1991, and entered the Ph. D. program in the fall of 1991. Linda currently teaches introductory physical science courses, freshman chemistry, secondary science methods, and has developed and teaches two laboratory courses for elementary education majors at Northwestern State University. She resides in Natchitoches with her husband, Scott; and daughter, Katie.
Candidate: Linda E. Roach

Major Field: Education

Title of Dissertation: Use of the History of Science in a Non-science Majors Course: Does It Affect Students' Understanding of the Nature of Science?

Approved:

[Signatures]

Major Professor and Chairman
Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:
October 22, 1993